5-1-2022

EFFECT OF SIMULTANEOUS APPLICATION OF THE TWO HORIZONTAL ORTHOGONAL GROUND MOTION COMPONENTS ON THE SEISMIC BEHAVIOR OF BUILDINGS (CASE OF FOUR-STORY STEEL FRAME)

JOEL MONDO KISEKINI
Southern Illinois University Carbondale, joelkisekini@gmail.com

EFFECT OF SIMULTANEOUS APPLICATION OF THE TWO HORIZONTAL

ORTHOGONAL GROUND MOTION COMPONENTS ON THE SEISMIC

BEHAVIOR OF BUILDINGS

(CASE OF FOUR-STORY STEEL FRAME)

by

Joel Mondo Kisekini

B.S., Southern Illinois University Carbondale, 2020

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Master of Science Degree

Department of Civil and Environmental Engineering
in the Graduate School
Southern Illinois University Carbondale
May 2022

THESIS APPROVAL

EFFECT OF SIMULTANEOUS APPLICATION OF THE TWO HORIZONTAL ORTHOGONAL GROUND MOTION COMPONENTS ON THE SEISMIC BEHAVIOR OF BUILDINGS

(CASE OF FOUR-STORY STEEL FRAME)

by

Joel Mondo Kisekini

A Thesis Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Science

in the field of Civil Engineering

Approved by:

Dr. Jale Tezcan, Chair

Dr. Prabir Kolay

Dr. Harvey Henson

Graduate School
Southern Illinois University Carbondale
March 25, 2022

AN ABSTRACT OF THE THESIS OF

Joel Mondo Kisekini, for the Master of Science degree in Civil Engineering, presented on March 25, 2022, at Southern Illinois University Carbondale.

TITLE: EFFECT OF SIMULTANEOUS APPLICATION OF THE TWO HORIZONTAL ORTHOGONAL GROUND MOTION COMPONENTS ON THE SEISMIC BEHAVIOR OF BUILDINGS

MAJOR PROFESSOR: Dr. Jale Tezcan

During an earthquake, buildings are simultaneously excited by two horizontal and one vertical ground motion components. Modern seismic codes and guidelines such as ASCE/SEI 41-06 (Seismic rehabilitation of existing buildings, American Society of Civil Engineers), EUROCODE 8 (1998-1) (Design provisions for earthquake resistance of structures, European Committee for Standardization, 2003), FEMA 356 (Prestandard and Commentary for Seismic Rehabilitation of the Buildings) and FEMA P-2082 (NEHRP Recommended Seismic Provisions for new buildings and other structures) require the consideration of the effects of two horizontal orthogonal ground motions in seismic design of buildings. Therefore, the main objective of this study is to evaluate the simultaneous effect of two horizontal orthogonal ground motion components to seismic behavior of buildings. A four-story steel frame is modeled, and it is subjected to a set of twenty ground motion pairs recorded distances between x and y kilometer from epicenter. Three methods for combining peak response to individual component of ground motions is used to estimate the displacement responses. The combination rules used in this present study are 30%, SRSS, and 20%. The response of the four-story steel frame is investigated within the context of linear response history analysis and the results are compared to the peak responses obtained from time history analyses under bidirectional and unidirectional ground motion. The structural response includes the following parameters: nodal displacements and the critical angle of excitation. The output results showed that the maximum response under two components was, on average, 23 % more than the maximum response under a single component, and the two horizontal orthogonal seismic excitations increased the structure displacement response compared to unidirectional excitation.

ACKNOWLEDGMENTS

May All the Glory, Honor, and Praise be to God who has done Great things in me. I give thanks to my Lord and Savior Jesus Christ for the gift of life and strength to finish this work.

It is with immense gratitude that I acknowledge the support and help of my academic advisor and thesis committee chair, Dr. Jale Tezcan, for teaching, mentoring, and guiding me throughout this research, which led to the successful completion of this thesis. I also want to extend my gratitude to Dr. Prabir Kolay and Dr. Harvey Henson for tutoring, encouragement, and being part of my graduate committee.

I am indebted to Dr. Henson and to the Southern Illinois University STEM Education Research Center for providing financial resources and thus facilitating me in pursuing my degree.

My special thanks go to my lovely and amazing family back in the Democratic Republic of the Congo, my parents Seraphin Kisekini and Faustine Mondo, my brothers and sister Hugues Kisekini, Guelord Kisekini, Cedrick Kisekini, and Christelle Kisekini. Thank you for your love, advice, and support provided to me throughout the graduate program.

I am thankful to my uncle and aunt, Francis and Mireille Mandamuna, for their prayers, guidance, and advice to me since the day I came to the United States.

Finally, I am thankful to Chi Alpha and the Calvary Campus Church family for making Carbondale a home away from home. I also would like to sincerely thank Pastor Kudzai Musumhi for discipling and setting a Christ-like example for me to follow. May the Lord, my God bless him.

DEDICATION

To my parents, Seraphin Kisekini and Faustine Mondo, who have raised me up to become the man I am now. I am and will be forever grateful for your love, training, and continued sacrifice you made for me.

I would also like to dedicate this work to my future spouse whom I daily pray for. You are what I ask the Lord for, the apple of my eyes, and thank you for choosing me.

To my future kids, you are mighty warriors in the Lord, and I have loved you before I even met you. Thank you for being the source of my inspirations.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

CHAPTER 1

INTRODUCTION

In the event of an earthquake, buildings are simultaneously excited by multiple horizontal and vertical ground motion components. The importance of horizontal orthogonal seismic effects on the response of structures has been subject of studies. De Stefano et. al (1998) concluded that the orthogonal seismic excitations increased the structure displacement response compared to unidirectional excitation in case of plan-asymmetric building. Their findings were later confirmed by Erduran and Ryan (2011). Therefore, it is important to consider the two horizontal orthogonal ground motions.

Modern seismic design codes and guidelines require at least two or three components of ground motions to be considered for time history analysis. Seismic designers have two choices: (1) the application of simultaneous seismic loads along the principal axes of structure and (2) the combination of the effect of loads applied independently in each orthogonal direction (Wang, Burton, Kaoshan, 2019). Some modern codes such as ASCE/SEI 41-06 (Seismic rehabilitation of existing buildings, American Society of Civil Engineers), EUROCODE 8 (1998-1) (Design provisions for earthquake resistance of structures, European Committee for Standardization, 2003), FEMA 356 (Prestandard and Commentary for Seismic Rehabilitation of the Buildings), FEMA P-2082 (NEHRP Recommended provisions for seismic regulations for new buildings and other structures) identify time history analysis using two or three translational ground motion components as one of the acceptable methods of seismic response analysis. As the time history analysis method is performed for each earthquake, the response of interest is obtained using the percent combination rules (30%, SRSS, and 20%) for combining the peak response. The percent combination rules are adopted in buildings codes, standards, and guidelines such as UBC (ICBO

1997), FHWA-HRT-06-032 (FHWA 2006), AASHTO LRFD Design Specifications (AASHTO 2010), National Building Code of Canada (NRCC 2010), GB 50011 (MoCPRC 2010), AASTHO Guide Specifications for LRFD Seismic Bridge Design (AASHTO 2011), EN 1998-1 (CEN 2013), ASCE/SEI 41-13 (ASCE 2014), International Building Code (ICC 2015), and ASCE 7-16 (ASCE 2016). The main objective of this study is to compare the displacement response of a four-story steel frame obtained from simultaneous application of two orthogonal components to those obtained from the three combination rules.

1.1 STATEMENT OF THE PROBLEM

The motion of a point in space can be fully described in terms of six components: three translational (along two horizontal and one vertical axes) and three rotational (rocking about two horizontal axes and torsion about the vertical axis) components. While accelerograph systems capable of recording all six components of ground motions have been recently installed in a few stations, most ground motion records available in seismic databases contain only the translational components. Time history analysis using the three orthogonal translational components is considered to be the most accurate method for determining the seismic response of structures. For most structures, modern seismic codes and guidelines allow combining responses independently for each principal axis of the structure as an approximation of two or three directional ground motions. The principal directions of the ground motions do not usually coincide with the principal axes of the structure, and the variation of excitation angles cause change in structure response. While the future earthquake is not known, the design criteria of structure are intended to resist any ground motion in any possible direction. Thus, it is critical to study the effects of two horizontal orthogonal ground motions to seismic behavior of buildings for future design.

1.2 SCOPE OF THE RESEARCH

This study evaluates the effect of simultaneous application of two horizontal orthogonal ground motion components on the seismic behavior of buildings and compares the results to the values obtained from the directional combination rules. For this reason, a four-story steel frame is modeled. The structure modeled is composed of B100x9 columns section type with fixed support, S75x11 floor beams section type that are stronger bending vertically, 45 nodes with a damping ratio of 5 percent (Johnson et al. 2004). The property of the structure is shown in Table 1 and the frame is shown in Figures 1, 2, and 3 with its description in Chapter 3 of the study.

Using linear time history analysis, the structure modeled is subjected to a set of twenty pairs of near-fault ground motions. As the structure is subjected to bidirectional and unidirectional ground motions, the critical excitation angles measured counterclockwise from the structure’s major axis are determined.

1.3 ORGANIZATION OF THESIS

This thesis includes six chapters. The remaining chapters of this thesis are organized as follows:

Chapter 2 is entirely devoted to literature review. This chapter starts with a discussion of principal axes of ground motions and structures. Next, this chapter discusses the critical displacement response of structures, the characterization of bidirectional ground motions, the response of building and bridge structures under the action of earthquakes, and finally concludes with a discussion of near and far-field earthquake.

Chapter 3 discusses the methodology carried out in the completion of this study. It presents the information about the selected ground motions and structure modeled. It describes the three directional combination rules (30%, SRSS, and 20% rule) used in this research.

Chapter 4 discusses the application and analysis of bidirectional and unidirectional ground motions to the four-story steel frame model. It starts by evaluating the displacement response in the x direction using one and two components and then repeats the same analysis in the y direction.

Chapter 5 presents the results of structural responses obtained from twenty sets of three-component ground motion records after linear time analysis using MATLAB code for computation. The results include tables (see Appendix A) showing the maximum responses to bidirectional and unidirectional application of ground motions.

Chapter 6 presents the conclusion and recommendations for future study to be carried out in this topic. It also summarizes the output results and observations retrieved from this study.

CHAPTER 2

LITERATURE REVIEW

2.1 PRINCIPAL AXIS

The devastating effect of earthquakes on buildings has drawn considerable attention from many structural engineers. The earthquake is a ground shaking event caused by the immediate release of concentrated seismic energy in the earth's crust. The gradual accumulation of stress and subsequent displacement carries a sudden release of energy in the earth's crust that further resulting the formation of ground displacement, building deformation and many other damages.

A major concern in designing of structures located in a seismic area is the determination of the strong ground motion direction. During an earthquake, the ground motion is recorded in the form of acceleration time-histories of two horizontal component and one vertical component. Seismic design of most structures is governed by the horizontal components of ground motions. Penzien and Watabe (1975) introduced the concept of the principal axes of ground motion as axes along which the ground motion components become uncorrelated. They recognized that the response of some structures such as nuclear reactors, dams, freeway bridges and 3D piping systems are dependent on the three translational components of ground motions. They demonstrated through the examination of real accelerograms that the direction of major axis of ground motion generally points in the direction from the recording station to the earthquake epicenter while the minor axis is almost vertical. The minor axis represents the direction of minimum variance (i.e., with an orientation angle of θ+90°). The principal axes of ground motion were determined for the following earthquakes Long Beach, California (1993); El Centro, California (1940); Taft, California (1952); Tokachi-Oki, Japan (1968); Hidaka-Sankei, Japan (1970) and Izu-Hanto-Oki, Japan (1974).

The direction of the two horizontal components of ground motion with respect to the principal axes of structure is critical to the structure's response. The response of structure is usually described in two dimensional or three dimensional cartesian coordinates and computed independently along the cartesian axis. Because the principal axis is critical for the evaluation of structure response, some engineers and researchers have worked on this topic. Chopra (1992) gave special attention to the quantification of the cross effect of structure. He noted that when the mass and stiffness, as well as loading are unevenly distributed, it can cause rotational response which further transfers energy from one direction to the perpendicular direction. The cross effect can cause a significant change in structural response.

Liang and Lee (1998) inspected in detail the issue of cross effect of a structure and found that the cross effect may become more significant in earthquake engineering applications. In 2002, Liang and Lee analyzed the principal axis of multi-degree of freedom structure and gave much detail on it by investigating the stiffness matrix with the goal of checking the decoupleability. They concluded that structure with four or more degree of freedom may not have principal axes. The cross effect is negligible in structures under static loading conditions. Structures without principal axes exhibit cross effect, which means that there will be some amount of energy that will be transferred between the perpendicular axes. The accumulation of energy over time can greatly affect the structure response. The response level can increase more than thirty percent under dynamic loading. Beside cross effect, those structures have quasi-principal direction for their stiffness. The quasi-principal direction is determined by rotating the stiffness or flexibility matrix, and the response is evaluated from different angles.

2.2 CRITICAL DISPLACEMENT RESPONSE OF STRUCTURES

The orientation of the structure with respect to the principal axes of the ground motion plays a big role in the response of a structure. It is suggested to design the structure based on its critical response which is defined as the highest response of a structure for all possible incident angles of the two horizontal ground motion components. Researchers have developed seismic codes and methods to determine the critical response of a structure. Among them are Rosenblueth and Contreras (1977), who proposed the 30% Rule (UBC, 1997:IS: 1893, 2002: IBC, 2009). The method assumed that the two components of the horizontal motion are uncorrelated Gaussian processes of equal intensity. They said that 30%-rule produces response values that can either be smaller or greater than the maximum ones over the incident angle. The incident angle is the angle between the ground motion components and the structure axes. Smeby and Der Kiureghian (1981) proposed the Complete Quadratic Combination with three components (CQC3) rule, which is one of the formulas adapted for determining the critical response of elastic structures to two horizontal and the vertical seismic components with arbitrary spectra. Smeby and Der Kiureghian (1981) set the foundation of this rule on the concepts of stationary vibrations. The design values should be determined based on all possible values of the incident angle and the response spectrum for each principal seismic component is required (Smeby and Der Kiureghian 1985; Lopez and Torres 1997; Anastassiadis et al. 1998; Menun and Der Kiureghian 1998; Lopez et al. 2000).

Priestley et.al (1996) noted that the 30% combination method works best for members that have linearly elastic behavior. He found that this method can be applied for columns and cap beams that go beyond the inelastic range, but when it comes to irregular bridges consisting of different column heights and high skew angles, this 30% combination rule is not reliable.

Besides the 30% combination rule, there is SRSS method which is well documented (UBC, 1997: IBC, 2009). It is assumed that there is no correlation between the horizontal ground motion components in this method. Khoushnoudian and Poursha (2004) found that the buildings with in-plane discontinuity are sensitive to the combinatorial effect of multicomponent ground motions. Salazar, Bisadi and Head (2004) concluded that the SRSS could underestimate structural demands compared to the results derived from bidirectional analysis (Reyes-Salazar et. al 2004, Bisadi and Head 2010).

Lopez, Chopra, and Hernandez (2004) have proposed an expression for the constant spectral ratio that predicts the critical response with all the accuracy and have evaluated the CQC3 method for elastic structure subjected to two horizontal and vertical ground components. Caltrans (2010) suggested that 30% combination rule should be used for seismic response analysis of bridges.

Potnis, Desai and Gupta (2012) have worked on the issue related to the computation of critical response of five and ten symmetric buildings undergoing simultaneous effect of two horizontal components of ground motions using the five methods discussed above. Their analysis was performed on a story building having rigid floor masses supported by massless inextensible columns and damping ratio of five percent. They concluded that the 30% rule leads to an unsafe result and is not able to ensure the desired conservatism while the SRSS provided conservative estimate of critical response. This conclusion is contrary to Wilson (1995) and Salazar (2004) studies that have shown that the 30% combination rule and SRSS method were both non-conservatives.

2.3 CHARACTERIZATION OF BIDIRECTIONAL GROUND MOTION

The accuracy of earthquake engineering analysis requires structural engineers to use consistent characterizations of bidirectional seismic demands (Baker and Cornell 2006a, b; Beyer and Bommer 2006, 2007; Boore et al. 2006; Hong and Goda 2007; Watson-Lamprey and Boore 2007). Boore et al. (2006) introduced two-orientation-independent geometric-mean response spectra for the recorded orthogonal components that measure the mean spectra demand: GMRotI50 and GMRotD50. The GMRotI50, geometric mean measure of the rotated ground motion components, gives a measure of spectral ordinates that are obtained from common orientation angle. That includes the spectral ordinates which are no longer exactly equal to the median response for all angles. He says that it is important to choose the period range T_h to be large enough so that all the peaks in the displacement response spectrum can be included. He also suggests that a large value of T_h will help to have enough values of the oscillator period to define each peak in the response spectrum. While the GMRotD50 is the period dependent measure that indicates the percentile of the geometric mean for sorted amplitudes of all rotation angles, he has also demonstrated the ratio between geometric mean spectrum over all nonredundant orientations and the GMRotD. When it comes to the orientation of a new or existing structure in a known location whereas the strongest direction of an earthquake is not known, Beyer and Boomer (2007), proposed that the seismic design codes need to require more than one response history analysis per input motion to be carried out with the larger values from all orientations that are considered in the design. Grant et al. (2005) and Beyer and Bommer (2007) suggest that the design of structure should take into consideration the worst possible orientation that may effectively increase the return period of the design ground motion.

Boore (2010) proposed a new method more reliable that represents the response of single degree of freedom system known as RotD100. It is another available measure of horizontal-component seismic intensity that shows any percentile without the computation of geometric mean. RotD100 method was adopted by the 2009 National Earthquake Hazards Reduction Program (NEHRP) Provisions and Commentary (Building Seismic Safety Council BSSC, 2009), and is the upper bound for intensity measures. To obtain the RotD100 spectrum, the two recorded horizontal ground acceleration components are calculated with respect to an angle using an accelerogram equation. The angle varies from zero degree to a hundred and eighty degrees. This method works in a way that a one-degree increment is taken each steps making a maximum of 181 values. Also, for each period of vibration in a range of rotation angles of one hundred eighty degree, five-percent-damped spectral ordinate is computed and then sorted to compute the percentile.

Damian N. Grant (2019) found that the seismic demand can be given as a geometric mean response spectrum. The geometric mean itself does not give a direct measure of the larger spectral demand for all possible directions of the ground motion with respect to the axes of the structure. However, the ground-motion prediction equations (GMPEs) are derived on the basis of the geometric mean of two orthogonal horizontal components of ground motion.

2.4 BUILDING STRUCTURE

The building design codes require to take into consideration the two orthogonal horizontal components of ground motion accelerations for response history analysis of building structures. This section reviews the setback structures, symmetric and asymmetric structures.

2.4.1 SETBACK STRUCTURE

Many researchers have worked on the effect of two horizontal orthogonal ground motions of many structures such as setback structures. Shahrooz and Moehle (1990), Duan and Chandler (1995) studied the distribution of drifts over height of the setback frame building. Duan and Chandler (1995) analyzed a setback frame building model to study the inelastic torsional demand of setback frame building as the principal cause of the poor seismic performance of one-side setback; torsional response is considered as the cause of damage to one-side setback structure during the occurrence of seismic activities. Then comes Karavasilis et. al. (2008) who also worked on the distribution of drifts over the height of setback frame building. He also demonstrated that the largest deformation of setback structures is concentrated in the tower and in its surrounding line for other geometrical irregularities. Pirizadeh and Shakib (2010) used the power spectral density analysis to evaluate the response of setback buildings subjected to a selected ground motion excitation and examined the structural displacements, velocities, and accelerations using the root-mean square method. Because of setback structural configuration, Shakib and Pirizadeh (2014) investigated the probabilistic seismic performance of such structure subjected to bidirectional ground motion. They both looked at the effect of two orthogonal ground motion components by studying the limit-state capacities of structure, its mean annual frequencies of exceeding performance levels. Shakib and Pirizadeh found that the performance of set-back structure to simultaneous action of orthogonal ground motion is significant over the entire range of structure responses from elasticity to global instability. The elastic and early inelastic performance levels did not have much larger influence on the area and value of the height setback ratios, and the mean annual frequency of exceeding performance levels increased because of the action of bidirectional ground motion.

2.4.2 SYMMETRIC AND ASYMMETRIC STRUCTURES

Kilar, Magliulo and Faella (2000) analyzed the response of a 3D reinforced concrete building subjected to two horizontal ground motion and compared the response under two and one directional excitation. A numerical modelling of four-story full scale reinforced concrete bare frame building tested in the laboratory of ELSA at Ispa with the beams idealized by uniaxial bending models and the columns by multi-springs models were used to investigate the effect of both bidirectional and unidirectional ground motion. Their analysis was carried out by exciting the structure under unidirectional and then bidirectional input of ground motion and comparing the two outputs. They concluded that there was no significant difference in terms of global parameters such as base shear, instantaneous period, and top displacement. However, they found that the structure had suffered greater damage under bidirectional than unidirectional effect. The simultaneous effect of horizontal components of ground motion caused more damage at the lower story of the buildings.

When it comes to the inelastic seismic behavior of asymmetric structures under bidirectional ground motion in comparison to their symmetric counterparts, some conclusions suggest these structures are more vulnerable during seismic activities because of a strong concentration of stress on one side of the structure arising due to lateral-torsional coupling. About fifty percent of the asymmetric structure damage is directly or indirectly caused by its geometric form and its location to the strong direction of seismic motion. Some previous earthquakes that happened in Mexico in 1985, Nepal in April 2015, and Bhuj, India in 2001 have shown that non-symmetric structures are more vulnerable to seismic damage than symmetric ones. Ghersi and Rossi (2001) worked on the effect of two directional ground motion excitation on the inelastic behavior of in-plan irregular and symmetric system. Using a one-story model with resisting element along the two orthogonal directions, Ghersi and Rossi concluded that the inelastic response of the one-story building was significantly due to the bidirectional excitation. Fernandez Davila and Ernesto. F. Cruz (2006) estimated the inelastic response of in-plan asymmetry multi-story buildings subjected to bidirectional ground motion. With a model of five story asymmetry-plan building, having six resisting plane frames connected at each floor by a rigid diaphragm, Davila, and Cruz (2006) showed a higher possibility of a larger response of structure undergoing a bidirectional excitation while considering its nonlinear behavior with the use of combination rules.

In addition to studying seismic behavior of symmetric and asymmetric structure, Ahsaan Hussain and Sekhar Chandra Dutta (2018) developed an adequate bidirectional hysteresis model capable of capturing the effect of bidirectional interaction. Their study was focused on a single-story building with the goal of understanding the simultaneous effect of bidirectional interaction specifically on an asymmetric structure. A set of twenty bidirectional ground motions were used with step by step integration following with Newmark's β-γ method, and each iteration followed by the application of the Newton-Raphson technique. This study showed that simultaneous effect of bidirectional interaction may cause an increase in the inelastic demand of the structure. It was concluded that the reciprocal action for seismic force in the inelastic range becomes smaller as the uncoupled lateral period of the structures increases and the extent of inelastic excursion decreases for flexible systems. They have also found that the extent of stiffness eccentricity of the system increases, as the response decreases. The result of Sekhar Chandra and Hussan (2018) demonstrates that it is important to consider the bidirectional interaction for any structure that is subjected to two directional ground motion whether it is a symmetric or asymmetric system.

Sashi Kunnath and Sekhar Chandra (2018) developed an accurate biaxial hysteresis model to study the effect of bidirectional interaction on seismic demand of single and multistorey building using twenty far fault ground motions. Based on the study, they found that the biaxial interaction increased the story displacement when the building was subjected to simultaneous actions of two horizontal orthogonal components of ground motions, while the single-story buildings have shown to have the ability to decrease the biaxial interaction effect when the system's period was increased. These phenomena were not observed in multistory because of the presence of higher modes and P-Δ effect.

2.5 BRIDGE STRUCTURE

Bridge researchers and engineers worked on the response of different bridges submitted to the effect of different ground motion. Caltrans (2010) studied the seismic response of bridges with the main goal of capturing the most unfavorable condition for all the parameters of bridges members. Atak, Yakut and Avcat (2014) investigated the directional effect of ground motion to the seismic behavior of a rigid and flexible bridges. The two types of bridges were modeled for seven skew angles beginning with the initial angle of zero to sixty degrees, and two extreme stiffness modeled for fourteen skewness created for variable geometric properties. Seven different analyses were performed, and it is found that the change in critical angle of attack is dependent on the skew angle, the geometrical properties, and the type of bridges. The result also showed that the highest values of column moment were reached between forty-five- and sixty-degree angle of attack for rigid bridges and around ninety to hundred and twenty degrees for flexible bridges. As the columns curvature were analyzed using a small skew angle in stiff bridges, it was found that the change in columns curvature were shown in twenty-degree angle of attack for rigid bridges and were almost negligible for flexible structures.

2.6 NEAR AND FAR-FIELD EARTHQUAKES

Earthquake causes different shaking intensities at different locations. Seismic damage induced in structures at these locations is also different. Numerous studies and research have sought to clarify the effect and characteristics of near-field and far-field earthquake. Shahbazi, Karami, Wan Hu, and Mansouri (2019) worked on a moment frame structure. The model was conducted using ETABS and Iranian national construction codes. The structure was subjected to simultaneous excitation of vertical and horizontal ground motion components, and it was found that the inter-story drift ratio was three times higher in the near-field earthquake than far-field earthquake. Other studies have shown that near-field earthquakes have critical energy pulses. Near-field earthquakes have a large potential for damage and their acceleration history and velocity usually have long-period pulses.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the selection of the structural model used and the set of ground motions selected for the analysis. Further, a description of different methods used to compute the response of the four-story steel structure undergoing bidirectional and unidirectional ground motion is presented. Finally, it concludes with explaining the time history analysis.

3.2 STRUCTURAL MODEL

A four-story steel frame model was created for this research (Figure 1, 2, and 3). The building model has two-bay by two-bay steel frame quarter-scale. The bay width is four meter in the x and y direction. The story height was designed to be three meters. The members are hot rolled grade 300 W steel having a nominal yield stress of 300 MPa. All columns were selected to have fixed supports and are oriented to be stronger bending toward the x-direction (i.e., about the y-axis). The floors are designed to be stronger bending vertically. The four-story steel model has a floor slab per floor and the mass of slabs are not equal in each floor. The mass of slab in the first, second, third and fourth floors are four 800kg, four 600kg, four 400kg and four 550kg respectively. The unevenly mass distribution creates asymmetry.

The steel model is composed of 45 nodes. For this research, 12 nodes were analyzed in order to estimate the response of the steel structure. The nodes are examined in this order, first front column (node 1, node 10, node 19, node 28, node 37), middle front column (node 2, node 11, node 20, node 29, node 38), and third front column (node 3, node 12, node 21, node 21, node 30, node 39). Since node 1, node 2, and node 3 are fixed supports and zero displacement, they were not taken into consideration in the computation. The time history analysis is run for damping ratio selected to be five percent of the critical damping.

The plan and 3D view, front view and top view of the steel frame model is shown in figure below.

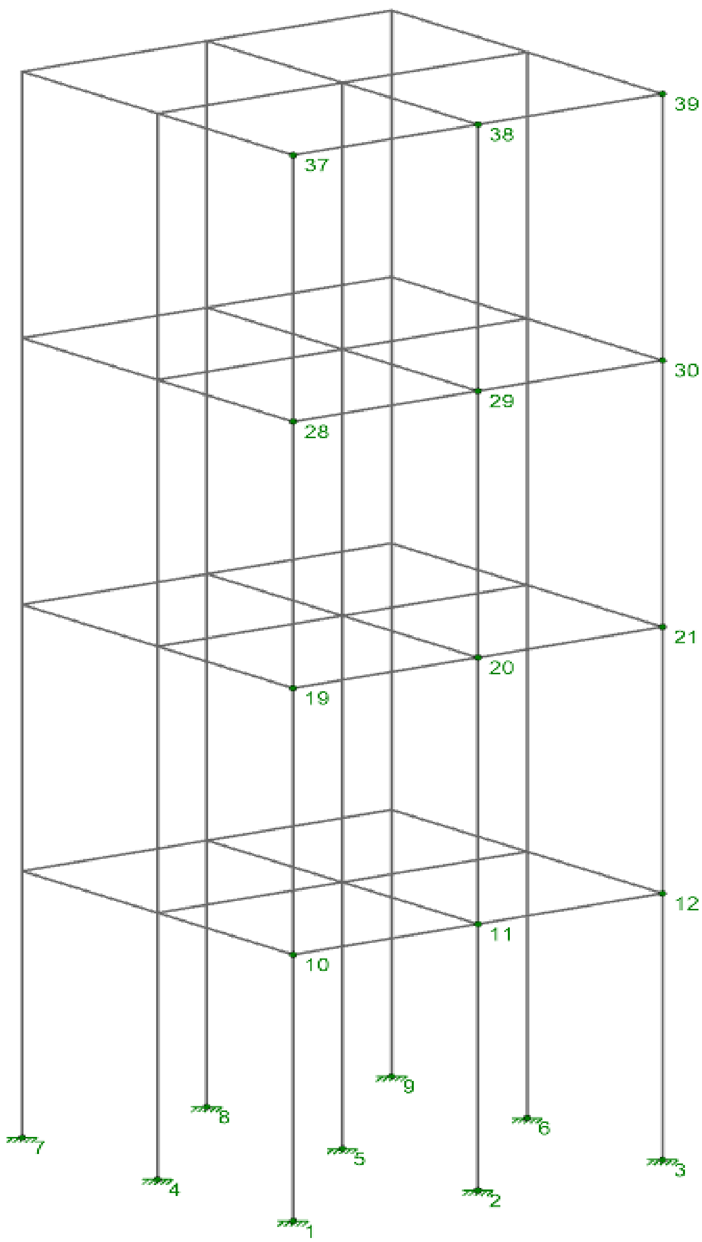

Figure 1 - 3D View of Steel Frame Model

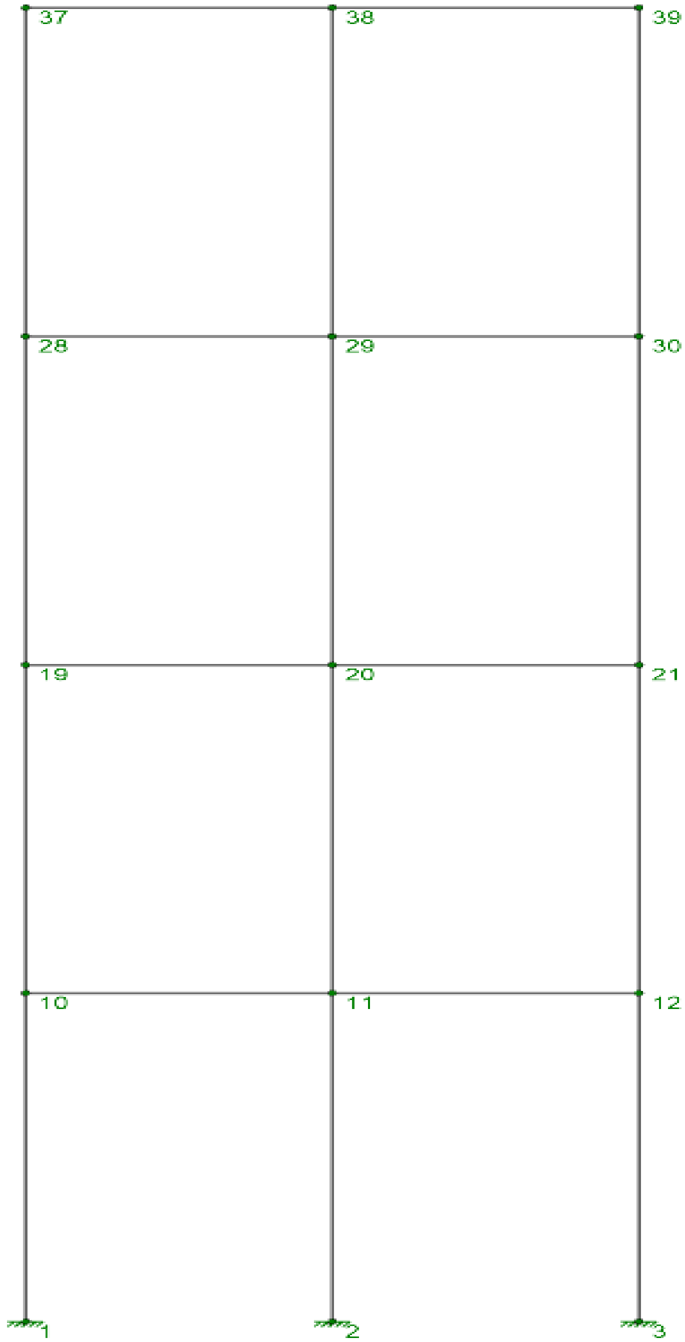

Figure 2 - Front View of Steel Frame Model

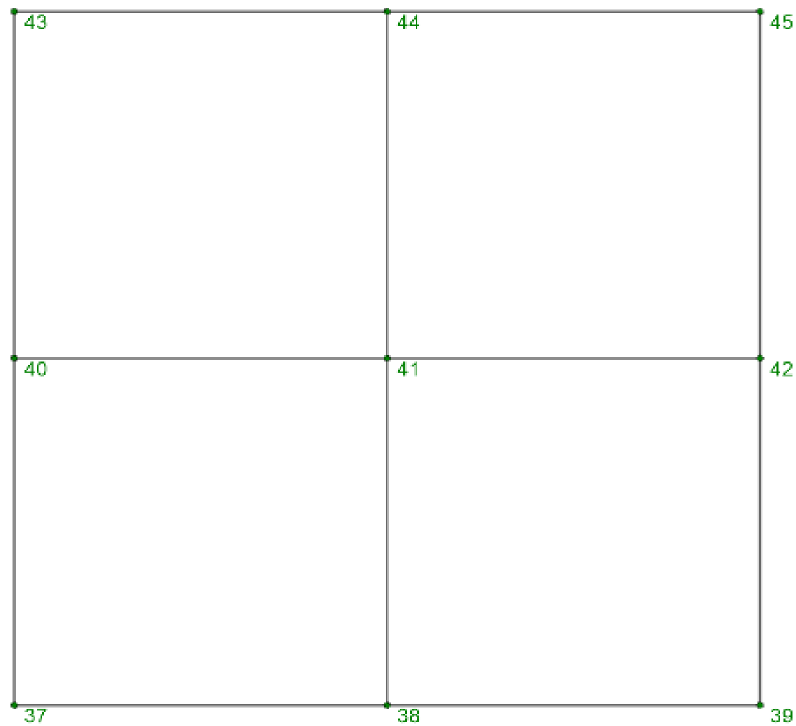

Figure 3 - Top View of Steel Frame Model

Table 1 - Properties of the Structural Members

Property	Columns	Floor Beams
Section Type	B100×9	S75x11
A	$1.133\text{x}10^{-3}$	$1.43\text{x}10^{-3}$
I_y	$1.97\text{x}10^{-6}$	$1.22\text{x}10^{-6}$
I_z	$0.664\text{x}10^{-6}$	$0.249\text{x}10^{-6}$
J	$8.01\text{x}10^{-9}$	$38.2\text{x}10^{-9}$
E	$2\text{x}10^{11}$	$2\text{x}10^{11}$
G	E/2.6	E/2.6
ρ	7800	7800

A= cross sectional area in (m^2)

I_y= Moment of Inertia (Strong direction) in (m^4)

I_z= Moment of Inertia (weak direction) in (m^4)

J= St. Venant torsional constant in (m^4)

E= Young’s modulus in (Pa)

G= Shear modulus in (Pa)

ρ= mass per unit volume in (kg/m^3)

3.3 GROUND MOTION DATA

To evaluate the effect of simultaneous application of two horizontal orthogonal ground motion components on the seismic behavior of the four-story steel frame, twenty sets of ground motion records were selected. The selected ground motions have this following configuration range:

- Earthquake Magnitude: $6.20 \leq M \leq 7.68$
- Epicentral distance: 7.04 km $\leq R_e \leq$ 75.20 km
- Shear wave velocity: 162.9 m/s $\leq V_s \leq$ 766.8 m/s

The earthquake magnitude is a measure of the size of earthquake while the epicentral distance is the distance from the epicenter to the recording station. The point directly above the focus on the ground surface is called an epicenter. Shear wave velocity is a property of soil and is related to the speed which are elastic wave. Figure 4 shows the graphical representation of the shear wave velocity with respect to the epicentral distance for the selected ground data and Figure 5 shows the graphical representation of the earthquake magnitude versus epicentral distance for the selected ground motion records are listed in Table 2.

Table 2 - Ground motion records use in this study

Ground motion number	Earthquake Name	Station Name	Earthquake Magnitude	Epicentral Distance (km)	Shear wave velocity Vs30 (m/s)
1	Imperial Valley-06	El Centro Array #3	6.53	28.65	162.9
2	Imperial Valley-06	El Centro Array #8	6.53	28.09	206.1
3	Imperial Valley-06	El Centro Differential Array	6.53	27.23	202.3
4	Imperial Valley-06	El Centro Array #12	6.53	31.99	196.9
5	Loma Prieta	Saratoga - Aloha Ave	6.93	27.23	370.8
6	Chi-Chi, Taiwan-04	CHY101	6.20	27.97	258.9
7	Imperial Valley-06	Calipatria Fire Station	6.53	57.14	205.8
8	Imperial Valley-06	El Centro Array #13	6.53	35.95	249.9
9	Landers	Mission Creek Fault	7.28	32.86	345.4
10	Chi-Chi, Taiwan-03	TCU122	6.20	24.47	475.5
11	Imperial Valley-06	Parachute Test Site	6.53	48.62	348.7
12	Hector Mine	Amboy	7.13	47.97	271.4
13	Chi-Chi, Taiwan	TCU089	7.62	7.04	553.4
14	Superstition Hills-01	Wildlife Liquef. Array	6.22	24.79	207.5
15	Gazli, USSR	Karakyr	6.80	12.82	659.6
16	Landers	Amboy	7.28	75.20	271.4
17	Chi-Chi, Taiwan	TCU049	7.62	38.91	487.3
18	Imperial Valley-06	Delta	6.53	33.73	274.5
19	Northridge-01	LA - Baldwin Hills	6.69	28.20	297.1
20	Tabas, Iran	Tabas	7.35	55.24	766.8

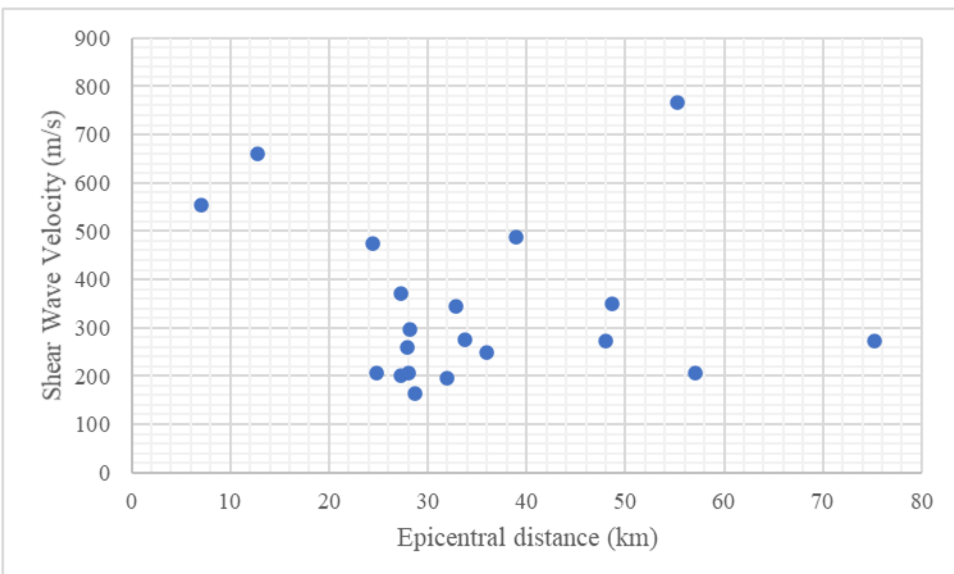

Figure 4 - Graphical representation of the shear wave velocity and epicentral distance for the selected ground motion

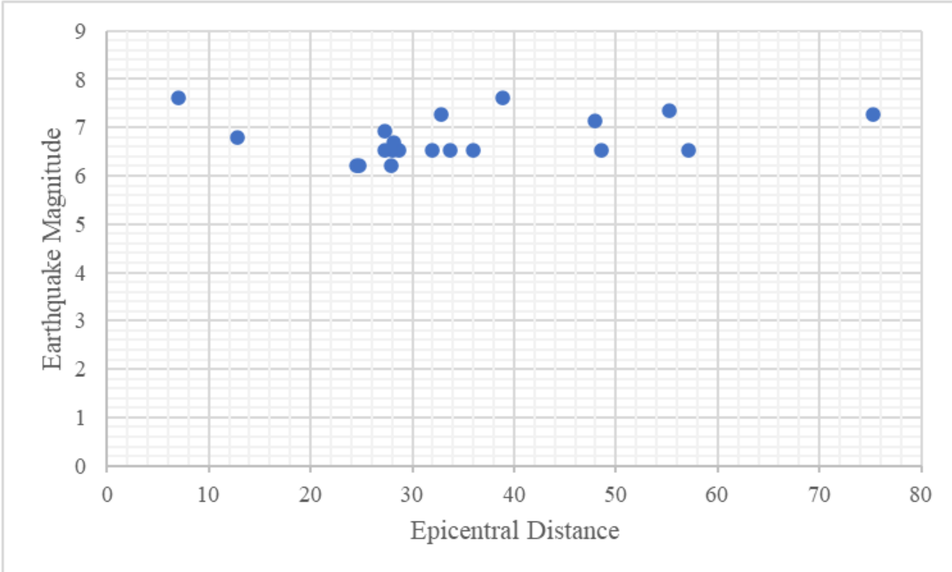

Figure 5 - Graphical representation of the earthquake magnitude and epicentral distance for the selected ground motions

3.4 METHOD OF COMPUTATION

In seismic analysis, principal components of bidirectional ground motions are typically assumed to act along the principal axes of the structure, however, structural response changes with variation of earthquake excitation angle. For this reason, the structure should be able to resist under variation of excitation angles of earthquakes, and the structure members need to be designed for 100% of prescribed seismic forces in one direction plus 30% in the orthogonal direction (International Building Code, IBC, 2000). For this research, SRSS, 30% and 20% combination rules were used to predict the bidirectional response of the four-story steel frame and the results were compared to the displacements obtained using unidirectional and bidirectional time history analyses.

3.4.1 SQUARE ROOT SUM OF SQUARE (SRSS) RULE

The SRSS rule can be described as the sum of the square root of the response of a structure under longitudinal component of earthquake when the excitation angle of earthquake is zero degree and the response of structure under longitudinal component of earthquake when the excitation angle of earthquake is ninety degrees. The longitudinal component of earthquake is defined as the major component of earthquake. The ground motion component a_1 is first applied in x-direction providing the response value R_{1x}. The same component is then applied in the y-direction producing R_{1y}. The same procedure is repeated using a_2, and responses R_{2x} and R_{2y} are obtained respectively, for the x and y directions. Those values are then combined using the SRSS formula described in time history analysis section. Some researchers such as Magliulo and Ramasco (2007) and Wilson et. al (1995) have found this method leads to conservative design.

3.4.2 30%-RULE

This response evaluation method was first introduced and developed by Rosenblueth and Contretas (1977). It is now documented in several regulatory documents (UBC, 1997:IS: 1893, 2002: IBC, 2009). It works with the assumption that two horizontal components are uncorrelated Gaussian process of equal intensity. It is based on finding the peak response of structure when the excitation angle is either zero or ninety degrees. Then the two peak values are again computed using the 30-percent rule formula describe in time history analysis section. For this research, the largest of the two estimated values were used because of the intensity that the component act in either x or y-direction. Oscar A. López1, Anil K. Chopra and Julio J. Hernández (2001) said that the largest estimate value between the two is to be used for design purpose.

3.4.3 20%-RULE

Twenty percent (20%) method is the third combination rule used in this research. The rule consists of using the maximum values between the response of structure under longitudinal component of earthquake when the excitation angle of earthquake is either zero or ninety degrees and then multiply it by 1.2. Some researchers such as Fernandez Davila, Cominetti, F. Cruz, (2000) and Khoushnoudian and Poursha (2004) said that this rule has a better estimation of the seismic response with respect to the exact response. It is more realistic. This method is obtained upon applying the longitudinal horizontal component of the seismic in each one of the two principal directions of the building. The 20%-rule amplifies 20% of the response from independent unidirectional analysis. The mathematical expression of 20%-rule used in this research is provided in Section 3.5.

3.5 TIME HISTORY ANALYSIS

To study the effect of two horizontal orthogonal ground motion to the steel frame model, a set of twenty recorded ground motion acceleration were used in linear time history analysis using MATLAB. The time history analysis can be defined as a step-by-step analysis of the dynamic response of a structure to a specified loading that may varies with time. It is also the standard against which all other methods of dynamic or equivalent dynamic analysis are measured (Duggai, 2010). For this research, the group of twenty ground motion were applied to the structure model in form of acceleration to the x and y directions.

Because the earthquake angle of attack might affect the structure from any direction, a MATLAB code was written to determine the responses under bidirectional or unidirectional ground motions with any excitation angle covering from 0^0 to 180^0. In case of this thesis, the response of structures was computed from 0^0 to 180^0. Here are the parameters of interest:

- Response: x-direction displacement of nodes
- Response: y-direction displacement of nodes
- ΔR Combination
- Maximum response under two components and one component

- Critical angle under two components and one component

The node displacements are measured with respect to the original, undeformed position. After the computation, the displacement response was recorded in x, y, z direction for each node. The Excel spreadsheet served to calculate the structure response using 30%, SSRS, and 20% formula described in this section. It means that the Excel spreadsheet helped to analyze the unidirectional and bidirectional impact on the building model. The following formulas were used for the computation of the response of structure under unidirectional and bidirectional ground motion.

$$R_1 = R_{1x}\cos\Theta + R_{1y}\sin\Theta \tag{1}$$

$$R = (R_{1x} + R_{2y})\cos\Theta + (R_{1y} - R_{2x})\sin\Theta \tag{2}$$

$$R_{\%30} = \max\{R_0 + 0.3R_{90}, R_{90} + 0.3R_0\} \tag{3}$$

$$R_{SRSS} = \sqrt{(R_0)^2 + (R_{90})^2} \tag{4}$$

$$R_{20\%} = 1.2 \times \max\{R_0, R_{90}\} \tag{5}$$

R_0: The response of structure under longitudinal component of ground motion when the excitation angle is 0^0

R_{90}: The response of structure under longitudinal component of ground motion when the excitation angle is 90^0

R_{1x}: The response of the structure when the first component of ground motion is applied in the x-direction

R_{1y}: The response of the structure when the first component of ground motion is applied in the y-direction

R_{2x}: The response of the structure when the second component of ground motion is applied in the x-direction

R_{2y}: The response of the structure when the second component of earthquake is applied in the y-direction

Θ: The excitation of the principal ground motion components relative to the principal axes of the structure angle goes from 0^0 and 180^0.

ΔR Combination: percent difference between combinations and maximum responses under two components

Rmax (bi): maximum response under two components

Rmax (uni): maximum response under one component

$\Theta_{cr_{bi}}$: critical angle under two components

$\Theta_{cr_{uni}}$:critical angle under one component

CHAPTER 4

APPLICATION AND ANALYSIS

4.1 INTRODUCTION

The twenty sets of three-component ground motion records are described in terms of two horizontal and one vertical component. The excitation angles are measured with respect to the reference axes of the structure. For the analysis of the steel frame building in this research, 30%, SRSS and 20% combination rule were used to evaluate the structure response for each ground motion. This combination rule combines the horizontal orthogonal ground motion in terms of peak response due to the ground motion components applied along the structure's principal axes. Therefore, R_{1x}, R_{1y}, R_{2x}, R_{2y} are time histories.

The purpose of this chapter is to describe in detail the sample computation of the structure subjected to an earthquake. The earthquake used as a computation sample is Imperial Valley-06 Earthquake recorded from El Centro Array #3 station. The response was computed for node 19 of the four-story steel structure. The same computation was done for the remaining ground motions and a summary of the results are listed in Appendix A.

4.2 RESPONSE: X-DIRECTION DISPLACEMENT OF NODE 19

Equation numbers correspond to time history section.

a1 applied in x direction: R^{1x}= 10.8374 cm

a1 applied in y direction: R^{1y}= 9.5076e-06 cm

a2 applied in x direction: R^{2x}= 4.5527 cm

a2 applied in y direction: R^{2y}= 9.5076e-06 cm

- **ONE-COMPONENT**

$$R_0 = R^{1x} \qquad \text{(using Equation 1)}$$

$$R_{90} = R^{1y} \quad \text{(using Equation 1)}$$

30% rule:

$$R_{\%30} = \text{larger of } (10.8374, \quad 3.2512) = 10.8374 \text{ cm} \qquad \text{(using Equation 3)}$$

SRSS:

$$R_{SRSS} = \ 10.8374 \text{ cm} \quad \text{(using Equation 4)}$$

20% rule:

$$R_{\%20} = 1.2 \times \text{larger of } (10.8374, \ \ 9.5076\text{x}10^{-6}) = 13.00488 \text{ cm} \qquad \text{(using Equation 5)}$$

$$R_{max,uni} = 10.8374 \text{ cm}, \qquad \theta_{cr,uni} = \ 0 \quad (\text{ using Equation 1 for } 0 < \theta < 180,)$$

$$\Delta R = \frac{R_{max,bi} - R_{max,uni}}{R_{max,bi}} 100\% = 1.7889 \ \%$$

$$\Delta R_{30\%} = \frac{R_{max,bi} - 10.8374}{R_{max,bi}} 100\% = 1.7889 \ \%$$

$$\Delta R_{SRSS} = \frac{R_{max,bi} - \ 10.8374}{R_{max,bi}} 100\% = 1.7889 \ \%$$

$$\Delta R_{20\%} = \frac{R_{max,bi} - 13.0049}{R_{max,bi}} 100\% = -17.8533 \ \%$$

- **TWO-COMPONENTS**

$$R_0 = R^{1x} + R^{2y} \quad \text{(using Equation 2)}$$

$$R_{90} = R^{1y} - R^{2x} \quad \text{(using Equation 2)}$$

30% rule:

$$R_{\%30} = \text{larger of } (12.2032, \ \ 7.8039) = 12.2032 \text{ cm} \qquad \text{(using Equation 3)}$$

SRSS:

$$R_{SRSS} = \ 11.7548 \ \text{ cm} \quad \text{(using Equation 4)}$$

20% rule:

$$R_{\%20} = 13.0049 \text{ cm} \qquad \text{(using Equation 5)}$$

$$R_{max,bi} = 11.0348 \text{ cm}, \qquad \theta_{cr,bi} = 169^{o} (\text{using Equation 2 for } 0 < \theta < 180^{0})$$

$$\Delta R = \frac{R_{max,bi} - R_{max,uni}}{R_{max,bi}} 100\% = 1.7889\ \%$$

$$\Delta R_{30\%} = \frac{R_{max,bi} - 12.2032}{R_{max,bi}} 100\% = -10.5885\ \%$$

$$\Delta R_{SRSS} = \frac{R_{max,bi} - 11.7548}{R_{max,bi}} 100\% = -6.5252\ \%$$

$$\Delta R_{20\%} = \frac{R_{max,bi} - 13.0049}{R_{max,bi}} 100\% = -17.8534\ \%$$

4.3 RESPONSE: Y-DIRECTION DISPLACEMENT OF NODE 19

Equation numbers correspond to time history section.

a1 applied in x direction: R^{1x}= 4.3463e-05 cm

a1 applied in y direction: R^{1y}= 6.1962 cm

a2 applied in x direction: R^{2x}= 2.7817e-05 cm

a2 applied in y direction: R^{2y}= 6.1962 cm

- **ONE-COMPONENT**

$$R_0 = R^{1x} \quad (\text{using Equation 1})$$

$$R_{90} = R^{1y} \quad (\text{using Equation 1})$$

30% rule:

$$R_{\%30} = \text{larger of } (1.8589, 6.1962) = 6.1962 \text{ cm} \qquad (\text{using Equation 3})$$

SRSS:

$$R_{SRSS} = 6.1962 \text{ cm} \quad (\text{using Equation 4})$$

20% rule:

$$R_{\%20} = 1.2 \times \text{larger of } (4.3463e-05,\ 6.1962) = 7.4354 \text{ cm} \qquad (\text{using Equation 5})$$

$$R_{max,uni} = 10.8374 \text{ cm}, \qquad \theta_{cr,uni} = 0 \quad (\text{ using Equation 1 for } 0 < \theta < 180^{0})$$

$$\Delta R = \frac{R_{max,bi} - R_{max,uni}}{R_{max,bi}} 100\% = 1.7889\ \%$$

$$\Delta R_{30\%} = \frac{R_{max,bi} - 6.1962}{R_{max,bi}} 100\% = 43.8484\ \%$$

$$\Delta R_{SRSS} = \frac{R_{max,bi} - 6.1962}{R_{max,bi}} 100\% = 43.8484\ \%$$

$$\Delta R_{20\%} = \frac{R_{max,bi} - 7.4353}{R_{max,bi}} 100\% = 32.6183\ \%$$

- **TWO-COMPONENTS**

$$R_0 = R^{1x} + R^{2y} \quad (\text{using Equation 2 })$$

$$R_{90} = R^{1y} - R^{2x} \quad (\text{using Equation 2 })$$

30% rule:

$$R_{\%30} = \text{larger of } (6.1962,\ \ 1.8589) = 6.1962 \text{ cm} \qquad (\text{using Equation 3 and 4})$$

SRSS:

$$R_{SRSS} = 6.1962 \ \text{ cm} \quad (\text{using Equation 5})$$

20% rule:

$$R_{\%20} = 7.4355 \text{ cm} \qquad (\text{using Equation 6})$$

$$R_{max,bi} = 11.0348 \text{ cm}, \qquad \theta_{cr,bi} = 169^{o} \quad (\text{ using Equation 2 for } 0 < \theta < 180,$$

$$\Delta R = \frac{R_{max,bi} - R_{max,uni}}{R_{max,bi}} 100\% = 1.7889\ \%$$

$$\Delta R_{30\%} = \frac{R_{max,bi} - 6.1962}{R_{max,bi}} 100\% = 43.8482\ \%$$

$$\Delta R_{SRSS} = \frac{R_{max,bi} - 6.1962}{R_{max,bi}} 100\% = 43.8482\ \%$$

$$\Delta R_{20\%} = \frac{R_{max,bi} - 7.4355}{R_{max,bi}} 100\% = 32.6178\ \%$$

ΔR is the comparison between the maximum value over all excitation angles and the corresponding values calculated by 30%, SRSS, and 20% rules. Notice that it was computed for each combination rule used in this thesis, and $R_{max,bi}$ is considered the most accurate.

CHAPTER 5

RESULTS AND DISCUSSION

The examined response parameters obtained in this analysis are in terms of node displacements in x, y, and z directions, maximum bidirectional and unidirectional responses under 30%-rule, SRSS-rule, and 20%-rule. For this research, the displacement of nodes and maximum responses were recorded for the first front column (node 10, node 19, node 28, node 37), middle front column (node 11, node 20, node 29, node 38), and third front column (node 12, node 21, node 30, node 39). Graphical representations of twenty earthquakes versus ΔR combination are plotted for node 11, 19, 30, 39. Those nodes are selected based on their locations on the four-story steel frame. Node 11 represents the first floor, node 19 represents second floor, node 30 represents third floor, and node 39 represents fourth floor. The MATLAB code produced a time history for each node and only the peak values were retrieved from time history analysis for further computation. The total number of plots of time history analysis response cases obtained were 2640 and 100 computation tables for responses in x and y directions. The results obtained from time history analysis were then used to compute the combination rules using an Excel spreadsheet. A complete analysis and results output for time history are included in Appendix A.

The maximum response value for a node is the highest absolute displacement of the node for all possible incident angles of the two horizontal ground motion components. The maximum response values were determined for unidirectional and bidirectional excitation and the critical angle (see Appendix A) for selected nodes in the structure.

The critical angle in unidirectional excitation comes out to be zero degree. The meaning behind $\Theta=0$ in unidirectional excitation is that the principal directions of the orthogonal ground motion components are aligned with the principal axes of structure.

The purpose of this thesis was to investigate the effect of two horizontal orthogonal ground motions to the seismic behavior of the building. The structure model used in this thesis was a four-story steel frame with property described in Table 1. The percent combination method (e.g., 30%-rule, SRSS-rule, and 20%-rule) adopted by modern seismic code were used to compute the response of the structure. Lastly, the purpose was also to compare how the structure of the building responds under unidirectional and bidirectional ground motion using linear analysis approach. The results obtained from linear time history analysis of the four-story steel frame model subjected to twenty earthquake excitations show that:

- During the application of two ground motion components, the node displacement in the x direction was greater than y direction for six earthquakes out of 20 selected earthquakes (30% of selected ground motions) while in the y direction the displacement was greater than x direction for 16 out of 20 earthquakes (70% of selected earthquakes).
- The maximum response under two components is more than the maximum response under one component. The peak response under two components was, on average, 23 % more than the peak response under a single component.
- The earthquake magnitude, epicenter distance or shear wave velocity have shown to have no effect on the output results.
- The output result for SRSS and 30% combinations in the studied structure yield very close response values under unidirectional excitation both in x and y direction. It was also

observed that the structure displayed a close response value when it was subjected to bidirectional excitation in the y direction.

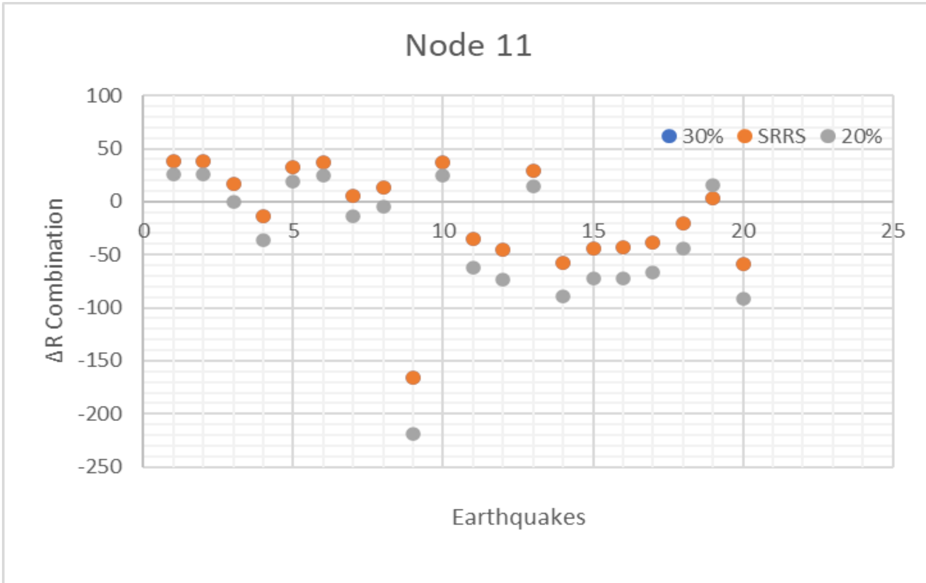

Figure 6 - Plot of ΔR Combination and twenty earthquakes under one component (y direction)

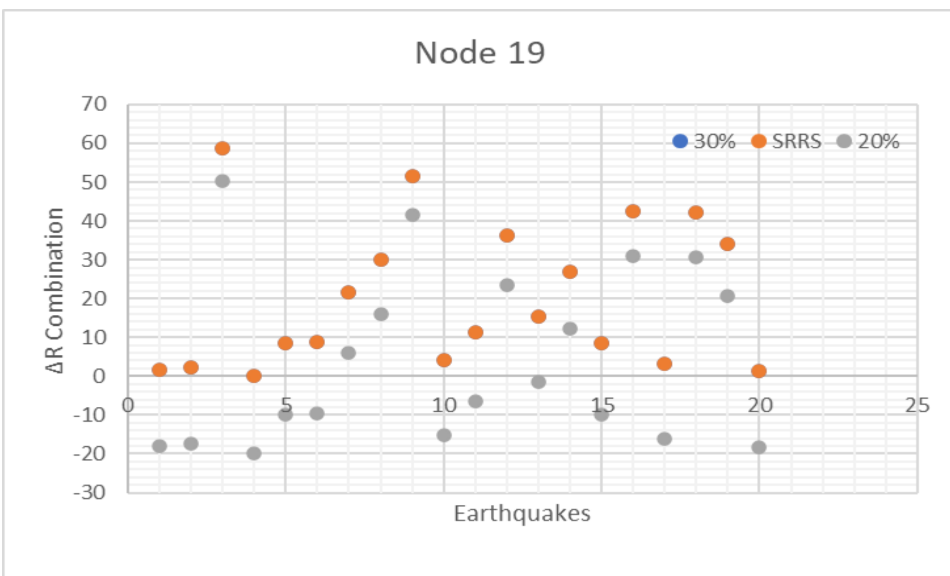

Figure 7 - Plot of ΔR Combination and twenty earthquakes under one component (x direction)

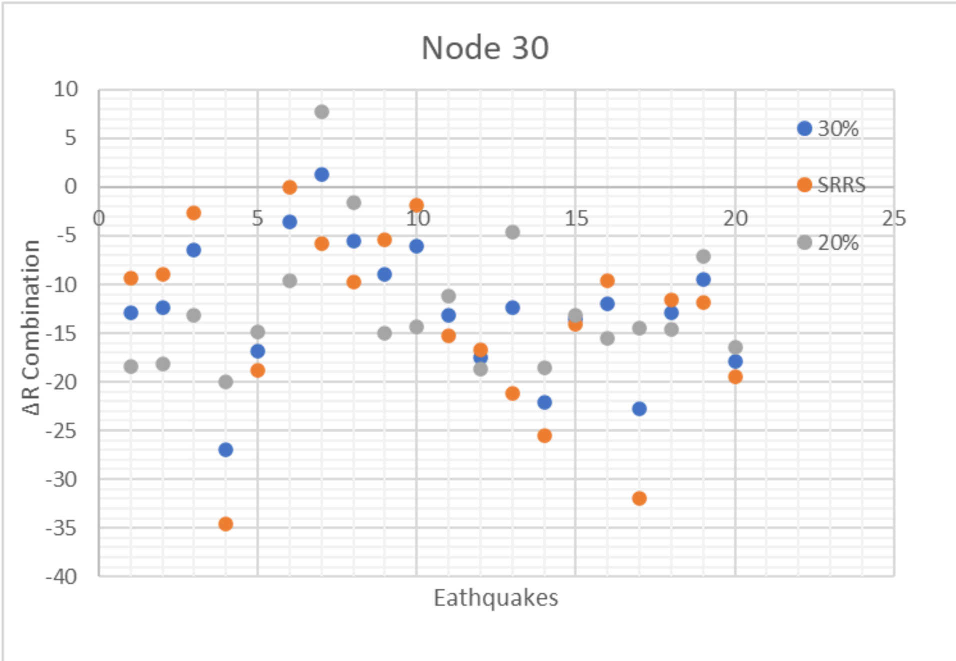

Figure 8 - Plot of ΔR Combination and twenty earthquakes under two components

(x direction)

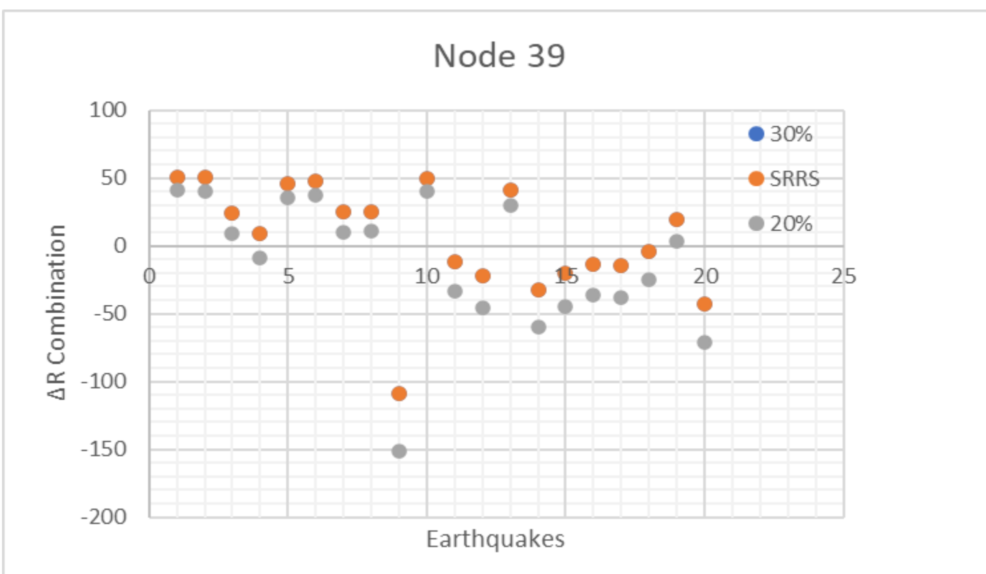

Figure 9 - Plot of ΔR Combination and twenty earthquakes under two components

(y direction)

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The modern seismic codes such as ASCE/SEI 41-06 (Seismic rehabilitation of existing buildings, American Society of Civil Engineers), EUROCODE 8 (1998-1) (Design provisions for earthquake resistance of structures, European Committee for Standardization, 2003), FEMA 356 (Prestandard and Commentary For Seismic Rehabilitation Of The Buildings), FEMA P-2082 (NEHRP Recommended Seismic Provisions for new buildings and other structures) suggest structures be designed for three translational components of ground motions: two horizontal, orthogonal and one vertical. In this research, twenty sets of three-component ground motion records were selected with different magnitude, epicenter distance, and shear wave velocity. This group of twenty ground motions was in the form of acceleration x, y, z-direction. It was then applied to the structure and the excitation angles varied between 0^0 to 180^0. The excitation angles were measured counterclockwise from the structure's axes. A four-story steel frame was modeled. It has a bay width of four meters in the x and y-direction, a height of three meters in each floor and a damping ratio of 5 percent. The MATLAB program was developed to estimate the response of the building under one and two components using linear response history. The response time histories were then used to determine the peak response and the corresponding critical angle. Lastly, the percent combination rules were used in this study. The combination rules were adopted in buildings codes, standards, and guidelines such as UBC (ICBO 1997), FHWA-HRT-06-032 (FHWA 2006), AASHTO LRFD Design Specifications (AASHTO 2010), National Building Code of Canada (NRCC 2010), GB 50011 (MoCPRC 2010), AASTHO Guide Specifications for LRFD Seismic Bridge Design (AASHTO 2011), EN

1998-1 (CEN 2013), ASCE/SEI 41-13 (ASCE 2014), International Building Code (ICC 2015), and ASCE 7-16 (ASCE 2016). The percent combination rules were used to determine the maximum response of the steel frame model under one and two simultaneously acting horizontal ground motion components within the context of linear response history. The combination rules were applied to seismic demands (i.e., r_x, r_y) and computed using linear response history analysis. The numerical values produced by the 30%-rule, SRSS-rule, and 20%-rule, and the maximum response under unidirectional and bidirectional motions were compared between them in terms of x and y direction. The excitation angles were also computed for one and two components. The Excel program were then used as calculation tool.

This thesis investigation has led to the following conclusions:

- The node displacement in the x direction produced larger values than y direction for six selected earthquakes while fourteen selected earthquakes for y direction over x direction. It is also observed that the node displacements (ux, uy, uz) under two components produced larger values than the node displacement under unidirectional. In case of unidirectional ground excitation, the displacements display significant values in the applied direction while are negligible in the non-applied ground motion direction.
- The maximum response of nodes under two components (bidirectional ground motion) is more than the maximum response under one component (unidirectional ground motion). The two horizontal orthogonal seismic excitations increased the structure displacement response compared to unidirectional excitation. This was observed for all the 20 cases of earthquakes used in the thesis whether the response was in the x or y direction. This result indicates the significance of designing structures based on two or even three

translational components of ground motion: two horizontal, orthogonal and the vertical one.

- There is variation of critical angle when the structure is subjected to bidirectional excitation. The angle computed in unidirectional ground motion was zero for all the 20 selected earthquakes. This might tell that the principal directions of the ground motion component were aligned with the principal axes of structure. It might also mean that the selected ground motions were converted into minor and major axes before it was used in this thesis.
- The computation of critical angle in every node located on the first floor is equal for first front column, middle front column, and third front column. The same observation was noticed for second, third, and fourth floors under bidirectional ground motions while the angle in the unidirectional motions were constant (zero degrees) for all the 20 selected earthquakes.

6.2 RECOMMENDATIONS

The recommendations for future works are as follows:

1. This thesis research was conducted using linear time history analysis. The output results are based on the linear behavior of the structure. A non-linear analysis needs to be investigated in order to see the response of the structure subjected to bidirectional and unidirectional excitation.
2. The four-story steel frame was investigated without braces. Future study needs to investigate the same structure with braces to compare the unidirectional versus bidirectional response.

3. The effect of two horizontal orthogonal ground motion needs to be investigated on different types of structures as well, such as concrete shear walls, wood structures, masonry buildings, and others.
4. The effect of vertical component of the ground motion as well as the rotational components need to be investigated.
5. The findings presented in this thesis are based on nodal displacements, and these findings do not necessarily apply to member forces, especially for nonlinear structures. It is recommended that a similar analysis be performed using member forces, for both linear and nonlinear structures.

REFERENCES

Ahsaan Hussain, Sekhar Chandra Dutta, Sumit Kumar. "Inelastic Seismic behavior of mass eccentric RC structure under bidirectional ground motion." *16th Symposium on Earthquake Engineering*. Ed. Ahsaan Hussain. 20-22 December 2018.

AK, Chopra. *Dynamics of Structures*. New Jersey, 1995.

Bengi Atak, Ahmet Yakut, Ozgur Avcar. "Directional effect of the strong motion on the seismic behavior of skewed bridges." *Proceedings of the 9th International Conference on Structural Dynamics, EURODYN 2014*. Ed. Ozgur Avcar. 2014.

De Stefano, Faella Giuseppe. "An evaluation of the inelastic response of system under biaxial seismic excitattions." *Engineering structures* 18 (1996): 724-731.

E. Johnson, A.M. ASCE, H.F. Lam, L.S. Katafygiots, A.M. ASCE, J.L. Bench, M. ASCE. "Phase I IASC-ASCE Structural Health Monitoring Benchmark Problem Using Simulated Data." *Journal of Engineering Mechanics @ ASCE* (2004).

Fernández-Dávila, E. F. Cruz. "Study of the Combination Rules to Estimate The Inelastic ." *Proceedings of the 8th U.S. National Conference on Earthquake Engineering* (April 18-22, 2006): Paper No. 1062.

Fernandez-Davila, Cominetti, F. Cruz. "Considering the bi-directional effects and the seismic angle variations in building design." *XII WCEE, Newzealand* (2020): No. 435.

Giuseppe Faella, vojko kilar, Gennaro Maglilo. "Symmetric 3D R/C Buildings subjected to bi-directional input ground motion." *Engineering structures* (n.d.).

Grant, Damian N. "Response Spectral Matching of Two." *Journal of Structural Engineering*. Ed. Damian Grant. n.d. January 2010.

H. Shakib and M. Pirizadeh. "Probabilistic Seismic Performance Assessment of Setback." *Journal of Structure Engineering*. 2014.

Jafar Shoja-Taheri, John Gregg Anderson. "The 1978 Tabas, Iran, Earthquake: An interpretation of the strong motion records." *Bulletin of the Seismological Society of America* 30 june 2015: 142-171.

Joseph Penzien, Makoto Watabe. "Characteristics of 3-Dimensional Eartquake Ground Motions." *Earthquake Engineering and Structural Dynamics* (1975): Vol. 3, 365-375.

Lee GC, Liang Z. "On Cross Effects of Seismic Responses of Structures." *Engineering Structures, 20(4-6): 503-509* (1998).

Oscar A. Lopez, Anil K. Chopra, M. Asce, and Julio J. Hernandez. "Adapting the CQC3 Rule for Three Seismic Components." *Journal of Structural Engineering* (March 2004).

S.C Potnis, R.S Desai, I.D Gupta. "Seismic Response Analysis Under Simultaneous Action of Two Horizontal Components of Ground Motion." *ISET Golden Jubilee Symposium (Indian Society of Earthquake Technology)*. OCctober 20-21, 2012. Paper No. D012.

Sanaz Rezaeian, Armen Der Kiureghian. "Simulation of orthogonal horizontal ground motion components for specified earthquake and site characteristics." *Earthquake engineering Structural dynamics 2011* (2011).

Shahrokh Shahbazi, Armin Karami , Jong Wan Hu, and Iman Mansouri. "Seismic Response of Steel Moment Frames (SMFs)." *Applied Science* (2019).

Xiaogang Lui, Jiansheng Fan, Jianguo Nie, Guo Li. "Behavior of composite rigid frame bridge under bi-directional seismic excitation." *journal of traffic and transportation engineering (english edition)* (2014): 62-71.

Zach Liang, George C. Lee. "Principal Axes of M-DOF Structures. Part 2: Dynamic Loading." *Earthquake Engineering and Engineering Vibration* (2003).

Zack Liang, George C. Lee. "Principal axes of M-DOF Structures Part 1.: Static Loading." *Earthquake Engineering and Engineering Vibration* (2002).

Zeris, C.A and Mahin. "Behavior of Reinforced Concrete Structure subjected to biaxial excitation." *Journal of structural engineering* (1991): 2657-2673.

APPENDICES

APPENDIX A

RESPONSE OF STRUCTURE UNDER UNIDIRECTIONAL AND BIDIRECTIONAL GROUND MOTIONS EXCITATION

The numerical values represent the difference between combinations and maximum response (nodes displacement) under two components and one component. The MATLAB code attached in Appendix C were used for computation, and Chapter 5 gives a sample computation of one of the selected earthquakes. The same computation was used for the twenty selected set of three-component ground motion records. The numerical values attached in this appendix are in centimeters.

Table 3 - Node displacement under Imperial Valley-06 Earthquake

station El Centro Array # 3

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	4.5700	2.8271	0.0109	4.5700	0.0000	0.0118	0.0000	2.8271	0.0036
node 19	10.8374	6.1962	0.0188	10.8374	0.0000	0.0204	0.0000	6.1962	0.0058
node 28	15.9665	8.6593	0.0233	15.9665	0.0001	0.0251	0.0000	8.6593	0.0068
node 37	19.8245	9.8646	0.0248	19.8245	0.0001	0.0267	0.0000	9.8646	0.0071
node 11	4.5704	2.8969	0.0037	4.5704	0.0000	0.0000	0.0000	2.8969	0.0037
node 20	10.8372	6.3431	0.0059	10.8372	0.0000	0.0000	0.0000	6.3431	0.0059
node 29	15.9665	8.8576	0.0069	15.9665	0.0000	0.0000	0.0000	8.8576	0.0069
node 38	19.8240	10.0798	0.0072	19.8240	0.0000	0.0000	0.0000	10.0798	0.0072
node 12	4.5700	2.8271	0.0128	4.5700	0.0000	0.0118	0.0000	2.8271	0.0036
node 21	10.8374	6.1962	0.0219	10.8374	0.0000	0.0204	0.0000	6.1962	0.0058
node 30	15.9665	8.6593	0.0269	15.9665	0.0001	0.0251	0.0000	8.6593	0.0068
node 39	19.8245	9.8646	0.0286	19.8245	0.0001	0.0267	0.0000	9.8646	0.0071

Table 4 - Percent difference between combinations and maximum response under one

one component x- direction under Imperial Valley-06 Earthquake

station El Centro Array #3

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	2.3692	2.3692	-17.1570	4.6809	4.5700	2.3692	167
node 19	1.7889	1.7889	-17.8533	11.0348	10.8374	1.7889	169
node 28	1.2701	1.2701	-18.4759	16.1719	15.9665	1.2701	171
node 37	1.3755	1.3756	-18.3493	20.1010	19.8245	1.3756	170
node 11	2.3690	2.3690	-17.1572	4.6813	4.5704	2.3690	167
node 20	1.7889	1.7889	-17.8533	11.0346	10.8372	1.7889	169
node 29	1.2701	1.2701	-18.4759	16.1719	15.9665	1.2701	171
node 38	1.3756	1.3756	-18.3493	20.1005	19.8240	1.3756	170
node 12	2.3692	2.3692	-17.1570	4.6809	4.5700	2.3692	167
node 21	1.7889	1.7889	-17.8533	11.0348	10.8374	1.7889	169
node 30	1.2701	1.2701	-18.4759	16.1719	15.9665	1.2701	171
node 39	1.3755	1.3756	-18.3493	20.1010	19.8245	1.3756	170

Table 5 - Percent difference between combinations and maximum response two components in x- direction under Imperial Valley-06 Earthquake, station El Centro Array #3

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.6854	-6.8894	-17.1571	4.6809	4.5700	2.3692	167
node 19	-10.5885	-6.5252	-17.8534	11.0348	10.8374	1.7889	169
node 28	-12.8472	-9.3710	-18.4760	16.1719	15.9665	1.2701	171
node 37	-13.0883	-9.7781	-18.3494	20.1010	19.8245	1.3756	170
node 11	-10.6857	-6.8898	-17.1572	4.6813	4.5704	2.3690	167
node 20	-10.5883	-6.5251	-17.8533	11.0346	10.8372	1.7889	169
node 29	-12.8472	-9.3710	-18.4759	16.1719	15.9665	1.2701	171
node 38	-13.0882	-9.7781	-18.3493	20.1005	19.8240	1.3756	170
node 12	-10.6854	-6.8894	-17.1571	4.6809	4.5700	2.3692	167
node 21	-10.5885	-6.5252	-17.8534	11.0348	10.8374	1.7889	169
node 30	-12.8472	-9.3710	-18.4760	16.1719	15.9665	1.2701	171
node 39	-13.0883	-9.7781	-18.3494	20.1010	19.8245	1.3756	170

Table 6 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station El Centro Array #3

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	39.6033	39.6035	27.5242	4.6809	4.5700	2.3692	167
node 19	43.8484	43.8486	32.6183	11.0348	10.8374	1.7889	169
node 28	46.4546	46.4547	35.7456	16.1719	15.9665	1.2701	171
node 37	50.9247	50.9248	41.1098	20.1010	19.8245	1.3756	170
node 11	38.1176	38.1176	25.7411	4.6813	4.5704	2.3690	167
node 20	42.5163	42.5163	31.0195	11.0346	10.8372	1.7889	169
node 29	45.2285	45.2285	34.2741	16.1719	15.9665	1.2701	171
node 38	49.8530	49.8530	39.8236	20.1005	19.8240	1.3756	170
node 12	39.6033	39.6035	27.5242	4.6809	4.5700	2.3692	167
node 21	43.8484	43.8486	32.6183	11.0348	10.8374	1.7889	169
node 30	46.4546	46.4547	35.7456	16.1719	15.9665	1.2701	171
node 39	50.9247	50.9248	41.1098	20.1010	19.8245	1.3756	170

Table 7 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station El Centro Array #3

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	39.6029	39.6029	27.5235	4.6809	4.5700	2.3692	167
node 19	43.8482	43.8482	32.6178	11.0348	10.8374	1.7889	169
node 28	46.4543	46.4543	35.7452	16.1719	15.9665	1.2701	171
node 37	50.9244	50.9244	41.1093	20.1010	19.8245	1.3756	170
node 11	38.1176	38.1176	25.7411	4.6813	4.5704	2.3690	167
node 20	42.5163	42.5163	31.0195	11.0346	10.8372	1.7889	169
node 29	45.2285	45.2285	34.2741	16.1719	15.9665	1.2701	171
node 38	49.8530	49.8530	39.8236	20.1005	19.8240	1.3756	170
node 12	39.6029	39.6029	27.5235	4.6809	4.5700	2.3692	167
node 21	43.8482	43.8482	32.6178	11.0348	10.8374	1.7889	169
node 30	46.4543	46.4543	35.7452	16.1719	15.9665	1.2701	171
node 39	50.9244	50.9244	41.1093	20.1010	19.8245	1.3756	170

Table 8 - Node displacement under Imperial Valley-06 Earthquake station El Centro Array #8

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	7.6720	4.8387	0.0240	7.6720	0.0000	0.0195	0.0000	4.8387	0.0061
node 19	19.1015	10.6028	0.0407	19.1015	0.0001	0.0330	0.0000	10.6028	0.0099
node 28	28.2989	14.8148	0.0492	28.2989	0.0001	0.0400	0.0000	14.8148	0.0116
node 37	33.5074	16.8736	0.0523	33.5074	0.0001	0.0423	0.0000	16.8736	0.0121
node 11	7.6728	4.9268	0.0062	7.6728	0.0000	0.0000	0.0000	4.9268	0.0062
node 20	19.1012	10.7928	0.0101	19.1012	0.0000	0.0000	0.0000	10.7928	0.0101
node 29	28.2988	15.0773	0.0118	28.2988	0.0000	0.0000	0.0000	15.0773	0.0118
node 38	33.5068	17.1649	0.0123	33.5068	0.0000	0.0000	0.0000	17.1649	0.0123
node 12	7.6720	4.8386	0.0175	7.6720	0.0000	0.0195	0.0000	4.8386	0.0061
node 21	19.1015	10.6028	0.0291	19.1015	0.0001	0.0330	0.0000	10.6028	0.0099
node 30	28.2989	14.8149	0.0349	28.2989	0.0001	0.0400	0.0000	14.8149	0.0116
node 39	33.5074	16.8737	0.0368	33.5074	0.0001	0.0423	0.0000	16.8737	0.0121

Table 9 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station El Centro Array #8

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	3.1472	3.1472	-16.2233	7.9213	7.6720	3.1472	165
node 19	2.2566	2.2566	-17.2921	19.5425	19.1015	2.2566	167
node 28	1.4998	1.4998	-18.2002	28.7298	28.7298	0.0000	169
node 37	1.2653	1.2653	-18.4816	33.9368	33.5074	1.2653	159
node 11	3.1457	3.1457	-16.2252	7.9220	7.6728	3.1457	165
node 20	2.2567	2.2567	-17.2920	19.5422	19.1012	2.2567	167
node 29	1.4998	1.4998	-18.2002	28.7297	28.2988	1.4998	169
node 38	1.2653	1.2653	-18.4816	33.9362	33.5068	1.2653	159
node 12	3.1472	3.1472	-16.2233	7.9213	7.6720	3.1472	165
node 21	2.2566	2.2566	-17.2921	19.5425	19.1015	2.2566	167
node 30	1.4998	1.4998	-18.2002	28.7298	28.2989	1.4998	169
node 39	1.2653	1.2653	-18.4816	33.9368	33.5074	1.2653	159

Table 10 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station El Centro Array #8

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.6506	-7.2184	-16.2235	7.9213	7.6720	3.1472	165
node 19	-10.7746	-6.9606	-17.2922	19.5425	19.1015	2.2566	167
node 28	-12.4255	-8.8893	-18.2003	28.7298	28.7298	0.0000	169
node 37	-13.3394	-10.0841	-18.4817	33.9368	33.5074	1.2653	159
node 11	-10.6520	-7.2196	-16.2252	7.9220	7.6728	3.1457	165
node 20	-10.7745	-6.9605	-17.2920	19.5422	19.1012	2.2567	167
node 29	-12.4255	-8.8894	-18.2002	28.7297	28.2988	1.4998	169
node 38	-13.3393	-10.0839	-18.4816	33.9362	33.5068	1.2653	159
node 12	-10.6506	-7.2184	-16.2235	7.9213	7.6720	3.1472	165
node 21	-10.7746	-6.9606	-17.2922	19.5425	19.1015	2.2566	167
node 30	-12.4255	-8.8893	-18.2003	28.7298	28.2989	1.4998	169
node 39	-13.3394	-10.0841	-18.4817	33.9368	33.5074	1.2653	159

Table 11 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station El Centro Array #8

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	38.9152	38.9153	26.6984	7.9213	7.6720	3.1472	165
node 19	45.7448	45.7449	34.8939	19.5425	19.1015	2.2566	167
node 28	48.4339	48.4340	38.1208	28.7298	28.7298	0.0000	169
node 37	50.2792	50.2793	40.3352	33.9368	33.5074	1.2653	159
node 11	37.8086	37.8086	25.3704	7.9220	7.6728	3.1457	165
node 20	44.7718	44.7718	33.7262	19.5422	19.1012	2.2567	167
node 29	47.5202	47.5202	37.0242	28.7297	28.2988	1.4998	169
node 38	49.4201	49.4201	39.3041	33.9362	33.5068	1.2653	159
node 12	38.9164	38.9166	26.6999	7.9213	7.6720	3.1472	165
node 21	45.7448	45.7449	34.8939	19.5425	19.1015	2.2566	167
node 30	48.4336	48.4337	38.1204	28.7298	28.2989	1.4998	169
node 39	50.2789	50.2790	40.3349	33.9368	33.5074	1.2653	159

Table 12 - Percent difference between combinations and maximum response under two components in y- direction under Imperial Valley-06 Earthquake, station El Centro Array #8

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	38.9148	38.9148	26.6978	7.9213	7.6720	3.1472	165
node 19	45.7446	45.7446	34.8935	19.5425	19.1015	2.2566	167
node 28	48.4338	48.4338	38.1205	28.7298	28.7298	0.0000	169
node 37	50.2790	50.2790	40.3348	33.9368	33.5074	1.2653	159
node 11	37.8086	37.8086	25.3704	7.9220	7.6728	3.1457	165
node 20	44.7718	44.7718	33.7262	19.5422	19.1012	2.2567	167
node 29	47.5202	47.5202	37.0242	28.7297	28.2988	1.4998	169
node 38	49.4201	49.4201	39.3041	33.9362	33.5068	1.2653	159
node 12	38.9161	38.9161	26.6993	7.9213	7.6720	3.1472	165
node 21	45.7446	45.7446	34.8935	19.5425	19.1015	2.2566	167
node 30	48.4334	48.4334	38.1201	28.7298	28.2989	1.4998	169
node 39	50.2787	50.2787	40.3344	33.9368	33.5074	1.2653	159

Table 13 - Node displacement under Imperial Valley-06 Earthquake station El Centro Differential Array

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	4.0383	7.9766	0.0120	4.0383	0.0000	0.0086	0.0000	7.9766	0.0101
node 19	9.2675	17.4813	0.0188	9.2675	0.0001	0.0148	0.0000	17.4813	0.0164
node 28	12.6017	24.4291	0.0217	12.6017	0.0000	0.0182	0.0000	24.4291	0.0192
node 37	14.4491	27.8279	0.0228	14.4491	0.0001	0.0193	0.0000	27.8279	0.0200
node 11	4.0387	8.1580	0.0103	4.0387	0.0000	0.0000	0.0000	8.1580	0.0103
node 20	9.2673	17.8655	0.0167	9.2673	0.0000	0.0000	0.0000	17.8655	0.0167
node 29	12.6016	24.9507	0.0196	12.6016	0.0000	0.0000	0.0000	24.9507	0.0196
node 38	14.4488	28.3970	0.0203	14.4488	0.0000	0.0000	0.0000	28.3970	0.0203
node 12	4.0383	7.9766	0.0150	4.0383	0.0000	0.0086	0.0000	7.9766	0.0101
node 21	9.2675	17.4813	0.0245	9.2675	0.0001	0.0148	0.0000	17.4813	0.0164
node 30	12.6017	24.4291	0.0289	12.6017	0.0000	0.0182	0.0000	24.4291	0.0192
node 39	14.4491	27.8279	0.0301	14.4491	0.0001	0.0193	0.0000	27.8279	0.0200

Table 14 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station El Centro Differential Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	58.5407	58.5407	50.2489	9.7404	4.0383	58.5407	104
node 19	58.7030	58.7030	50.4436	22.4411	9.2675	58.7030	107
node 28	59.5774	59.5774	51.4929	31.1749	12.6017	59.5774	109
node 37	60.7574	60.7575	52.9090	36.8200	14.4491	60.7575	109
node 11	58.5417	58.5417	50.2501	9.7416	4.0387	58.5417	104
node 20	58.7032	58.7032	50.4438	22.4407	9.2673	58.7032	107
node 29	59.5775	59.5775	51.4930	31.1747	12.6016	59.5775	109
node 38	60.7575	60.7575	52.9090	36.8193	14.4488	60.7575	109
node 12	58.5419	58.5420	50.2504	9.7407	4.0383	58.5420	104
node 21	58.7030	58.7030	50.4436	22.4411	9.2675	58.7030	107
node 30	59.5774	59.5774	51.4929	31.1749	12.6017	59.5774	109
node 39	60.7574	60.7575	52.9090	36.8200	14.4491	60.7575	109

Table 15 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station El Centro Differential Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-9.2992	-5.3613	-16.2336	9.7404	4.0383	58.5407	104
node 19	-8.1731	-4.3073	-14.9407	22.4411	9.2675	58.7030	107
node 28	-6.4474	-2.6176	-13.1847	31.1749	12.6017	59.5774	109
node 37	-6.4457	-2.4839	-13.6075	36.8200	14.4491	60.7575	109
node 11	-9.2963	-5.3585	-16.2306	9.7416	4.0387	58.5417	104
node 20	-8.1731	-4.3073	-14.9408	22.4407	9.2673	58.7032	107
node 29	-6.4475	-2.6176	-13.1849	31.1747	12.6016	59.5775	109
node 38	-6.4459	-2.4841	-13.6078	36.8193	14.4488	60.7575	109
node 12	-9.2958	-5.3581	-16.2301	9.7407	4.0383	58.5420	104
node 21	-8.1731	-4.3073	-14.9407	22.4411	9.2675	58.7030	107
node 30	-6.4474	-2.6176	-13.1847	31.1749	12.6017	59.5774	109
node 39	32.3555	-2.4839	-13.6075	36.8200	14.4491	60.7575	109

Table 16 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station El Centro Differential Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	18.1080	18.1081	1.7297	9.7404	4.0383	58.5407	104
node 19	22.1013	22.1014	6.5217	22.4411	9.2675	58.7030	107
node 28	21.6385	21.6386	5.9663	31.1749	12.6017	59.5774	109
node 37	24.4217	24.4218	9.3061	36.8200	14.4491	60.7575	109
node 11	16.2561	16.2561	-0.4927	9.7416	4.0387	58.5417	104
node 20	20.3880	20.3880	4.4655	22.4407	9.2673	58.7032	107
node 29	19.9649	19.9649	3.9579	31.1747	12.6016	59.5775	109
node 38	22.8747	22.8747	7.4496	36.8193	14.4488	60.7575	109
node 12	18.1105	18.1106	1.7327	9.7407	4.0383	58.5420	104
node 21	22.1013	22.1014	6.5217	22.4411	9.2675	58.7030	107
node 30	21.6385	21.6386	5.9663	31.1749	12.6017	59.5774	109
node 39	24.4217	24.4218	9.3061	36.8200	14.4491	60.7575	109

Table 17 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station El Centro Differential Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	18.1078	18.1078	1.7293	9.7404	4.0383	58.5407	104
node 19	22.1012	22.1012	6.5214	22.4411	9.2675	58.7030	107
node 28	21.6384	21.6384	5.9661	31.1749	12.6017	59.5774	109
node 37	24.4216	24.4216	9.3059	36.8200	14.4491	60.7575	109
node 11	16.2561	16.2561	-0.4927	9.7416	4.0387	58.5417	104
node 20	20.3880	20.3880	4.4655	22.4407	9.2673	58.7032	107
node 29	19.9649	19.9649	3.9579	31.1747	12.6016	59.5775	109
node 38	22.8747	22.8747	7.4496	36.8193	14.4488	60.7575	109
node 12	18.1103	18.1103	1.7323	9.7407	4.0383	58.5420	104
node 21	22.1012	22.1012	6.5214	22.4411	9.2675	58.7030	107
node 30	21.6384	21.6384	5.9661	31.1749	12.6017	59.5774	109
node 39	24.4216	24.4216	9.3059	36.8200	14.4491	60.7575	109

Table 18 - Node displacement Imperial underValley-06 Earthquake station El Centro Array#12

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	2.5516	2.8270	0.0086	2.5516	0.0000	0.0061	0.0000	2.8270	0.0036
node 19	6.2376	6.1970	0.0144	6.2376	0.0000	0.0102	0.0000	6.1970	0.0058
node 28	9.0699	8.6619	0.0172	9.0699	2.5631	0.0125	0.0000	8.6619	0.0068
node 37	10.6032	9.8694	0.0181	10.6032	0.0000	0.0133	0.0000	9.8694	0.0071
node 11	2.5519	2.9133	0.0037	2.5519	0.0000	0.0000	0.0000	2.9133	0.0037
node 20	6.2375	6.3764	0.0059	6.2375	0.0000	0.0000	0.0000	6.3764	0.0059
node 29	9.0699	8.9009	0.0070	9.0699	0.0000	0.0000	0.0000	8.9009	0.0070
node 38	10.6030	10.1254	0.0072	10.6030	0.0000	0.0000	0.0000	10.1254	0.0072
node 12	2.5516	2.8269	0.0084	2.5516	0.0000	0.0061	0.0000	2.8269	0.0036
node 21	6.2376	6.1970	0.0141	6.2376	0.0000	0.0102	0.0000	6.1970	0.0058
node 30	9.0699	8.6618	0.0171	9.0699	0.0000	0.0125	0.0000	8.6618	0.0068
node 39	10.6032	9.8694	0.0180	10.6032	0.0000	0.0133	0.0000	9.8694	0.0071

Table 19 - Percent difference between combinations and maximum response under one component in x-direction underValley-06 Earthquake, station El Centro Array#12

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	0.4331	0.4331	-19.4802	2.5627	2.5516	0.4331	6
node 19	0.1072	0.1073	-19.8712	6.2443	6.2376	0.1073	3
node 28	0.0055	0.0055	-19.9934	9.0704	9.0699	0.0055	179
node 37	2.7229	2.7229	-16.7325	10.9000	10.6032	2.7229	156
node 11	0.4331	0.4331	-19.4803	2.5630	2.5519	0.4331	6
node 20	0.1073	0.1073	-19.8712	6.2442	6.2375	0.1073	3
node 29	0.0044	0.0044	-19.9947	9.0703	9.0699	0.0044	179
node 38	2.7230	2.7230	-16.7324	10.8998	10.6030	2.7230	156
node 12	0.4447	0.4448	-19.4663	2.5630	2.5516	0.4448	6
node 21	0.1072	0.1073	-19.8712	6.2443	6.2376	0.1073	3
node 30	0.0055	0.0055	-19.9934	9.0704	9.0699	0.0055	179
node 39	2.7229	2.7229	-16.7325	10.9000	10.6032	2.7229	156

Table 20 - Percent difference between combinations and maximum response under two components in x- direction underValley-06 Earthquake station El Centro Array#12

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-25.5868	-32.0460	-19.4805	2.5627	2.5516	0.4331	6
node 19	-26.1752	-32.8672	-19.8715	6.2443	6.2376	0.1073	3
node 28	-26.9921	-34.5266	-19.9936	9.0704	9.0699	0.0055	179
node 37	-24.0641	-32.0436	-16.7327	10.9000	10.6032	2.7229	156
node 11	-25.5860	-32.0444	-19.4803	2.5630	2.5519	0.4331	6
node 20	-26.1755	-32.8681	-19.8712	6.2442	6.2375	0.1073	3
node 29	-26.9934	-34.5280	-19.9947	9.0703	9.0699	0.0044	179
node 38	-24.0641	-32.0436	-16.7327	10.8998	10.6030	2.7230	156
node 12	-25.5721	-32.0305	-19.4665	2.5630	2.5516	0.4448	6
node 21	-26.1750	-32.8671	-19.8713	6.2443	6.2376	0.1073	3
node 30	-26.9921	-34.5266	-19.9936	9.0704	9.0699	0.0055	179
node 39	-23.0733	-29.8331	-16.7327	10.9000	10.6032	2.7229	156

Table 21 - Percent difference between combinations and maximum response under one component in y-direction underValley-06 Earthquake, station El Centro Array#12

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.3135	-10.3133	-32.3760	2.5627	2.5516	0.4331	6
node 19	0.7574	0.7575	-19.0910	6.2443	6.2376	0.1073	3
node 28	4.5036	4.5037	-14.5956	9.0704	9.0699	0.0055	179
node 37	9.4549	9.4550	-8.6539	10.9000	10.6032	2.7229	156
node 11	-13.6676	-13.6676	-36.4011	2.5630	2.5519	0.4331	6
node 20	-2.1172	-2.1172	-22.5406	6.2442	6.2375	0.1073	3
node 29	1.8676	1.8676	-17.7588	9.0703	9.0699	0.0044	179
node 38	7.1047	7.1047	-11.4743	10.8998	10.6030	2.7230	156
node 12	-10.3006	-10.3004	-32.3605	2.5630	2.5516	0.4448	6
node 21	0.7574	0.7575	-19.0910	6.2443	6.2376	0.1073	3
node 30	4.5047	4.5048	-14.5943	9.0704	9.0699	0.0055	179
node 39	9.4549	9.4550	-8.6539	10.9000	10.6032	2.7229	156

Table 22 - Percent difference between combinations and maximum response under two components in y-direction underValley-06 Earthquake, station El Centro Array#12

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.3139	-10.3139	-32.3767	2.5627	2.5516	0.4331	6
node 19	0.7571	0.7571	-19.0915	6.2443	6.2376	0.1073	3
node 28	4.5034	4.5034	-14.5959	9.0704	9.0699	0.0055	179
node 37	9.4547	9.4547	-8.6544	10.9000	10.6032	2.7229	156
node 11	-13.6676	-13.6676	-36.4011	2.5630	2.5519	0.4331	6
node 20	-2.1172	-2.1172	-22.5406	6.2442	6.2375	0.1073	3
node 29	1.8676	1.8676	-17.7588	9.0703	9.0699	0.0044	179
node 38	7.1047	7.1047	-11.4743	10.8998	10.6030	2.7230	156
node 12	-10.3010	-10.3010	-32.3612	2.5630	2.5516	0.4448	6
node 21	0.7571	0.7571	-19.0915	6.2443	6.2376	0.1073	3
node 30	4.5045	4.5045	-14.5946	9.0704	9.0699	0.0055	179
node 39	9.4547	9.4547	-8.6544	10.9000	10.6032	2.7229	156

Table 23 - Node displacement under Loma Prieta Earthquake, station Saratoga-Aloha Ave

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	6.6109	4.7570	0.0186	6.6109	0.0000	0.0178	0.0000	4.7570	0.0060
node 19	15.8564	10.4256	0.0312	15.8564	0.0001	0.0305	0.0000	10.4256	0.0098
node 28	24.4020	14.5696	0.0378	24.4020	0.0001	0.0373	0.0000	14.5696	0.0115
node 37	30.1032	16.5972	0.0399	30.1032	0.0001	0.0396	0.0000	16.5972	0.0119
node 11	6.6115	4.8776	0.0062	6.6115	0.0000	0.0000	0.0000	4.8776	0.0062
node 20	15.8562	10.6786	0.0100	15.8562	0.0000	0.0000	0.0000	10.6786	0.0100
node 29	24.4020	14.9098	0.0117	24.4020	0.0000	0.0000	0.0000	14.9098	0.0117
node 38	30.1026	16.9649	0.0121	30.1026	0.0000	0.0000	0.0000	16.9649	0.0121
node 12	6.6109	4.7570	0.0181	6.6109	0.0000	0.0178	0.0000	4.7570	0.0060
node 21	15.8564	10.4256	0.0310	15.8564	0.0001	0.0305	0.0000	10.4256	0.0098
node 30	24.4020	14.5695	0.0379	24.4020	0.0001	0.0373	0.0000	14.5696	0.0115
node 39	30.1032	16.5971	0.0402	30.1032	0.0001	0.0396	0.0000	16.5972	0.0119

Table 24 - Percent difference between combinations and maximum response under one component in x-direction under Loma Prieta Earthquake, station Saratoga-Aloha Ave

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	8.7938	8.7938	-9.4475	7.2483	6.6109	8.7938	155
node 19	8.4979	8.4979	-9.8025	17.3290	15.8564	8.4979	154
node 28	4.2582	4.2582	-14.8902	25.4873	24.4020	4.2582	150
node 37	2.3498	2.3498	-17.1802	30.8276	30.1032	2.3498	149
node 11	8.7931	8.7931	-9.4483	7.2489	6.6115	8.7931	155
node 20	8.4980	8.4980	-9.8024	17.3288	15.8562	8.4980	154
node 29	4.2582	4.2582	-14.8902	25.4873	24.4020	4.2582	150
node 38	2.3499	2.3499	-17.1801	30.8270	30.1026	2.3499	149
node 12	8.7938	8.7938	-9.4475	7.2483	6.6109	8.7938	155
node 21	8.4979	8.4979	-9.8025	17.3290	15.8564	8.4979	154
node 30	4.2582	4.2582	-14.8902	25.4873	24.4020	4.2582	150
node 39	2.3498	2.3498	-17.1802	30.8276	30.1032	2.3498	149

Table 25 - Percent difference between combinations and maximum response under two components in x-direction under Loma Prieta Earthquake, station Saratoga-Aloha Ave

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.6206	-11.8327	-9.4476	7.2483	6.6109	8.7938	155
node 19	-12.0668	-14.3309	-9.8026	17.3290	15.8564	8.4979	154
node 28	-16.8591	-18.8333	-14.8903	25.4873	24.4020	4.2582	150
node 37	-18.6049	-20.0602	-17.1803	30.8276	30.1032	2.3498	149
node 11	-10.6217	-11.8341	-9.4483	7.2489	6.6115	8.7931	155
node 20	-12.0665	-14.3306	-9.8024	17.3288	15.8562	8.4980	154
node 29	-16.8589	-18.8331	-14.8902	25.4873	24.4020	4.2582	150
node 38	-34.0157	-32.8973	-35.6731	30.8270	30.1026	2.3499	149
node 12	-10.6206	-11.8327	-9.4476	7.2483	6.6109	8.7938	155
node 21	-12.0668	-14.3309	-9.8026	17.3290	15.8564	8.4979	154
node 30	-16.8591	-18.8333	-14.8903	25.4873	24.4020	4.2582	150
node 39	-18.6049	-20.0602	-17.1803	30.8276	30.1032	2.3498	149

Table 26 - Percent difference between combinations and maximum response under one component in y-direction under Loma Prieta Earthquake, station Saratoga-Aloha Ave

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	34.3707	34.3708	21.2450	7.2483	6.6109	8.7938	155
node 19	39.8372	39.8373	27.8047	17.3290	15.8564	8.4979	154
node 28	42.8358	42.8358	31.4030	25.4873	24.4020	4.2582	150
node 37	46.1611	46.1612	35.3935	30.8276	30.1032	2.3498	149
node 11	32.7125	32.7125	19.2551	7.2489	6.6115	8.7931	155
node 20	38.3766	38.3766	26.0519	17.3288	15.8562	8.4980	154
node 29	41.5011	41.5011	29.8013	25.4873	24.4020	4.2582	150
node 38	44.9674	44.9674	33.9609	30.8270	30.1026	2.3499	149
node 12	34.3707	34.3708	21.2450	7.2483	6.6109	8.7938	155
node 21	39.8372	39.8373	27.8047	17.3290	15.8564	8.4979	154
node 30	42.8358	42.8358	31.4030	25.4873	24.4020	4.2582	150
node 39	46.1611	46.1612	35.3935	30.8276	30.1032	2.3498	149

Table 27 - Percent difference between combinations and maximum response under two components in y-direction under Loma Prieta Earthquake, station Saratoga-Aloha Ave

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	34.3704	34.3704	21.2445	7.2483	6.6109	8.7938	155
node 19	39.8369	39.8369	27.8043	17.3290	15.8564	8.4979	154
node 28	42.8356	42.8356	31.4027	25.4873	24.4020	4.2582	150
node 37	46.1609	46.1609	35.3931	30.8276	30.1032	2.3498	149
node 11	32.7125	32.7125	19.2551	7.2489	6.6115	8.7931	155
node 20	38.3766	38.3766	26.0519	17.3288	15.8562	8.4980	154
node 29	41.5011	41.5011	29.8013	25.4873	24.4020	4.2582	150
node 38	44.9674	44.9674	33.9609	30.8270	30.1026	2.3499	149
node 12	34.3704	34.3704	21.2445	7.2483	6.6109	8.7938	155
node 21	39.8369	39.8369	27.8043	17.3290	15.8564	8.4979	154
node 30	42.8356	42.8356	31.4027	25.4873	24.4020	4.2582	150
node 39	46.1609	46.1609	35.3931	30.8276	30.1032	2.3498	149

Table 28 - Node displacement under Chi-Chi, Taiwan-04 Earthquake, station CHY101

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	4.1699	2.7914	0.0104	4.1699	0.0000	0.0097	0.0000	2.7914	0.0035
node 19	10.1124	6.1173	0.0171	10.1124	0.0000	0.0159	0.0000	6.1173	0.0057
node 28	14.5919	8.5484	0.0204	14.5919	0.0000	0.0190	0.0000	8.5484	0.0067
node 37	16.9746	9.7376	0.0214	16.9746	0.0001	0.0199	0.0000	9.7376	0.0070
node 11	4.1703	2.8560	0.0036	4.1703	0.0000	0.0000	0.0000	2.8560	0.0036
node 20	10.1123	6.2538	0.0058	10.1123	0.0000	0.0000	0.0000	6.2538	0.0058
node 29	14.5918	6.7331	0.0068	14.5918	0.0000	0.0000	0.0000	6.7331	0.0068
node 38	16.9743	9.9383	0.0071	16.9743	0.0000	0.0000	0.0000	9.9383	0.0071
node 12	4.1699	2.7914	0.0107	4.1699	0.0000	0.0097	0.0000	2.7914	0.0035
node 21	10.1124	6.1173	0.0174	10.1124	0.0000	0.0159	0.0000	6.1173	0.0057
node 30	14.5919	8.5484	0.0207	14.5919	0.0000	0.0190	0.0000	8.5484	0.0067
node 39	16.9746	9.7375	0.0217	16.9746	0.0001	0.0199	0.0000	9.7376	0.0070

Table 29 - Percent difference between combinations and maximum response one component in x-direction under Chi-Chi, Taiwan-04 Earthquake, station CHY101

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	8.7249	8.7250	-9.5300	4.5685	4.1699	8.7250	156
node 19	8.7040	8.7040	-9.5552	11.0765	10.1124	8.7040	156
node 28	8.6762	8.6762	-9.5886	15.9782	14.5919	8.6762	156
node 37	8.6031	8.6031	-9.6763	18.5724	16.9746	8.6031	156
node 11	8.7242	8.7242	-9.5310	4.5689	4.1703	8.7242	156
node 20	8.7033	8.7033	-9.5561	11.0763	10.1123	8.7033	156
node 29	8.6768	8.6768	-9.5878	15.9782	14.5918	8.6768	156
node 38	77.5476	77.5476	73.0571	18.5722	16.9743	8.6037	156
node 12	31.7631	31.7632	18.1158	4.5685	4.1699	8.7250	156
node 21	8.7040	8.7040	-9.5552	11.0765	10.1124	8.7040	156
node 30	8.6762	8.6762	-9.5886	15.9782	14.5919	8.6762	156
node 39	8.6031	8.6031	-9.6763	18.5724	16.9746	8.6031	156

Table 30 - Percent difference between combinations and maximum response under two components in x-direction under Chi-Chi, Taiwan-04 Earthquake, station CHY101

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-4.1170	-0.8142	-9.5302	4.5685	4.1699	8.7250	156
node 19	-3.7660	-0.3132	-9.5553	11.0765	10.1124	8.7040	156
node 28	-3.8115	-0.3630	-9.5887	15.9782	14.5919	8.6762	156
node 37	-3.5875	-0.0230	-9.6764	18.5724	16.9746	8.6031	156
node 11	-4.1178	-0.8151	-9.5310	4.5689	4.1703	8.7242	156
node 20	-3.7666	-0.3137	-9.5561	11.0763	10.1123	8.7033	156
node 29	-3.5461	0.0004	-9.5878	15.9782	14.5918	8.6768	156
node 38	74.3887	75.2011	73.0571	18.5722	16.9743	8.6037	156
node 12	21.8316	24.1567	18.1157	4.5685	4.1699	8.7250	156
node 21	-3.7660	-0.3132	-9.5553	11.0765	10.1124	8.7040	156
node 30	-3.5469	-0.0004	-9.5887	15.9782	14.5919	8.6762	156
node 39	-3.5875	-0.0230	-9.6764	18.5724	16.9746	8.6031	156

Table 31 - Percent difference between combinations and maximum response under one component in y-direction under Chi-Chi, Taiwan-04 Earthquake, station CHY101

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	38.8988	38.8990	26.6788	4.5685	4.1699	8.7250	156
node 19	44.7722	44.7723	33.7267	11.0765	10.1124	8.7040	156
node 28	46.4995	46.4996	35.7995	15.9782	14.5919	8.6762	156
node 37	47.5694	47.5695	37.0834	18.5724	16.9746	8.6031	156
node 11	37.4904	37.4904	24.9885	4.5689	4.1703	8.7242	156
node 20	43.5389	43.5389	32.2467	11.0763	10.1123	8.7033	156
node 29	57.8607	57.8607	49.4329	15.9782	14.5918	8.6768	156
node 38	84.9700	84.9700	81.9640	18.5722	16.9743	8.6037	156
node 12	56.8282	56.8283	48.1939	4.5685	4.1699	8.7250	156
node 21	44.7722	44.7723	33.7267	11.0765	10.1124	8.7040	156
node 30	46.4995	46.4996	35.7995	15.9782	14.5919	8.6762	156
node 39	47.5694	47.5695	37.0834	18.5724	16.9746	8.6031	156

Table 32 - Percent difference between combinations and maximum response under two components in y-direction under Chi-Chi, Taiwan-04 Earthquake, station CHY101

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	38.8984	38.8984	26.6780	4.5685	4.1699	8.7250	156
node 19	44.7719	44.7719	33.7263	11.0765	10.1124	8.7040	156
node 28	46.4994	46.4994	35.7993	15.9782	14.5919	8.6762	156
node 37	47.5692	47.5692	37.0831	18.5724	16.9746	8.6031	156
node 11	37.4904	37.4904	24.9885	4.5689	4.1703	8.7242	156
node 20	43.5389	43.5389	32.2467	11.0763	10.1123	8.7033	156
node 29	57.8607	57.8607	49.4329	15.9782	14.5918	8.6768	156
node 38	84.9699	84.9699	81.9638	18.5722	16.9743	8.6037	156
node 12	56.8279	56.8279	48.1934	4.5685	4.1699	8.7250	156
node 21	44.7719	44.7719	33.7263	11.0765	10.1124	8.7040	156
node 30	46.4994	46.4994	35.7993	15.9782	14.5919	8.6762	156
node 39	47.5692	47.5692	37.0831	18.5724	16.9746	8.6031	156

Table 33 - Node displacement under Imperial Valley-06 Earthquake, station Calipatria Fire Station

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	1.3665	1.5322	0.0038	1.3665	0.0000	0.0028	0.0000	1.5322	0.0019
node 19	3.1538	3.3578	0.0064	3.1538	0.0000	0.0046	0.0000	3.3578	0.0031
node 28	4.3288	4.6923	0.0078	4.3288	0.0000	0.0055	0.0000	4.6923	0.0037
node 37	4.8928	5.3450	0.0082	4.8928	0.0000	0.0059	0.0000	5.3450	0.0038
node 11	1.3667	1.5663	0.0020	1.3667	0.0000	0.0000	0.0000	1.5663	0.0020
node 20	3.1538	3.4302	0.0032	3.1538	0.0000	0.0000	0.0000	3.4302	0.0032
node 29	4.3288	4.7907	0.0038	4.3288	0.0000	0.0000	0.0000	4.7907	0.0038
node 38	4.8927	5.4525	0.0039	4.8927	0.0000	0.0000	0.0000	5.4525	0.0039
node 12	1.3665	1.5322	0.0036	1.3665	0.0001	0.0028	0.0000	1.5322	0.0019
node 21	3.1538	3.3578	0.0058	3.1538	0.0000	0.0046	0.0000	3.3578	0.0031
node 30	4.3288	4.6923	0.0069	4.3288	0.0000	0.0055	0.0000	4.6923	0.0037
node 39	4.8928	5.3450	0.0073	4.8928	0.0000	0.0059	0.0000	5.3450	0.0038

Table 34 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station Calipatria Fire Station

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	17.6112	17.6112	1.1335	1.6586	1.3665	17.6112	144
node 19	21.7011	21.7011	6.0414	4.0279	3.1538	21.7011	139
node 28	27.3459	27.3460	12.8152	5.9581	4.3288	27.3460	133
node 37	31.6017	31.6018	17.9221	7.1534	4.8928	31.6018	131
node 11	17.6091	17.6091	1.1309	1.6588	1.3667	17.6091	144
node 20	21.6992	21.6992	6.0390	4.0278	3.1538	21.6992	139
node 29	27.6737	27.6737	13.2085	5.9851	4.3288	27.6737	133
node 38	31.6022	31.6022	17.9226	7.1533	4.8927	31.6022	131
node 12	17.6112	17.6112	1.1335	1.6586	1.3655	17.6715	144
node 21	21.7011	21.7011	6.0414	4.0279	3.1538	21.7011	139
node 30	27.3459	27.3460	12.8152	5.9581	4.3288	27.3460	133
node 39	31.6017	31.6018	17.9221	7.1534	4.8928	31.6018	131

Table 35 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station Calipatria Fire Station

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-3.5007	-8.3523	1.1333	1.6586	1.3665	17.6112	144
node 19	-0.6267	-8.0274	6.0412	4.0279	3.1538	21.7011	139
node 28	1.3002	-5.7960	7.7157	5.9581	4.3288	27.3460	133
node 37	2.1202	-3.2616	7.1676	7.1534	4.8928	31.6018	131
node 11	-3.5037	-8.3562	1.1309	1.6588	1.3667	17.6091	144
node 20	-0.6284	-8.0284	6.0390	4.0278	3.1538	21.6992	139
node 29	1.7453	-5.3187	8.1319	5.9851	4.3288	27.6737	133
node 38	2.1206	-3.2610	7.1679	7.1533	4.8927	31.6022	131
node 12	-3.5007	-8.3523	1.1333	1.6586	1.3655	17.6715	144
node 21	-0.6267	-8.0274	6.0412	4.0279	3.1538	21.7011	139
node 30	1.3002	-5.7960	7.7157	5.9581	4.3288	27.3460	133
node 39	8.3936	-3.2616	7.1676	7.1534	4.8928	31.6018	131

Table 36 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station Calipatria Fire Station

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	7.6207	7.6209	-10.8549	1.6586	1.3665	17.6112	144
node 19	16.6364	16.6365	-0.0362	4.0279	3.1538	21.7011	139
node 28	21.2450	21.2450	5.4940	5.9581	4.3288	27.3460	133
node 37	25.2803	25.2803	10.3363	7.1534	4.8928	31.6018	131
node 11	5.5763	5.5763	-13.3084	1.6588	1.3667	17.6091	144
node 20	14.8369	14.8369	-2.1957	4.0278	3.1538	21.6992	139
node 29	19.9562	19.9562	3.9475	5.9851	4.3288	27.6737	133
node 38	23.7764	23.7764	8.5317	7.1533	4.8927	31.6022	131
node 12	7.6193	7.6209	-10.8549	1.6586	1.3655	17.6715	144
node 21	16.6364	16.6365	-0.0362	4.0279	3.1538	21.7011	139
node 30	21.2450	21.2450	5.4940	5.9581	4.3288	27.3460	133
node 39	25.2802	25.2803	10.3363	7.1534	4.8928	31.6018	131

Table 37 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station Calipatria Fire Station

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	7.6203	7.6203	-10.8556	1.6586	1.3665	17.6112	144
node 19	16.6361	16.6361	-0.0367	4.0279	3.1538	21.7011	139
node 28	21.2448	21.2448	5.4938	5.9581	4.3288	27.3460	133
node 37	25.2803	25.2803	10.3363	7.1534	4.8928	31.6018	131
node 11	5.5763	5.5763	-13.3084	1.6588	1.3667	17.6091	144
node 20	14.8369	14.8369	-2.1957	4.0278	3.1538	21.6992	139
node 29	19.9562	19.9562	3.9475	5.9851	4.3288	27.6737	133
node 38	23.7764	23.7764	8.5317	7.1533	4.8927	31.6022	131
node 12	7.6155	7.6155	-10.8614	1.6586	1.3655	17.6715	144
node 21	16.6361	16.6361	-0.0367	4.0279	3.1538	21.7011	139
node 30	21.2448	21.2448	5.4938	5.9581	4.3288	27.3460	133
node 39	25.2800	25.2800	10.3360	7.1534	4.8928	31.6018	131

Table 38 - Node displacement under Imperial Valley-06 Earthquake, station El Centro Array #13

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	1.5830	1.9171	0.0047	1.5830	0.0000	0.0037	0.0000	1.9171	0.0024
node 19	3.7935	4.2013	0.0078	3.7935	0.0000	0.0064	0.0000	4.2013	0.0039
node 28	5.4098	5.8711	0.0093	5.4098	0.0000	0.0078	0.0000	5.8711	0.0046
node 37	6.3417	6.6878	0.0098	6.3417	0.0000	0.0083	0.0000	6.6878	0.0048
node 11	1.5831	1.9600	0.0025	1.5831	0.0000	0.0000	0.0000	1.9600	0.0025
node 20	3.7935	4.2923	0.0040	3.7935	0.0000	0.0000	0.0000	4.2923	0.0040
node 29	5.4097	5.9948	0.0047	5.4097	0.0000	0.0000	0.0000	5.9948	0.0047
node 38	6.3416	6.8229	0.0049	6.3416	0.0000	0.0000	0.0000	6.8229	0.0049
node 12	1.5830	1.9171	0.0044	1.5830	0.0000	0.0037	0.0000	1.9171	0.0024
node 21	3.7935	4.2013	0.0073	3.7935	0.0000	0.0064	0.0000	4.2013	0.0039
node 30	5.4097	5.8711	0.0087	5.4097	0.0000	0.0078	0.0000	5.8711	0.0046
node 39	6.3417	6.6878	0.0092	6.3417	0.0000	0.0083	0.0000	6.6878	0.0048

Table 39 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station El Centro Array #13

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	29.5693	29.5693	15.4832	2.2476	1.5830	29.5693	46
node 19	29.9717	29.9718	15.9661	5.4171	3.7935	29.9718	46
node 28	30.2789	30.2789	16.3347	7.7592	5.4098	30.2789	46
node 37	29.3144	29.3144	15.1773	8.9717	6.3417	29.3144	46
node 11	29.5743	29.5743	15.4891	2.2479	1.5831	29.5743	46
node 20	29.9705	29.9705	15.9646	5.4170	3.7935	29.9705	46
node 29	30.2793	30.2793	16.3351	7.7591	5.4097	30.2793	46
node 38	29.3147	29.3147	15.1777	8.9716	6.3416	29.3147	46
node 12	29.5693	29.5693	15.4832	2.2476	1.5830	29.5693	46
node 21	29.9717	29.9718	15.9661	5.4171	3.7935	29.9718	46
node 30	30.2802	30.2802	16.3362	7.7592	5.4098	30.2789	46
node 39	29.3144	29.3144	15.1773	8.9717	6.3417	29.3144	46

Table 40 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station El Centro Array #13

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-7.7548	-11.6445	-3.9507	2.2476	1.5830	29.5693	46
node 19	-6.6889	-10.6576	-2.8165	5.4171	3.7935	29.9718	46
node 28	-5.5912	-9.6854	-1.6098	7.7592	5.4098	30.2789	46
node 37	-5.1707	-9.7570	-0.7580	8.9717	6.3417	29.3144	46
node 11	-7.7508	-11.6393	-3.9477	2.2479	1.5831	29.5743	46
node 20	-6.6891	-10.6582	-2.8163	5.4170	3.7935	29.9705	46
node 29	-5.5910	-9.6850	-1.6097	7.7591	5.4097	30.2793	46
node 38	-5.1694	-9.7558	-0.7566	8.9716	6.3416	29.3147	46
node 12	-7.7549	-11.6445	-3.9509	2.2476	1.5830	29.5693	46
node 21	-6.6889	-10.6576	-2.8165	5.4171	3.7935	29.9718	46
node 30	-5.5908	-9.6845	-1.6098	7.7592	5.4098	30.2789	46
node 39	4.1248	-9.7570	-0.7580	8.9717	6.3417	29.3144	46

Table 41 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station El Centro Array #13

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	14.7044	14.7046	-2.3545	2.2476	1.5830	29.5693	46
node 19	22.4436	22.4437	6.9325	5.4171	3.7935	29.9718	46
node 28	24.3337	24.3337	9.2004	7.7592	5.4098	30.2789	46
node 37	25.4566	25.4567	10.5481	8.9717	6.3417	29.3144	46
node 11	12.8075	12.8075	-4.6310	2.2479	1.5831	29.5743	46
node 20	20.7624	20.7624	4.9149	5.4170	3.7935	29.9705	46
node 29	22.7385	22.7385	7.2862	7.7591	5.4097	30.2793	46
node 38	23.9500	23.9500	8.7400	8.9716	6.3416	29.3147	46
node 12	14.7044	14.7046	-2.3545	2.2476	1.5830	29.5693	46
node 21	22.4436	22.4437	6.9325	5.4171	3.7935	29.9718	46
node 30	24.3336	24.3337	9.2004	7.7592	5.4098	30.2789	46
node 39	25.4566	25.4567	10.5481	8.9717	6.3417	29.3144	46

Table 42 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station El Centro Array #13

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	14.7040	14.7040	-2.3552	2.2476	1.5830	29.5693	46
node 19	22.4434	22.4434	6.9321	5.4171	3.7935	29.9718	46
node 28	24.3337	24.3337	9.2004	7.7592	5.4098	30.2789	46
node 37	25.4564	25.4564	10.5477	8.9717	6.3417	29.3144	46
node 11	12.8075	12.8075	-4.6310	2.2479	1.5831	29.5743	46
node 20	20.7624	20.7624	4.9149	5.4170	3.7935	29.9705	46
node 29	22.7385	22.7385	7.2862	7.7591	5.4097	30.2793	46
node 38	23.9500	23.9500	8.7400	8.9716	6.3416	29.3147	46
node 12	14.7040	14.7040	-2.3552	2.2476	1.5830	29.5693	46
node 21	22.4434	22.4434	6.9321	5.4171	3.7935	29.9718	46
node 30	24.3335	24.3335	9.2002	7.7592	5.4098	30.2789	46
node 39	25.4564	25.4564	10.5477	8.9717	6.3417	29.3144	46

Table 43 - Node displacement under Landers Earthquake, station Mission Creek Fault

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	0.7927	3.8732	0.0052	0.7927	0.0000	0.0017	0.0000	3.8732	0.0049
node 19	1.7412	8.4893	0.0084	1.7412	0.0000	0.0030	0.0000	8.4893	0.0079
node 28	2.3407	11.8643	0.0098	2.3407	0.0000	0.0038	0.0000	11.8643	0.0093
node 37	2.7996	13.5163	0.0103	2.7996	0.0000	0.0040	0.0000	13.5163	0.0097
node 11	0.7928	3.9739	0.0050	0.7928	0.0000	0.0000	0.0000	3.9739	0.0050
node 20	1.7412	8.7006	0.0081	1.7412	0.0000	0.0000	0.0000	8.7006	0.0081
node 29	2.3406	12.1486	0.0095	2.3406	0.0000	0.0000	0.0000	12.1486	0.0095
node 38	2.7995	13.8237	0.0099	2.7995	0.0000	0.0000	0.0000	13.8237	0.0099
node 12	0.7927	3.8732	0.0052	0.7927	0.0000	0.0017	0.0000	3.8732	0.0049
node 21	1.7412	8.4893	0.0084	1.7412	0.0000	0.0030	0.0000	8.4893	0.0079
node 30	2.3406	11.8643	0.0098	2.3406	0.0000	0.0038	0.0000	11.8643	0.0093
node 39	2.7996	13.5163	0.0102	2.7996	0.0000	0.0040	0.0000	13.5163	0.0097

Table 44 - Percent difference between combinations and maximum response under one component in x-direction under Landers Earthquake, station Mission Creek Fault

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	47.0347	47.0348	36.4418	1.4967	0.7927	47.0368	73
node 19	51.4024	51.4025	41.6830	3.5829	1.7412	51.4025	72
node 28	56.3065	56.3066	47.5679	5.3571	2.3406	56.3085	73
node 37	56.6497	56.6498	47.9797	6.4581	2.7996	56.6498	73
node 11	47.0372	47.0372	36.4447	1.4969	0.7928	47.0372	73
node 20	51.4011	51.4011	41.6814	3.5828	1.7412	51.4011	72
node 29	56.3085	56.3085	47.5701	5.3571	2.3406	56.3085	73
node 38	56.6507	56.6507	47.9808	6.4580	2.7995	56.6507	73
node 12	47.0354	47.0355	36.4426	1.4967	0.7927	47.0368	73
node 21	51.4024	51.4025	41.6830	3.5829	1.7412	51.4025	72
node 30	56.3084	56.3085	47.5701	5.3571	2.3406	56.3085	73
node 39	56.6497	56.6498	47.9797	6.4581	2.7996	56.6498	73

Table 45 - Percent difference between combinations and maximum response under two components in x-direction under Landers Earthquake, station Mission Creek Fault

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-11.6399	-9.4233	-14.9003	1.4967	0.7927	47.0368	73
node 19	-9.8873	-6.9829	-14.3695	3.5829	1.7412	51.4025	72
node 28	-8.9880	-5.3665	-15.0559	5.3571	2.3406	56.3085	73
node 37	-8.7079	-5.0633	-14.8433	6.4581	2.7996	56.6498	73
node 11	-11.6334	-9.4170	-14.8934	1.4969	0.7928	47.0372	73
node 20	-9.8878	-6.9836	-14.3698	3.5828	1.7412	51.4011	72
node 29	-8.9877	-5.3659	-15.0563	5.3571	2.3406	56.3085	73
node 38	-8.7078	-5.0630	-14.8436	6.4580	2.7995	56.6507	73
node 12	-11.6397	-9.4230	-14.9003	1.4967	0.7927	47.0368	73
node 21	-9.8873	-6.9829	-14.3695	3.5829	1.7412	51.4025	72
node 30	-8.9875	-5.3657	-15.0559	5.3571	2.3406	56.3085	73
node 39	27.9387	-5.0633	-14.8433	6.4581	2.7996	56.6498	73

Table 46 - Percent difference between combinations and maximum response under one component in y-direction under Landers Earthquake, station Mission Creek Fault

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-158.7829	-158.7827	-210.5392	1.4967	0.7927	47.0368	73
node 19	-136.9395	-136.9394	-184.3272	3.5829	1.7412	51.4025	72
node 28	-121.4687	-121.4687	-165.7624	5.3571	2.3406	56.3085	73
node 37	-109.2923	-109.2922	-151.1506	6.4581	2.7996	56.6498	73
node 11	-165.4753	-165.4753	-218.5704	1.4969	0.7928	47.0372	73
node 20	-142.8436	-142.8436	-191.4123	3.5828	1.7412	51.4011	72
node 29	-126.7757	-126.7757	-172.1308	5.3571	2.3406	56.3085	73
node 38	-114.0554	-114.0554	-156.8665	6.4580	2.7995	56.6507	73
node 12	-158.7829	-158.7827	-210.5392	1.4967	0.7927	47.0368	73
node 21	-136.9395	-136.9394	-184.3272	3.5829	1.7412	51.4025	72
node 30	-121.4687	-121.4687	-165.7624	5.3571	2.3406	56.3085	73
node 39	-109.2923	-109.2922	-151.1506	6.4581	2.7996	56.6498	73

Table 47 - Percent difference between combinations and maximum response under two components in y-direction under Landers Earthquake, station Mission Creek Fault

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-158.7834	-158.7834	-210.5401	1.4967	0.7927	47.0368	73
node 19	-136.9398	-136.9398	-184.3278	3.5829	1.7412	51.4025	72
node 28	-121.4689	-121.4689	-165.7626	5.3571	2.3406	56.3085	73
node 37	-109.2925	-109.2925	-151.1510	6.4581	2.7996	56.6498	73
node 11	-165.4753	-165.4753	-218.5704	1.4969	0.7928	47.0372	73
node 20	-142.8436	-142.8436	-191.4123	3.5828	1.7412	51.4011	72
node 29	-126.7757	-126.7757	-172.1308	5.3571	2.3406	56.3085	73
node 38	-114.0554	-114.0554	-156.8665	6.4580	2.7995	56.6507	73
node 12	-158.7834	-158.7834	-210.5401	1.4967	0.7927	47.0368	73
node 21	-136.9398	-136.9398	-184.3278	3.5829	1.7412	51.4025	72
node 30	-121.4689	-121.4689	-165.7626	5.3571	2.3406	56.3085	73
node 39	-109.2925	-109.2925	-151.1510	6.4581	2.7996	56.6498	73

Table 48 - Node displacement under Chi-Chi, Taiwan-03 Earthquake, station TCU122

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	3.1174	1.9723	0.0078	3.1174	0.0000	0.0075	0.0000	1.9723	0.0025
node 19	7.5035	4.3228	0.0129	7.5035	0.0000	0.0125	0.0000	4.3228	0.0040
node 28	11.0572	6.0413	0.0154	11.0573	0.0000	0.0150	0.0000	6.0413	0.0047
node 37	13.0551	6.8823	0.0162	13.0551	0.0000	0.0158	0.0000	6.8823	0.0049
node 11	3.1177	2.0220	0.0026	3.1177	0.0000	0.0000	0.0000	2.0220	0.0026
node 20	7.5034	4.4273	0.0041	7.5034	0.0000	0.0000	6.3856	4.4273	0.0041
node 29	11.0572	6.1821	0.0048	11.0572	0.0000	0.0000	0.0000	6.1821	0.0048
node 38	13.0548	7.0350	0.0050	13.0548	0.0000	0.0000	0.0000	7.0350	0.0050
node 12	3.1174	1.9723	0.0093	3.1174	0.0000	0.0075	0.0000	1.9723	0.0025
node 21	7.5035	4.3228	0.0153	7.5035	0.0000	0.0125	0.0000	4.3228	0.0040
node 30	11.0573	6.0413	0.0182	11.0573	0.0000	0.0150	0.0000	6.0413	0.0047
node 39	13.0551	6.8823	0.0191	13.0551	0.0000	0.0158	0.0000	6.8823	0.0049

Table 49 - Percent difference between combinations and maximum response under one component in x-direction under Chi-Chi, Taiwan-03 Earthquake, station TCU122

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	77.3306	77.3306	72.7968	13.7516	13.0551	5.0649	19
node 19	4.1160	4.1160	-15.0595	7.8256	7.5035	4.1160	17
node 28	4.7187	4.7187	-14.3396	11.6049	11.0573	4.7187	18
node 37	5.0489	5.0489	-13.9413	13.7515	13.0551	5.0642	19
node 11	3.4947	3.4947	-15.8064	3.2306	3.1177	3.4947	15
node 20	4.1173	4.1173	-15.0593	7.8256	7.5035	4.1160	17
node 29	4.7196	4.7196	-14.3365	11.6049	11.0572	4.7196	18
node 38	5.0650	5.0650	-13.9220	13.7513	13.0548	5.0650	19
node 12	3.4950	3.4950	-15.8060	3.2303	3.1174	3.4950	15
node 21	4.1160	4.1160	-15.0595	7.8256	7.5035	4.1160	17
node 30	4.7187	4.7187	-14.3376	11.6049	11.0573	4.7187	18
node 39	5.0648	5.0649	-13.9222	13.7516	13.0551	5.0649	19

Table 50 - Percent difference between combinations and maximum response under two components in x-direction under Chi-Chi, Taiwan-03 Earthquake, station TCU122

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	74.0312	74.8036	72.7967	13.7516	13.0551	5.0649	19
node 19	-7.8004	-3.7859	-15.0609	7.8256	7.5035	4.1160	17
node 28	-6.0437	-1.8112	-14.3377	11.6049	11.0573	4.7187	18
node 37	-6.3639	-2.2885	-13.9414	13.7515	13.0551	5.0642	19
node 11	-10.5507	-7.2622	-15.8064	3.2306	3.1177	3.4947	15
node 20	-7.7986	-3.7842	-15.0593	7.8256	7.5035	4.1160	17
node 29	-6.0428	-1.8103	-14.3365	11.6049	11.0572	4.7196	18
node 38	-6.3477	-2.2735	-13.9220	13.7513	13.0548	5.0650	19
node 12	-10.5508	-7.2625	-15.8061	3.2303	3.1174	3.4950	15
node 21	-7.8004	-3.7859	-15.0609	7.8256	7.5035	4.1160	17
node 30	-6.0437	-1.8112	-14.3377	11.6049	11.0573	4.7187	18
node 39	-6.3478	-2.2736	-13.9222	13.7516	13.0551	5.0649	19

Table 51 - Percent difference between combinations and maximum response under one component in y-direction under Chi-Chi, Taiwan-03 Earthquake, station TCU122

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	85.6576	85.6577	82.7892	13.7516	13.0551	5.0649	19
node 19	44.7607	44.7608	33.7129	7.8256	7.5035	4.1160	17
node 28	47.9417	47.9418	37.5302	11.6049	11.0573	4.7187	18
node 37	49.9523	49.9524	39.9428	13.7515	13.0551	5.0642	19
node 11	37.4110	37.4110	24.8932	3.2306	3.1177	3.4947	15
node 20	43.4254	43.4254	32.1105	7.8256	7.5035	4.1160	17
node 29	46.7285	46.7285	36.0742	11.6049	11.0572	4.7196	18
node 38	48.8412	48.8412	38.6094	13.7513	13.0548	5.0650	19
node 12	38.9436	38.9438	26.7325	3.2303	3.1174	3.4950	15
node 21	44.7607	44.7608	33.7129	7.8256	7.5035	4.1160	17
node 30	47.9417	47.9418	37.5302	11.6049	11.0573	4.7187	18
node 39	49.9526	49.9527	39.9433	13.7516	13.0551	5.0649	19

Table 52 - Percent difference between combinations and maximum response under two components in y-direction under Chi-Chi, Taiwan-03 Earthquake, station TCU122

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	85.6575	85.6575	82.7890	13.7516	13.0551	5.0649	19
node 19	44.7604	44.7604	33.7125	7.8256	7.5035	4.1160	17
node 28	47.9415	47.9415	37.5298	11.6049	11.0573	4.7187	18
node 37	49.9520	49.9520	39.9424	13.7515	13.0551	5.0642	19
node 11	37.4110	37.4110	24.8932	3.2306	3.1177	3.4947	15
node 20	43.4254	43.4254	32.1105	7.8256	7.5035	4.1160	17
node 29	46.7285	46.7285	36.0742	11.6049	11.0572	4.7196	18
node 38	48.8412	48.8412	38.6094	13.7513	13.0548	5.0650	19
node 12	38.9432	38.9432	26.7318	3.2303	3.1174	3.4950	15
node 21	44.7604	44.7604	33.7125	7.8256	7.5035	4.1160	17
node 30	47.9415	47.9415	37.5298	11.6049	11.0573	4.7187	18
node 39	49.9524	49.9524	39.9429	13.7516	13.0551	5.0649	19

Table 53 - Node displacement under Imperial Valley-06 Earthquake, station Parachute Test Site

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	1.7256	2.5581	0.0076	1.7256	0.0000	0.0047	0.0000	2.5581	0.0032
node 19	4.1887	5.6061	0.0127	4.1887	0.0000	0.0081	0.0000	5.6061	0.0052
node 28	6.3380	7.8339	0.0154	6.3380	0.0000	0.0100	0.0000	7.8339	0.0062
node 37	7.8914	8.9234	0.0162	7.8914	0.0000	0.0106	0.0000	8.9234	0.0064
node 11	1.7257	2.6128	0.0033	1.7257	0.0000	0.0000	0.0000	2.6128	0.0033
node 20	4.1886	5.7225	0.0053	4.1886	0.0000	0.0000	0.0000	5.7225	0.0053
node 29	6.3380	7.9926	0.0063	6.3380	0.0000	0.0000	0.0000	7.9926	0.0063
node 38	7.8912	9.0974	0.0065	7.8912	0.0000	0.0000	0.0000	9.0974	0.0065
node 12	1.7256	2.5581	0.0066	1.7256	0.0000	0.0047	0.0000	2.5581	0.0032
node 21	4.1887	5.6061	0.0110	4.1887	0.0000	0.0081	0.0000	5.6061	0.0052
node 30	6.3380	7.8339	0.0131	6.3380	0.0000	0.0100	0.0000	7.8339	0.0062
node 39	7.8914	8.9234	0.0138	7.8914	0.0000	0.0106	0.0000	8.9234	0.0064

Table 54 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station Parachute Test Site

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	10.9551	10.9552	-6.8538	1.9379	1.7256	10.9552	29
node 19	11.2676	11.2676	-6.4788	4.7206	4.1887	11.2676	28
node 28	7.3838	7.3839	-11.1394	6.8433	6.3380	7.3839	27
node 37	1.3242	1.3242	-18.4110	7.9973	7.8914	1.3242	171
node 11	10.9592	10.9592	-6.8490	1.9381	1.7257	10.9592	29
node 20	11.2679	11.2679	-6.4786	4.7205	4.1886	11.2679	28
node 29	7.3825	7.3825	-11.1410	6.8432	6.3380	7.3825	27
node 38	1.3242	1.3242	-18.4109	7.9971	7.8912	1.3242	171
node 12	10.9551	10.9552	-6.8538	1.9379	1.7256	10.9552	29
node 21	11.2676	11.2676	-6.4788	4.7206	4.1887	11.2676	28
node 30	7.3838	7.3839	-11.1394	6.8433	6.3380	7.3839	27
node 39	1.3242	1.3242	-18.4110	7.9973	7.8914	1.3242	171

Table 55 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station Parachute Test Site

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.4486	-14.1014	-6.8540	1.9379	1.7256	10.9552	29
node 19	-8.9017	-11.3258	-6.4790	4.7206	4.1887	11.2676	28
node 28	-13.1717	-15.2063	-11.1395	6.8433	6.3380	7.3839	27
node 37	-20.7251	-23.0397	-18.4111	7.9973	7.8914	1.3242	171
node 11	-10.4453	-14.1001	-6.8490	1.9381	1.7257	10.9592	29
node 20	-8.9018	-11.3264	-6.4786	4.7205	4.1886	11.2679	28
node 29	-13.1732	-15.2079	-11.1410	6.8432	6.3380	7.3825	27
node 38	-20.7251	-23.0400	-18.4109	7.9971	7.8912	1.3242	171
node 12	-10.4486	-14.1014	-6.8540	1.9379	1.7256	10.9552	29
node 21	-8.9017	-11.3258	-6.4790	4.7206	4.1887	11.2676	28
node 30	-13.1717	-15.2063	-11.1395	6.8433	6.3380	7.3839	27
node 39	-20.7251	-23.0397	-18.4111	7.9973	7.8914	1.3242	171

Table 56 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station Parachute Test Site

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-32.0039	-32.0037	-58.4045	1.9379	1.7256	10.9552	29
node 19	-18.7583	-18.7582	-42.5099	4.7206	4.1887	11.2676	28
node 28	-14.4756	-14.4755	-37.3706	6.8433	6.3380	7.3839	27
node 37	-11.5803	-11.5802	-33.8962	7.9973	7.8914	1.3242	171
node 11	-34.8124	-34.8124	-61.7749	1.9381	1.7257	10.9592	29
node 20	-21.2266	-21.2266	-45.4719	4.7205	4.1886	11.2679	28
node 29	-16.7962	-16.7962	-40.1555	6.8432	6.3380	7.3825	27
node 38	-13.7587	-13.7587	-36.5105	7.9971	7.8912	1.3242	171
node 12	-32.0039	-32.0037	-58.4045	1.9379	1.7256	10.9552	29
node 21	-18.7583	-18.7582	-42.5099	4.7206	4.1887	11.2676	28
node 30	-14.4756	-14.4755	-37.3706	6.8433	6.3380	7.3839	27
node 39	-11.5803	-11.5802	-33.8962	7.9973	7.8914	1.3242	171

Table 57 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station Parachute Test Site

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-32.0043	-32.0043	-58.4052	1.9379	1.7256	10.9552	29
node 19	-18.7586	-18.7586	-42.5103	4.7206	4.1887	11.2676	28
node 28	-14.4757	-14.4757	-37.3709	6.8433	6.3380	7.3839	27
node 37	-11.5805	-11.5805	-33.8966	7.9973	7.8914	1.3242	171
node 11	-34.8124	-34.8124	-61.7749	1.9381	1.7257	10.9592	29
node 20	-21.2266	-21.2266	-45.4719	4.7205	4.1886	11.2679	28
node 29	-16.7962	-16.7962	-40.1555	6.8432	6.3380	7.3825	27
node 38	-13.7587	-13.7587	-36.5105	7.9971	7.8912	1.3242	171
node 12	-32.0043	-32.0043	-58.4052	1.9379	1.7256	10.9552	29
node 21	-18.7586	-18.7586	-42.5103	4.7206	4.1887	11.2676	28
node 30	-14.4757	-14.4757	-37.3709	6.8433	6.3380	7.3839	27
node 39	-11.5805	-11.5805	-33.8966	7.9973	7.8914	1.3242	171

Table 58 - Node displacement under Hector Mine Earthquake, station Amboy

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	2.2334	5.1700	0.0113	2.2334	0.0000	0.0053	0.0000	5.1700	0.0066
node 19	5.3940	11.3310	0.0183	5.3940	0.0000	0.0088	0.0000	11.3310	0.0106
node 28	7.7541	15.8352	0.0215	7.7541	0.0000	0.0107	0.0000	15.8352	0.0124
node 37	9.0586	18.0393	0.0225	9.0586	0.0000	0.0113	0.0000	18.0393	0.0129
node 11	2.2336	5.2967	0.0067	2.2336	0.0000	0.0000	0.0000	5.2967	0.0067
node 20	5.3939	11.5979	0.0108	5.3939	0.0000	0.0000	0.0000	11.5979	0.0108
node 29	7.7540	16.1957	0.0127	7.7540	0.0000	0.0000	0.0000	16.1957	0.0127
node 38	9.0585	18.4307	0.0132	9.0585	0.0000	0.0000	0.0000	18.4307	0.0132
node 12	2.2334	5.1700	0.0069	2.2334	0.0000	0.0053	0.0000	5.1700	0.0066
node 21	5.3939	11.3310	0.0112	5.3939	0.0000	0.0088	0.0000	11.3310	0.0106
node 30	7.7541	15.8352	0.0132	7.7541	0.0000	0.0107	0.0000	15.8352	0.0124
node 39	9.0586	18.0393	0.0137	9.0586	0.0000	0.0113	0.0000	18.0393	0.0129

Table 59 - Percent difference between combinations and maximum response under one component in x-direction under Hector Mine Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	38.8779	38.8779	26.6535	3.6540	2.2334	38.8779	68
node 19	36.2102	36.2102	23.4523	8.4559	5.3940	36.2102	68
node 28	37.8548	37.8548	25.4258	12.4774	7.7541	37.8548	99
node 37	38.9063	38.9063	26.6876	14.8274	9.0586	38.9063	99
node 11	38.8775	38.8775	26.6563	3.6543	2.2336	38.8775	68
node 20	36.2099	36.2099	23.4519	8.4557	5.3939	36.2099	68
node 29	37.8551	37.8551	25.4262	12.4773	7.7540	37.8551	99
node 38	38.9062	38.9062	26.6874	14.8272	9.0585	38.9062	99
node 12	38.8779	38.8779	26.6535	3.6540	2.2334	38.8779	68
node 21	36.2102	36.2102	23.4523	8.4559	5.3940	36.2102	68
node 30	37.8548	37.8548	25.4258	12.4774	7.7541	37.8548	99
node 39	38.9063	38.9063	26.6876	14.8274	9.0586	38.9063	99

Table 60 - Percent difference between combinations and maximum response under two components in x-direction under Hector Mine Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-12.1570	-11.9740	-12.5844	3.6540	2.2334	38.8779	68
node 19	-17.4019	-17.1544	-17.9179	8.4559	5.3940	36.2102	68
node 28	-17.5054	-16.7720	-18.6341	12.4774	7.7541	37.8548	99
node 37	-16.9704	-16.0291	-18.3707	14.8274	9.0586	38.9063	99
node 11	-12.1577	-11.9747	-12.5852	3.6543	2.2336	38.8775	68
node 20	-17.4033	-17.1556	-17.9195	8.4557	5.3939	36.2099	68
node 29	-17.5062	-16.7725	-18.6353	12.4773	7.7540	37.8551	99
node 38	-16.9698	-16.0286	-18.3700	14.8272	9.0585	38.9062	99
node 12	-12.1569	-11.9740	-12.5843	3.6540	2.2334	38.8779	68
node 21	-17.4019	-17.1544	-17.9179	8.4559	5.3940	36.2102	68
node 30	-17.5054	-16.7720	-18.6341	12.4774	7.7541	37.8548	99
node 39	9.3135	-16.0291	-18.3707	14.8274	9.0586	38.9063	99

Table 61 - Percent difference between combinations and maximum response under one component in y-direction under Hector Mine Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-41.4889	-41.4888	-69.7865	3.6540	2.2334	38.8779	68
node 19	-34.0012	-34.0011	-60.8013	8.4559	5.3940	36.2102	68
node 28	-26.9111	-26.9111	-52.2933	12.4774	7.7541	37.8548	99
node 37	-21.6620	-21.6619	-45.9943	14.8274	9.0586	38.9063	99
node 11	-44.9443	-44.9443	-73.9332	3.6543	2.2336	38.8775	68
node 20	-37.1607	-37.1607	-64.5929	8.4557	5.3939	36.2099	68
node 29	-29.8013	-29.8013	-55.7616	12.4773	7.7540	37.8551	99
node 38	-24.3033	-24.3033	-49.1640	14.8272	9.0585	38.9062	99
node 12	-41.4889	-41.4888	-69.7865	3.6540	2.2334	38.8779	68
node 21	-34.0012	-34.0011	-60.8013	8.4559	5.3940	36.2102	68
node 30	-26.9111	-26.9111	-52.2933	12.4774	7.7541	37.8548	99
node 39	-21.6620	-21.6619	-45.9943	14.8274	9.0586	38.9063	99

Table 62 - Percent difference between combinations and maximum response under two components in y-direction under Hector Mine Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-41.4890	-41.4890	-69.7868	3.6540	2.2334	38.8779	68
node 19	-34.0013	-34.0013	-60.8016	8.4559	5.3940	36.2102	68
node 28	-26.9112	-26.9112	-52.2935	12.4774	7.7541	37.8548	99
node 37	-21.6621	-21.6621	-45.9945	14.8274	9.0586	38.9063	99
node 11	-44.9443	-44.9443	-73.9332	3.6543	2.2336	38.8775	68
node 20	-37.1607	-37.1607	-64.5929	8.4557	5.3939	36.2099	68
node 29	-29.8013	-29.8013	-55.7616	12.4773	7.7540	37.8551	99
node 38	-24.3033	-24.3033	-49.1640	14.8272	9.0585	38.9062	99
node 12	-41.4890	-41.4890	-69.7868	3.6540	2.2334	38.8779	68
node 21	-34.0013	-34.0013	-60.8016	8.4559	5.3940	36.2102	68
node 30	-26.9112	-26.9112	-52.2935	12.4774	7.7541	37.8548	99
node 39	-21.6621	-21.6621	-45.9945	14.8274	9.0586	38.9063	99

Table 63 - Node displacement under Chi-Chi, Taiwan Earthquake, station TCU089

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	4.1663	3.4248	0.0084	4.1663	0.0000	0.0099	0.0000	3.4248	0.0044
node 19	9.7446	7.5072	0.0144	9.7446	0.0000	0.0164	0.0000	7.5072	0.0070
node 28	14.4533	10.4926	0.0178	14.4533	0.0000	0.0197	0.0000	10.4926	0.0083
node 37	17.1099	11.9546	0.0190	17.1099	0.0001	0.0207	0.0000	11.9546	0.0086
node 11	4.1667	3.5229	0.0045	4.1667	0.0000	3.9682	0.0000	3.5229	0.0045
node 20	9.7445	7.7117	0.0072	9.7445	0.0000	0.0000	0.0000	7.7117	0.0072
node 29	14.4533	10.7660	0.0084	14.4533	0.0000	0.0000	0.0000	10.7660	0.0084
node 38	17.1096	12.2485	0.0088	17.1096	0.0000	0.0000	0.0000	12.2485	0.0088
node 12	4.1663	3.4249	0.0142	4.1663	0.0000	0.0099	0.0000	3.4248	0.0043
node 21	9.7447	7.5020	0.0234	9.7446	0.0000	0.0164	0.0000	7.5072	0.0070
node 30	14.4533	10.4926	0.0279	14.4533	0.0000	0.0197	0.0000	10.4926	0.0083
node 39	17.1100	11.9546	0.0292	17.1099	0.0001	0.0207	0.0000	11.9546	0.0086

Table 64 - Percent difference between combinations and maximum response under one component in x-direction under Chi-Chi, Taiwan Earthquake, station TCU089

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	16.1406	16.1407	-0.6312	4.9682	4.1663	16.1407	74
node 19	15.3401	15.3402	-1.5918	11.5103	9.7446	15.3402	32
node 28	15.8209	15.8209	-1.0149	17.1697	14.4533	15.8209	33
node 37	16.3068	16.3068	-0.4318	20.4436	17.1099	16.3068	34
node 11	16.1410	16.1410	-0.6307	4.9687	4.1667	16.1410	74
node 20	15.3396	15.3396	-1.5925	11.5101	9.7445	15.3396	32
node 29	15.8209	15.8209	-1.0149	17.1697	14.4533	15.8209	33
node 38	16.3071	16.3071	-0.4315	20.4433	17.1096	16.3071	34
node 12	16.1423	16.1423	-0.6292	4.9683	4.1663	16.1423	74
node 21	15.3401	15.3402	-1.5918	11.5103	9.7446	15.3402	32
node 30	15.8214	15.8214	-1.0143	17.1698	14.4533	15.8214	33
node 39	16.3072	16.3072	-0.4313	20.4437	17.1099	16.3072	34

Table 65 - Percent difference between combinations and maximum response under two components in x-direction under Chi-Chi, Taiwan Earthquake, station TCU089

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-21.5709	-27.7806	-15.6957	4.9682	4.1663	16.1407	74
node 19	-20.0974	-27.0247	-13.6393	11.5103	9.7446	15.3402	32
node 28	-12.4072	-21.1687	-4.5841	17.1697	14.4533	15.8209	33
node 37	-8.3667	-17.3404	-0.4319	20.4436	17.1099	16.3068	34
node 11	-21.5712	-27.7807	-15.6963	4.9687	4.1667	16.1410	74
node 20	-20.0976	-27.0251	-13.6393	11.5101	9.7445	15.3396	32
node 29	-12.4067	-21.1683	-4.5835	17.1697	14.4533	15.8209	33
node 38	-8.3665	-17.3403	-0.4315	20.4433	17.1096	16.3071	34
node 12	-21.5685	-27.7781	-15.6933	4.9683	4.1663	16.1423	74
node 21	-20.0974	-27.0247	-13.6393	11.5103	9.7446	15.3402	32
node 30	-12.4065	-21.1680	-4.5835	17.1698	14.4533	15.8214	33
node 39	-8.3662	-17.3398	-0.4315	20.4437	17.1099	16.3072	34

Table 66 - Percent difference between combinations and maximum response under one component in y-direction under Chi-Chi, Taiwan Earthquake, station TCU089

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	31.0654	31.0656	17.2787	4.9682	4.1663	16.1407	74
node 19	34.7783	34.7784	21.7341	11.5103	9.7446	15.3402	32
node 28	38.8888	38.8889	26.6666	17.1697	14.4533	15.8209	33
node 37	41.5239	41.5240	29.8288	20.4436	17.1099	16.3068	34
node 11	29.0982	29.0982	14.9178	4.9687	4.1667	16.1410	74
node 20	33.0006	33.0006	19.6007	11.5101	9.7445	15.3396	32
node 29	37.2965	37.2965	24.7558	17.1697	14.4533	15.8209	33
node 38	40.0855	40.0855	28.1026	20.4433	17.1096	16.3071	34
node 12	31.0668	31.0670	17.2804	4.9683	4.1663	16.1423	74
node 21	34.7783	34.7784	21.7341	11.5103	9.7446	15.3402	32
node 30	38.8891	38.8892	26.6671	17.1698	14.4533	15.8214	33
node 39	41.5242	41.5243	29.8291	20.4437	17.1099	16.3072	34

Table 67 - Percent difference between combinations and maximum response under two components in y-direction under Chi-Chi, Taiwan Earthquake, station TCU089

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	31.0650	31.0650	17.2779	4.9682	4.1663	16.1407	74
node 19	34.7780	34.7780	21.7336	11.5103	9.7446	15.3402	32
node 28	38.8886	38.8886	26.6663	17.1697	14.4533	15.8209	33
node 37	41.5237	41.5237	29.8285	20.4436	17.1099	16.3068	34
node 11	29.0982	29.0982	14.9178	4.9687	4.1667	16.1410	74
node 20	33.0006	33.0006	19.6007	11.5101	9.7445	15.3396	32
node 29	37.2965	37.2965	24.7558	17.1697	14.4533	15.8209	33
node 38	40.0855	40.0855	28.1026	20.4433	17.1096	16.3071	34
node 12	31.0663	31.0663	17.2796	4.9683	4.1663	16.1423	74
node 21	34.7780	34.7780	21.7336	11.5103	9.7446	15.3402	32
node 30	38.8890	38.8890	26.6668	17.1698	14.4533	15.8214	33
node 39	41.5240	41.5240	29.8288	20.4437	17.1099	16.3072	34

Table 68 - Node displacement under Superstition Hills-01 Earthquake, station Wildlife Liquef Array

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	1.3552	3.0712	0.0051	1.3552	0.0000	0.0036	0.0000	3.0712	0.0039
node 19	3.4426	6.7310	0.0085	3.4426	0.0000	0.0061	0.0000	6.7310	0.0063
node 28	5.1972	9.4064	0.0102	5.1972	0.0000	0.0073	0.0000	9.4064	0.0074
node 37	6.2251	10.7155	0.0107	6.2251	0.0000	0.0077	0.0000	10.7155	0.0077
node 11	1.3554	3.1444	0.0040	1.3554	0.0000	0.0000	0.0000	3.1444	0.0040
node 20	3.4426	6.8855	0.0064	3.4426	0.0000	0.0000	0.0000	6.8855	0.0064
node 29	5.1972	9.6155	0.0075	5.1972	0.0000	0.0000	0.0000	9.6155	0.0075
node 38	6.2250	10.9429	0.0078	6.2250	0.0000	0.0000	0.0000	10.9429	0.0078
node 12	1.3552	3.0712	0.0051	1.3552	0.0000	0.0036	0.0000	3.0712	0.0039
node 21	3.4426	6.7310	0.0082	3.4426	0.0000	0.0061	0.0000	6.7310	0.0063
node 30	5.1972	9.4064	0.0097	5.1972	0.0000	0.0073	0.0000	9.4064	0.0074
node 39	6.2251	10.7155	0.0101	6.2251	0.0000	0.0077	0.0000	10.7155	0.0077

Table 69 - Percent difference between combinations and maximum response under one component in x-direction under Superstition Hills-01 Earthquake, station Wildlife Liquef Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	32.1381	32.1382	18.5658	1.9970	1.3552	32.1382	90
node 19	26.9211	26.9211	12.3053	4.7108	3.4426	26.9211	85
node 28	22.4807	22.4808	6.9769	6.7044	5.1972	22.4808	81
node 37	22.8353	22.8354	7.4025	8.0673	6.2251	22.8354	69
node 11	32.1350	32.1350	18.5620	1.9972	1.3554	32.1350	90
node 20	26.9196	26.9196	12.3035	4.7107	3.4426	26.9196	85
node 29	22.4808	22.4808	6.9769	6.7044	5.1972	22.4808	81
node 38	22.8357	22.8357	7.4028	8.0672	6.2250	22.8357	69
node 12	32.1415	32.1416	18.5699	1.9971	1.3552	32.1416	90
node 21	26.9211	26.9211	12.3053	4.7108	3.4426	26.9211	85
node 30	22.4807	22.4808	6.9769	6.7044	5.1972	22.4808	81
node 39	22.8353	22.8354	7.4025	8.0673	6.2251	22.8354	69

Table 70 - Percent difference between combinations and maximum response under two components in x-direction under Superstition Hills-01 Earthquake, station Wildlife Liquef Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-20.3634	-20.8561	-20.0057	1.9970	1.3552	32.1382	90
node 19	-21.6178	-23.6101	-19.6329	4.7108	3.4426	26.9211	85
node 28	-22.0475	-25.5749	-18.5500	6.7044	5.1972	22.4808	81
node 37	-18.7711	-22.8735	-14.7460	8.0673	6.2251	22.8354	69
node 11	-20.3595	-20.8539	-20.0000	1.9972	1.3554	32.1350	90
node 20	-21.6184	-23.6111	-19.6332	4.7107	3.4426	26.9196	85
node 29	-22.0476	-25.5749	-18.5502	6.7044	5.1972	22.4808	81
node 38	-18.7711	-22.8733	-14.7461	8.0672	6.2250	22.8357	69
node 12	-20.3573	-20.8501	-19.9997	1.9971	1.3552	32.1416	90
node 21	-21.6178	-23.6101	-19.6329	4.7108	3.4426	26.9211	85
node 30	-22.0475	-25.5749	-18.5500	6.7044	5.1972	22.4808	81
node 39	-5.8513	-22.8735	-14.7460	8.0673	6.2251	22.8354	69

Table 71 - Percent difference between combinations and maximum response under one component in y-direction under Superstition Hills-01 Earthquake, station Wildlife Liquef Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-53.7909	-53.7907	-84.5488	1.9970	1.3552	32.1382	90
node 19	-42.8846	-42.8844	-71.4613	4.7108	3.4426	26.9211	85
node 28	-40.3019	-40.3019	-68.3623	6.7044	5.1972	22.4808	81
node 37	-32.8264	-32.8263	-59.3916	8.0673	6.2251	22.8354	69
node 11	-57.4404	-57.4404	-88.9285	1.9972	1.3554	32.1350	90
node 20	-46.1672	-46.1672	-75.4007	4.7107	3.4426	26.9196	85
node 29	-43.4207	-43.4207	-72.1049	6.7044	5.1972	22.4808	81
node 38	-35.6468	-35.6468	-62.7762	8.0672	6.2250	22.8357	69
node 12	-53.7832	-53.7830	-84.5396	1.9971	1.3552	32.1416	90
node 21	-42.8846	-42.8844	-71.4613	4.7108	3.4426	26.9211	85
node 30	-40.3019	-40.3019	-68.3623	6.7044	5.1972	22.4808	81
node 39	-32.8264	-32.8263	-59.3916	8.0673	6.2251	22.8354	69

Table 72 - Percent difference between combinations and maximum response under two components in y-direction under Superstition Hills-01 Earthquake, station Wildlife Liquef Array

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-53.7913	-53.7913	-84.5496	1.9970	1.3552	32.1382	90
node 19	-42.8848	-42.8848	-71.4618	4.7108	3.4426	26.9211	85
node 28	-40.3021	-40.3021	-68.3625	6.7044	5.1972	22.4808	81
node 37	-32.8266	-32.8266	-59.3920	8.0673	6.2251	22.8354	69
node 11	-57.4404	-57.4404	-88.9285	1.9972	1.3554	32.1350	90
node 20	-46.1672	-46.1672	-75.4007	4.7107	3.4426	26.9196	85
node 29	-43.4207	-43.4207	-72.1049	6.7044	5.1972	22.4808	81
node 38	-35.6468	-35.6468	-62.7762	8.0672	6.2250	22.8357	69
node 12	-53.7836	-53.7836	-84.5404	1.9971	1.3552	32.1416	90
node 21	-42.8848	-42.8848	-71.4618	4.7108	3.4426	26.9211	85
node 30	-40.3021	-40.3021	-68.3625	6.7044	5.1972	22.4808	81
node 39	-32.8266	-32.8266	-59.3920	8.0673	6.2251	22.8354	69

Table 73 - Node displacement under Gazli, USSR Earthquake, station Karakyr

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	8.7249	13.7793	0.0267	8.7249	0.0000	0.0221	0.0000	13.7793	0.0175
node 19	21.5230	30.2039	0.0440	21.5231	0.0001	0.0370	0.0001	30.2040	0.0283
node 28	31.9673	42.2150	0.0525	31.9673	0.0001	0.0446	0.0001	42.2151	0.0332
node 37	38.0784	48.0970	0.0551	38.0785	0.0001	0.0471	0.0001	48.0971	0.0345
node 11	8.7257	14.1729	0.0179	8.7257	0.0000	0.0000	0.0000	14.1729	0.0179
node 20	21.5228	31.0244	0.0289	21.5228	0.0000	0.0000	0.0000	31.0244	0.0289
node 29	31.9672	43.3116	0.0339	31.9672	0.0000	0.0000	0.0000	43.3116	0.0339
node 38	38.0778	49.2759	0.0353	38.0778	0.0000	0.0000	0.0000	49.2759	0.0353
node 12	8.7249	13.7793	0.0337	8.7249	0.0000	0.0221	0.0000	13.7793	0.0175
node 21	21.5231	30.2040	0.0560	21.5231	0.0001	0.0370	0.0001	30.2040	0.0283
node 30	31.9674	42.2151	0.0671	31.9673	0.0001	0.0446	0.0001	42.2151	0.0332
node 39	38.0785	48.0971	0.0706	38.0785	0.0001	0.0471	0.0001	48.0971	0.0345

Table 74 - Percent difference between combinations and maximum response under one component in x-direction under Gazli, USSR Earthquake, station Karakyr

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	11.3494	11.3494	-6.3807	9.8419	8.7249	11.3494	32
node 19	8.4127	8.4127	-9.9047	23.5001	21.5231	8.4127	32
node 28	5.7348	5.7348	-13.1182	33.9121	31.9673	5.7348	21
node 37	4.6755	4.6755	-14.3894	39.9462	38.0785	4.6755	19
node 11	11.3494	11.3494	-6.3807	9.8428	8.7257	11.3494	32
node 20	8.4124	8.4124	-9.9051	23.4997	21.5228	8.4124	32
node 29	5.7348	5.7348	-13.1182	33.9120	31.9672	5.7348	21
node 38	4.6759	4.6759	-14.3890	39.9456	38.0778	4.6759	19
node 12	11.3494	11.3494	-6.3807	9.8419	8.7249	11.3494	32
node 21	8.4123	8.4123	-9.9052	23.5000	21.5231	8.4123	32
node 30	5.7350	5.7351	-13.1179	33.9122	31.9673	5.7351	21
node 39	4.6757	4.6758	-14.3891	39.9463	38.0785	4.6758	19

Table 75 - Percent difference between combinations and maximum response under two components in x-direction under Gazli, USSR Earthquake, station Karakyr

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-9.3532	-12.3434	-6.3810	9.8419	8.7249	11.3494	32
node 19	-10.3871	-10.9740	-9.9050	23.5001	21.5231	8.4127	32
node 28	-13.5531	-14.1030	-13.1185	33.9121	31.9673	5.7348	21
node 37	-15.5214	-16.7009	-14.3896	39.9462	38.0785	4.6755	19
node 11	-9.3529	-12.3432	-6.3807	9.8428	8.7257	11.3494	32
node 20	-10.3872	-10.9741	-9.9051	23.4997	21.5228	8.4124	32
node 29	-13.5530	-14.1030	-13.1182	33.9120	31.9672	5.7348	21
node 38	-15.5208	-16.7004	-14.3890	39.9456	38.0778	4.6759	19
node 12	-9.3532	-12.3434	-6.3810	9.8419	8.7249	11.3494	32
node 21	-10.3876	-10.9745	-9.9055	23.5000	21.5231	8.4123	32
node 30	-13.5528	-14.1026	-13.1181	33.9122	31.9673	5.7351	21
node 39	-15.5211	-16.7006	-14.3893	39.9463	38.0785	4.6758	19

Table 76 - Percent difference between combinations and maximum response under one component in y-direction under Gazli, USSR Earthquake, station Karakyr

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-40.0066	-40.0065	-68.0078	9.8419	8.7249	11.3494	32
node 19	-28.5272	-28.5271	-54.2325	23.5001	21.5231	8.4127	32
node 28	-24.4843	-24.4842	-49.3810	33.9121	31.9673	5.7348	21
node 37	-20.4048	-20.4047	-44.4856	39.9462	38.0785	4.6755	19
node 11	-43.9926	-43.9926	-72.7911	9.8428	8.7257	11.3494	32
node 20	-32.0204	-32.0204	-58.4245	23.4997	21.5228	8.4124	32
node 29	-27.7176	-27.7176	-53.2611	33.9120	31.9672	5.7348	21
node 38	-23.3575	-23.3575	-48.0290	39.9456	38.0778	4.6759	19
node 12	-40.0066	-40.0065	-68.0078	9.8419	8.7249	11.3494	32
node 21	-28.5278	-28.5277	-54.2332	23.5000	21.5231	8.4123	32
node 30	-24.4836	-24.4835	-49.3802	33.9122	31.9673	5.7351	21
node 39	-20.4045	-20.4044	-44.4853	39.9463	38.0785	4.6758	19

Table 77 - Percent difference between combinations and maximum response under two components in y-direction under Gazli, USSR Earthquake, station Karakyr

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-40.0069	-40.0069	-68.0083	9.8419	8.7249	11.3494	32
node 19	-28.5274	-28.5274	-54.2329	23.5001	21.5231	8.4127	32
node 28	-24.4845	-24.4845	-49.3813	33.9121	31.9673	5.7348	21
node 37	-20.4050	-20.4050	-44.4860	39.9462	38.0785	4.6755	19
node 11	-43.9926	-43.9926	-72.7911	9.8428	8.7257	11.3494	32
node 20	-32.0204	-32.0204	-58.4245	23.4997	21.5228	8.4124	32
node 29	-27.7176	-27.7176	-53.2611	33.9120	31.9672	5.7348	21
node 38	-23.3575	-23.3575	-48.0290	39.9456	38.0778	4.6759	19
node 12	-40.0069	-40.0069	-68.0083	9.8419	8.7249	11.3494	32
node 21	-28.5280	-28.5280	-54.2336	23.5000	21.5231	8.4123	32
node 30	-24.4838	-24.4838	-49.3805	33.9122	31.9673	5.7351	21
node 39	-20.4047	-20.4047	-44.4856	39.9463	38.0785	4.6758	19

Table 78 - Node displacement under Landers Earthquake, station Amboy

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	1.8766	4.2174	0.0070	1.8766	0.0000	0.0041	0.0000	4.2174	0.0054
node 19	4.2375	9.2433	0.0116	4.2375	0.0000	0.0068	0.0000	9.2433	0.0086
node 28	5.6563	12.9176	0.0139	5.6563	0.0000	0.0083	0.0000	12.9176	0.0102
node 37	6.8321	14.7157	0.0146	6.8321	0.0000	0.0088	0.0000	14.7157	0.0106
node 11	1.8768	4.3213	0.0055	1.8768	0.0000	0.0000	0.0000	4.3213	0.0055
node 20	4.2374	9.4620	0.0088	4.2374	0.0000	0.0000	0.0000	9.4620	0.0088
node 29	5.6562	13.2129	0.0104	5.6562	0.0000	0.0000	0.0000	13.2129	0.0104
node 38	6.8320	15.0362	0.0108	6.8320	0.0000	0.0000	0.0000	15.0362	0.0108
node 12	1.8766	4.2174	0.0072	1.8766	0.0000	0.0040	0.0000	4.2174	0.0054
node 21	4.2375	9.2433	0.0119	4.2375	0.0000	0.0068	0.0000	9.2433	0.0086
node 30	5.6563	12.9176	0.0141	5.6563	0.0000	0.0083	0.0000	12.9176	0.0102
node 39	6.8321	14.7157	0.0147	6.8321	0.0000	0.0088	0.0000	14.7157	0.0106

Table 79 - Percent difference between combinations and maximum response under one component in x-direction under Landers Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	37.6503	37.6503	25.1804	3.0098	1.8766	37.6503	66
node 19	42.5400	42.5400	31.0480	7.3747	4.2375	42.5400	64
node 28	47.6985	47.6985	37.2382	10.8148	5.6563	47.6985	74
node 37	47.1706	47.1707	36.6048	12.9324	6.8321	47.1707	74
node 11	37.6499	37.6499	25.1799	3.0101	1.8768	37.6499	66
node 20	42.5414	42.5414	31.0497	7.3747	4.2374	42.5414	64
node 29	47.6990	47.6990	37.2388	10.8147	5.6562	47.6990	74
node 38	47.1702	47.1702	36.6043	12.9321	6.8320	47.1702	74
node 12	37.6503	37.6503	25.1804	3.0098	1.8766	37.6503	66
node 21	42.5408	42.5408	31.0490	7.3748	4.2375	42.5408	64
node 30	47.6985	47.6985	37.2382	10.8148	5.6563	47.6985	74
node 39	47.1706	47.1707	36.6048	12.9324	6.8321	47.1707	74

Table 80 - Percent difference between combinations and maximum response under two components in x-direction under Landers Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.7740	-11.1945	-10.4828	3.0098	1.8766	37.6503	66
node 19	-11.5875	-10.4694	-13.2193	7.3747	4.2375	42.5400	64
node 28	-12.0120	-9.6052	-15.5858	10.8148	5.6563	47.6985	74
node 37	-12.0737	-9.7733	-15.4698	12.9324	6.8321	47.1707	74
node 11	-17.5639	-25.2983	-10.4801	3.0101	1.8768	37.6499	66
node 20	-11.5858	-10.4676	-13.2179	7.3747	4.2374	42.5414	64
node 29	-12.0129	-9.6058	-15.5871	10.8147	5.6562	47.6990	74
node 38	-12.0746	-9.7742	-15.4708	12.9321	6.8320	47.1702	74
node 12	-10.7740	-11.1945	-10.4828	3.0098	1.8766	37.6503	66
node 21	-11.5859	-10.4679	-13.2178	7.3748	4.2375	42.5408	64
node 30	-12.0120	-9.6052	-15.5858	10.8148	5.6563	47.6985	74
node 39	18.3031	-9.7733	-15.4698	12.9324	6.8321	47.1707	74

Table 81 - Percent difference between combinations and maximum response under one component in y-direction under Landers Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-40.1224	-40.1223	-68.1467	3.0098	1.8766	37.6503	66
node 19	-25.3381	-25.3380	-50.4056	7.3747	4.2375	42.5400	64
node 28	-19.4438	-19.4437	-43.3325	10.8148	5.6563	47.6985	74
node 37	-13.7895	-13.7894	-36.5473	12.9324	6.8321	47.1707	74
node 11	-43.5600	-43.5600	-72.2720	3.0101	1.8768	37.6499	66
node 20	-28.3035	-28.3035	-53.9642	7.3747	4.2374	42.5414	64
node 29	-22.1754	-22.1754	-46.6104	10.8147	5.6562	47.6990	74
node 38	-16.2704	-16.2704	-39.5244	12.9321	6.8320	47.1702	74
node 12	-40.1224	-40.1223	-68.1467	3.0098	1.8766	37.6503	66
node 21	-25.3364	-25.3363	-50.4035	7.3748	4.2375	42.5408	64
node 30	-19.4438	-19.4437	-43.3325	10.8148	5.6563	47.6985	74
node 39	-13.7895	-13.7894	-36.5473	12.9324	6.8321	47.1707	74

Table 82 - Percent difference between combinations and maximum response under two components in y-direction under Landers Earthquake, station Amboy

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-40.1227	-40.1227	-68.1473	3.0098	1.8766	37.6503	66
node 19	-25.3383	-25.3383	-50.4059	7.3747	4.2375	42.5400	64
node 28	-19.4439	-19.4439	-43.3327	10.8148	5.6563	47.6985	74
node 37	-13.7896	-13.7896	-36.5475	12.9324	6.8321	47.1707	74
node 11	-43.5600	-43.5600	-72.2720	3.0101	1.8768	37.6499	66
node 20	-28.3035	-28.3035	-53.9642	7.3747	4.2374	42.5414	64
node 29	-22.1754	-22.1754	-46.6104	10.8147	5.6562	47.6990	74
node 38	-376.5112	-376.5112	-471.8134	12.9321	6.8320	47.1702	74
node 12	-40.1227	-40.1227	-68.1473	3.0098	1.8766	37.6503	66
node 21	-25.3366	-25.3366	-50.4039	7.3748	4.2375	42.5408	64
node 30	-19.4439	-19.4439	-43.3327	10.8148	5.6563	47.6985	74
node 39	-13.7896	-13.7896	-36.5475	12.9324	6.8321	47.1707	74

Table 83 - Node displacement under Chi-Chi, Taiwan Earthquake, station TCU049

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	3.4734	4.9707	0.0103	3.4734	0.0000	0.0085	0.0000	4.9707	0.0063
node 19	8.3464	10.8971	0.0173	8.3464	0.0000	0.0143	0.0000	10.8971	0.0102
node 28	12.1827	15.2323	0.0210	12.1827	0.0000	0.0174	0.0000	15.2323	0.0120
node 37	14.5091	17.3569	0.0222	14.5091	0.0001	0.0185	0.0000	17.3569	0.0125
node 11	3.4737	5.1355	0.0065	3.4737	0.0000	0.0000	0.0000	5.1355	0.0065
node 20	8.3463	11.2383	0.0105	8.3463	0.0000	0.0000	0.0000	11.2383	0.0105
node 29	12.1826	15.6849	0.0123	12.1826	0.0000	0.0000	0.0000	15.6849	0.0123
node 38	14.5088	17.8395	0.0128	14.5088	0.0000	0.0000	0.0000	17.8395	0.0128
node 12	3.4733	4.9707	0.0098	3.4740	0.0000	0.0085	0.0000	4.9707	0.0063
node 21	8.3464	10.8971	0.0165	8.3464	0.0000	0.0143	0.0000	10.8971	0.0102
node 30	12.1827	15.2323	0.0199	12.1827	0.0000	0.0174	0.0000	15.2323	0.0120
node 39	14.5091	17.3569	0.0210	14.5091	0.0001	0.0185	0.0000	17.3569	0.0125

Table 84 - Percent difference between combinations and maximum response under one component in x-direction under Chi-Chi, Taiwan Earthquake, station TCU049

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	4.0396	4.0397	-15.1523	15.1199	14.5091	4.0397	87
node 19	3.1425	3.1426	-16.2289	8.6172	8.3464	3.1426	116
node 28	4.5534	4.5535	-14.5358	12.7639	12.1827	4.5535	144
node 37	4.0396	4.0397	-15.1523	15.1199	14.5091	4.0397	145
node 11	6.0527	6.0527	-12.7367	3.6975	3.4737	6.0527	87
node 20	3.1415	3.1415	-16.2302	8.6170	8.3463	3.1415	116
node 29	4.5543	4.5543	-14.5349	12.7639	12.1826	4.5543	144
node 38	4.0404	4.0404	-15.1515	15.1197	14.5088	4.0404	145
node 12	6.0531	6.0532	-12.7361	3.6972	3.4734	6.0532	87
node 21	3.1425	3.1426	-16.2289	8.6172	8.3464	3.1426	116
node 30	4.5534	4.5535	-14.5358	12.7639	12.1827	4.5535	144
node 39	4.0396	4.0397	-15.1523	15.1199	14.5091	4.0397	145

Table 85 - Percent difference between combinations and maximum response under two components in x-direction under Chi-Chi, Taiwan Earthquake, station TCU049

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-23.1822	-32.0682	-15.1526	15.1199	14.5091	4.0397	87
node 19	-24.8711	-34.5395	-16.2293	8.6172	8.3464	3.1426	116
node 28	-22.7851	-31.9635	-14.5361	12.7639	12.1827	4.5535	144
node 37	-23.1822	-32.0682	-15.1526	15.1199	14.5091	4.0397	145
node 11	-28.0354	-37.0998	-19.8215	3.6975	3.4737	6.0527	87
node 20	-24.8723	-34.5410	-16.2302	8.6170	8.3463	3.1415	116
node 29	-22.7839	-31.9624	-14.5349	12.7639	12.1826	4.5543	144
node 38	-23.1813	-32.0676	-15.1515	15.1197	14.5088	4.0404	145
node 12	-28.0324	-37.0975	-19.8179	3.6972	3.4734	6.0532	87
node 21	-24.8711	-34.5395	-16.2293	8.6172	8.3464	3.1426	116
node 30	-22.7851	-31.9635	-14.5361	12.7639	12.1827	4.5535	144
node 39	-23.1822	-32.0682	-15.1526	15.1199	14.5091	4.0397	145

Table 86 - Percent difference between combinations and maximum response under one component in y-direction under Chi-Chi, Taiwan Earthquake, station TCU049

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-14.7952	-14.7951	-37.7541	15.1199	14.5091	4.0397	87
node 19	-26.4577	-26.4576	-51.7491	8.6172	8.3464	3.1426	116
node 28	-19.3390	-19.3389	-43.2067	12.7639	12.1827	4.5535	144
node 37	-14.7952	-14.7951	-37.7541	15.1199	14.5091	4.0397	145
node 11	-38.8911	-38.8911	-66.6694	3.6975	3.4737	6.0527	87
node 20	-30.4201	-30.4201	-56.5041	8.6170	8.3463	3.1415	116
node 29	-22.8849	-22.8849	-47.4618	12.7639	12.1826	4.5543	144
node 38	-17.9885	-17.9885	-41.5861	15.1197	14.5088	4.0404	145
node 12	-34.4452	-34.4450	-61.3340	3.6972	3.4734	6.0532	87
node 21	-26.4577	-26.4576	-51.7491	8.6172	8.3464	3.1426	116
node 30	-19.3390	-19.3389	-43.2067	12.7639	12.1827	4.5535	144
node 39	-14.7952	-14.7951	-37.7541	15.1199	14.5091	4.0397	145

Table 87 - Percent difference between combinations and maximum response under two components in y-direction under Chi-Chi, Taiwan Earthquake, station TCU049

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-14.7955	-14.7955	-37.7546	15.1199	14.5091	4.0397	87
node 19	-26.4580	-26.4580	-51.7496	8.6172	8.3464	3.1426	116
node 28	-19.3392	-19.3392	-43.2070	12.7639	12.1827	4.5535	144
node 37	-14.7955	-14.7955	-37.7546	15.1199	14.5091	4.0397	145
node 11	-38.8911	-38.8911	-66.6694	3.6975	3.4737	6.0527	87
node 20	-30.4201	-30.4201	-56.5041	8.6170	8.3463	3.1415	116
node 29	-22.8849	-22.8849	-47.4618	12.7639	12.1826	4.5543	144
node 38	-17.9885	-17.9885	-41.5861	15.1197	14.5088	4.0404	145
node 12	-34.4457	-34.4457	-61.3348	3.6972	3.4734	6.0532	87
node 21	-26.4580	-26.4580	-51.7496	8.6172	8.3464	3.1426	116
node 30	-19.3392	-19.3392	-43.2070	12.7639	12.1827	4.5535	144
node 39	-14.7955	-14.7955	-37.7546	15.1199	14.5091	4.0397	145

Table 88 - Node displacement under Imperial Valley-06 Earthquake, station Delta

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	3.7533	7.6734	0.0104	3.7533	0.0000	0.0081	0.0000	7.6734	0.0097
node 19	8.7071	16.8178	0.0175	8.7071	0.0000	0.0137	0.0000	16.8178	0.0157
node 28	12.3445	23.5030	0.0213	12.3445	0.0000	0.0165	0.0000	23.5030	0.0185
node 37	14.2062	26.7743	0.0225	14.2062	0.0001	0.0174	0.0000	26.7743	0.0192
node 11	3.7537	7.8606	0.0099	3.7537	0.0000	0.0000	0.0000	7.8606	0.0099
node 20	8.7069	17.2121	0.0161	8.7069	0.0000	0.0000	0.0000	17.2121	0.0161
node 29	12.3444	24.0357	0.0188	12.3444	0.0000	0.0000	0.0000	24.0357	0.0188
node 38	14.2059	27.3529	0.0196	14.2059	0.0000	0.0000	0.0000	27.3529	0.0196
node 12	3.7533	7.6734	0.0137	3.7533	0.0000	0.0081	0.0000	7.6734	0.0097
node 21	8.7071	16.8178	0.0222	8.7071	0.0000	0.0137	0.0000	16.8178	0.0157
node 30	12.3444	23.5030	0.0264	12.3444	0.0000	0.0165	0.0000	23.5030	0.0185
node 39	14.2061	26.7743	0.0276	14.2061	0.0001	0.0174	0.0000	26.7743	0.0192

Table 89 - Percent difference between combinations and maximum response under one component in x-direction under Imperial Valley-06 Earthquake, station Delta

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	42.6802	42.6802	31.2162	6.5480	3.7533	42.6802	84
node 19	42.1589	42.1590	30.5908	15.0535	8.7071	42.1590	84
node 28	42.2401	42.2401	30.6881	21.3721	12.3444	42.2406	108
node 37	44.6650	44.6650	33.5980	25.6731	14.2061	44.6654	108
node 11	42.6794	42.6794	31.2152	6.5486	3.7537	42.6794	84
node 20	42.1591	42.1591	30.5910	15.0532	8.7069	42.1591	84
node 29	42.2406	42.2406	30.6887	21.3721	12.3444	42.2406	108
node 38	44.6651	44.6651	33.5982	25.6726	14.2059	44.6651	108
node 12	42.6802	42.6802	31.2162	6.5480	3.7533	42.6802	84
node 21	42.1589	42.1590	30.5908	15.0535	8.7071	42.1590	84
node 30	42.2406	42.2406	30.6887	21.3721	12.3444	42.2406	108
node 39	44.6654	44.6654	33.5985	25.6731	14.2061	44.6654	108

Table 90 - Percent difference between combinations and maximum response under two components in x-direction under Imperial Valley-06 Earthquake, station Delta

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-16.7056	-14.8379	-19.4115	6.5480	3.7533	42.6802	84
node 19	-16.8161	-15.0593	-19.3565	15.0535	8.7071	42.1590	84
node 28	-12.8486	-11.6262	-14.6248	21.3721	12.3444	42.2406	108
node 37	-11.6173	-9.9553	-14.0202	25.6731	14.2061	44.6654	108
node 11	-16.7060	-14.8384	-19.4118	6.5486	3.7537	42.6794	84
node 20	-16.8162	-15.0593	-19.3567	15.0532	8.7069	42.1591	84
node 29	-12.8482	-11.6256	-14.6244	21.3721	12.3444	42.2406	108
node 38	-11.6177	-9.9556	-14.0207	25.6726	14.2059	44.6651	108
node 12	-16.7056	-14.8379	-19.4115	6.5480	3.7533	42.6802	84
node 21	-16.8161	-15.0593	-19.3565	15.0535	8.7071	42.1590	84
node 30	-12.8486	-11.6260	-14.6249	21.3721	12.3444	42.2406	108
node 39	16.1602	-9.9551	-14.0202	25.6731	14.2061	44.6654	108

Table 91 - Percent difference between combinations and maximum response under one component in y-direction under Imperial Valley-06 Earthquake, station Delta

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-17.1871	-17.1869	-40.6243	6.5480	3.7533	42.6802	84
node 19	-11.7203	-11.7202	-34.0642	15.0535	8.7071	42.1590	84
node 28	-9.9705	-9.9705	-31.9646	21.3721	12.3444	42.2406	108
node 37	-4.2894	-4.2893	-25.1472	25.6731	14.2061	44.6654	108
node 11	-20.0348	-20.0348	-44.0418	6.5486	3.7537	42.6794	84
node 20	-14.3418	-14.3418	-37.2102	15.0532	8.7069	42.1591	84
node 29	-12.4630	-12.4630	-34.9556	21.3721	12.3444	42.2406	108
node 38	-6.5451	-6.5451	-27.8541	25.6726	14.2059	44.6651	108
node 12	-17.1871	-17.1869	-40.6243	6.5480	3.7533	42.6802	84
node 21	-11.7203	-11.7202	-34.0642	15.0535	8.7071	42.1590	84
node 30	-9.9705	-9.9705	-31.9646	21.3721	12.3444	42.2406	108
node 39	-4.2894	-4.2893	-25.1472	25.6731	14.2061	44.6654	108

Table 92 - Percent difference between combinations and maximum response under two components in y-direction under Imperial Valley-06 Earthquake, station Delta

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-17.1875	-17.1875	-40.6250	6.5480	3.7533	42.6802	84
node 19	-11.7205	-11.7205	-34.0646	15.0535	8.7071	42.1590	84
node 28	-9.9706	-9.9706	-31.9648	21.3721	12.3444	42.2406	108
node 37	-4.2895	-4.2895	-25.1474	25.6731	14.2061	44.6654	108
node 11	-20.0348	-20.0348	-44.0418	6.5486	3.7537	42.6794	84
node 20	-14.3418	-14.3418	-37.2102	15.0532	8.7069	42.1591	84
node 29	-12.4630	-12.4630	-34.9556	21.3721	12.3444	42.2406	108
node 38	-6.5451	-6.5451	-27.8541	25.6726	14.2059	44.6651	108
node 12	-17.1875	-17.1875	-40.6250	6.5480	3.7533	42.6802	84
node 21	-11.7205	-11.7205	-34.0646	15.0535	8.7071	42.1590	84
node 30	-9.9706	-9.9706	-31.9648	21.3721	12.3444	42.2406	108
node 39	-4.2895	-4.2895	-25.1474	25.6731	14.2061	44.6654	108

Table 93 - Node displacement under Northridge-01 Earthquake, station LA-Baldwin Hills

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	2.3814	3.4336	0.0073	2.3814	0.0000	0.0058	0.0000	3.4336	0.0044
node 19	5.8498	7.5267	0.0121	5.8498	0.0000	0.0097	0.0000	7.5267	0.0070
node 28	8.6054	10.5200	0.0145	8.6054	0.0000	0.0116	0.0000	10.5200	0.0083
node 37	10.1325	11.9862	0.0153	10.1325	0.0000	0.0122	0.0000	11.9862	0.0086
node 11	2.3816	3.5346	0.0045	2.3816	0.0000	0.0000	0.0000	3.5346	0.0045
node 20	5.8497	7.7370	0.0072	5.8497	0.0000	0.0000	0.0000	7.7370	0.0072
node 29	8.6053	10.8009	0.0085	8.6053	0.0000	0.0000	0.0000	10.8009	0.0085
node 38	10.1324	12.2876	0.0088	10.1324	0.0000	0.0000	0.0000	12.2876	0.0088
node 12	2.3814	3.4336	0.0080	2.3814	0.0000	0.0058	0.0000	3.4336	0.0044
node 21	5.8498	7.5267	0.0131	5.8498	0.0000	0.0097	0.0000	7.5267	0.0070
node 30	8.6054	10.5200	0.0157	8.6054	0.0000	0.0116	0.0000	10.5200	0.0083
node 39	10.1325	11.9862	0.0165	10.1325	0.0000	0.0122	0.0000	11.9862	0.0086

Table 94 - Percent difference between combinations and maximum response under one component in x-direction under Northridge-01 Earthquake, station LA-Baldwin Hills

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	34.8293	34.8294	21.7952	3.6541	2.3814	34.8294	123
node 19	33.9751	33.9752	20.7702	8.8600	5.8499	33.9740	124
node 28	32.6988	32.6988	19.2386	12.7864	8.6054	32.6988	124
node 37	31.7846	31.7847	18.1416	14.8537	10.1325	31.7847	125
node 11	34.8292	34.8292	21.7951	3.6544	2.3816	34.8292	123
node 20	34.0405	34.0405	20.8486	8.8659	5.8497	34.0202	124
node 29	32.6996	32.6996	19.2395	12.7864	8.6053	32.6996	124
node 38	31.7840	31.7840	18.1408	14.8534	10.1324	31.7840	125
node 12	34.8293	34.8294	21.7952	3.6541	2.3814	34.8294	123
node 21	34.0198	34.0199	20.8238	8.8660	5.8498	34.0199	124
node 30	32.6988	32.6988	19.2386	12.7864	8.6054	32.6988	124
node 39	31.7846	31.7847	18.1416	14.8537	10.1325	31.7847	125

Table 95 - Percent difference between combinations and maximum response under two components in x-direction under Northridge-01 Earthquake, station LA-Baldwin Hills

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-10.5666	-11.9421	-9.2185	3.6541	2.3814	34.8294	123
node 19	-8.8006	-10.8109	-6.7917	8.8600	5.8499	33.9740	124
node 28	-9.4617	-11.7982	-7.1255	12.7864	8.6054	32.6988	124
node 37	-14.5596	-16.2205	-12.9139	14.8537	10.1325	31.7847	125
node 11	-10.5675	-11.9428	-9.2196	3.6544	2.3816	34.8292	123
node 20	-8.7207	-10.7236	-6.7195	8.8659	5.8497	34.0202	124
node 29	-9.4615	-11.7977	-7.1257	12.7864	8.6053	32.6996	124
node 38	-14.5604	-16.2214	-12.9148	14.8534	10.1324	31.7840	125
node 12	-10.5666	-11.9421	-9.2185	3.6541	2.3814	34.8294	123
node 21	-8.7269	-10.7360	-6.7194	8.8660	5.8498	34.0199	124
node 30	-9.4617	-11.7982	-7.1255	12.7864	8.6054	32.6988	124
node 39	3.5561	-16.2205	-12.9139	14.8537	10.1325	31.7847	125

Table 96 - Percent difference between combinations and maximum response under one component in y-direction under Northridge-01 Earthquake, station LA-Baldwin Hills

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	6.0341	6.0343	-12.7588	3.6541	2.3814	34.8294	123
node 19	15.0484	15.0485	-1.9418	8.8600	5.8499	33.9740	124
node 28	17.7250	17.7251	1.2701	12.7864	8.6054	32.6988	124
node 37	19.3049	19.3050	3.1659	14.8537	10.1325	31.7847	125
node 11	3.2782	3.2782	-16.0661	3.6544	2.3816	34.8292	123
node 20	12.7331	12.7331	-4.7203	8.8659	5.8497	34.0202	124
node 29	15.5282	15.5282	-1.3661	12.7864	8.6053	32.6996	124
node 38	17.2742	17.2742	0.7290	14.8534	10.1324	31.7840	125
node 12	6.0341	6.0343	-12.7588	3.6541	2.3814	34.8294	123
node 21	15.1059	15.1060	-1.8728	8.8660	5.8498	34.0199	124
node 30	17.7250	17.7251	1.2701	12.7864	8.6054	32.6988	124
node 39	19.3049	19.3050	3.1659	14.8537	10.1325	31.7847	125

Table 97 - Percent difference between combinations and maximum response under two components in y-direction under Northridge-01 Earthquake, station LA-Baldwin Hills

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	6.0337	6.0337	-12.7595	3.6541	2.3814	34.8294	123
node 19	15.0482	15.0482	-1.9421	8.8600	5.8499	33.9740	124
node 28	17.7249	17.7249	1.2698	12.7864	8.6054	32.6988	124
node 37	19.3047	19.3047	3.1656	14.8537	10.1325	31.7847	125
node 11	3.2782	3.2782	-16.0661	3.6544	2.3816	34.8292	123
node 20	12.7331	12.7331	-4.7203	8.8659	5.8497	34.0202	124
node 29	15.5282	15.5282	-1.3661	12.7864	8.6053	32.6996	124
node 38	17.2742	17.2742	0.7290	14.8534	10.1324	31.7840	125
node 12	6.0337	6.0337	-12.7595	3.6541	2.3814	34.8294	123
node 21	15.1057	15.1057	-1.8731	8.8660	5.8498	34.0199	124
node 30	17.7249	17.7249	1.2698	12.7864	8.6054	32.6988	124
node 39	19.3047	19.3047	3.1656	14.8537	10.1325	31.7847	125

Table 98 - Node displacement under Tabas, Iran Earthquake, station Tabas

	Two-components			One component (x-direction)			One Component (y-direction)		
Response of Structure	Ux	Uy	Uz	Ux	Uy	Uz	Ux	Uy	Uz
node 10	10.9297	17.2768	0.0328	10.9297	0.0001	0.0240	0.0000	17.2769	0.0219
node 19	24.4102	37.8640	0.0546	24.4102	0.0001	0.0406	0.0001	37.8640	0.0354
node 28	33.5231	52.9131	0.0660	33.5232	0.0001	0.0494	0.0001	52.9131	0.0416
node 37	40.8119	60.2755	0.0696	40.8119	0.0002	0.0523	0.0001	60.2755	0.0433
node 11	10.9307	17.7382	0.0224	10.9307	0.0000	0.0000	0.0000	17.7382	0.0224
node 20	24.4097	38.8184	0.0361	24.4097	0.0000	0.0000	0.0000	38.8184	0.0361
node 29	33.5231	54.1789	0.0424	33.5231	0.0000	0.0000	0.0000	54.1789	0.0424
node 38	40.8111	61.6229	0.0441	40.8111	0.0000	0.0000	0.0000	61.6229	0.0441
node 12	10.9297	17.2769	0.0331	10.9297	0.0001	0.0240	0.0000	17.2769	0.0219
node 21	24.4102	37.8640	0.0547	24.4102	0.0001	0.0406	0.0001	37.8640	0.0354
node 30	33.5232	52.9131	0.0655	33.5232	0.0001	0.0494	0.0001	52.9131	0.0416
node 39	40.8119	60.2754	0.0688	40.8119	0.0002	0.0523	0.0001	60.2755	0.0433

Table 99 - Percent difference between combinations and maximum response under one component in x-direction under Tabas, Iran Earthquake, station Tabas

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	1.9458	1.9459	-17.6649	11.1466	10.9297	1.9459	168
node 19	1.2895	1.2896	-18.4525	24.7291	24.4102	1.2896	171
node 28	2.9814	2.9815	-16.4222	34.5534	33.5232	2.9815	163
node 37	3.2377	3.2377	-16.1147	42.1775	40.8119	3.2377	163
node 11	1.9457	1.9457	-17.6651	11.1476	10.9307	1.9457	168
node 20	1.2896	1.2896	-18.4525	24.7286	24.4097	1.2896	171
node 29	2.9818	2.9818	-16.4219	34.5534	33.5231	2.9818	163
node 38	3.2378	3.2378	-16.1146	42.1767	40.8111	3.2378	163
node 12	1.9458	1.9459	-17.6649	11.1466	10.9297	1.9459	168
node 21	1.2895	1.2896	-18.4525	24.7291	24.4102	1.2896	171
node 30	2.9817	2.9818	-16.4219	34.5535	33.5232	2.9818	163
node 39	3.2377	3.2377	-16.1147	42.1775	40.8119	3.2377	163

Table 100 - Percent difference between combinations and maximum response under two components in x-direction under Tabas, Iran Earthquake, station Tabas

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-18.2697	-18.9761	-17.6653	11.1466	10.9297	1.9459	168
node 19	-19.6630	-20.9196	-18.4529	24.7291	24.4102	1.2896	171
node 28	-17.9224	-19.4477	-16.4226	34.5534	33.5232	2.9815	163
node 37	-17.6797	-19.2662	-16.1150	42.1775	40.8119	3.2377	163
node 11	-18.2698	-18.9763	-17.6651	11.1476	10.9307	1.9457	168
node 20	-19.6628	-20.9197	-18.4525	24.7286	24.4097	1.2896	171
node 29	-17.9218	-19.4472	-16.4219	34.5534	33.5231	2.9818	163
node 38	-163.7860	-152.6790	-191.4424	42.1767	40.8111	3.2378	163
node 12	-18.2697	-18.9761	-17.6653	11.1466	10.9297	1.9459	168
node 21	-19.6630	-20.9196	-18.4529	24.7291	24.4102	1.2896	171
node 30	-17.9220	-19.4473	-16.4222	34.5535	33.5232	2.9818	163
node 39	-17.6797	-19.2662	-16.1150	42.1775	40.8119	3.2377	163

Table 101 - Percent difference between combinations and maximum response under one component in y-direction under Tabas, Iran Earthquake, station Tabas

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-54.9973	-54.9970	-85.9964	11.1466	10.9297	1.9459	168
node 19	-53.1155	-53.1152	-83.7382	24.7291	24.4102	1.2896	171
node 28	-53.1344	-53.1343	-83.7611	34.5534	33.5232	2.9815	163
node 37	-42.9093	-42.9091	-71.4910	42.1775	40.8119	3.2377	163
node 11	-59.1212	-59.1212	-90.9455	11.1476	10.9307	1.9457	168
node 20	-56.9778	-56.9778	-88.3733	24.7286	24.4097	1.2896	171
node 29	-56.7976	-56.7976	-88.1571	34.5534	33.5231	2.9818	163
node 38	-46.1065	-46.1065	-75.3278	42.1767	40.8111	3.2378	163
node 12	-54.9973	-54.9970	-85.9964	11.1466	10.9297	1.9459	168
node 21	-53.1153	-53.1152	-83.7382	24.7291	24.4102	1.2896	171
node 30	-53.1340	-53.1338	-83.7606	34.5535	33.5232	2.9818	163
node 39	-42.9093	-42.9091	-71.4910	42.1775	40.8119	3.2377	163

Table 102 - Percent difference between combinations and maximum response under two components in y-direction under Tabas, Iran Earthquake, station Tabas

	ΔR Combination						
Response of Structure	30%	SRSS	20%	Rmax (bi)	Rmax (uni)	ΔR	θcr(bi)
node 10	-54.9978	-54.9978	-85.9974	11.1466	10.9297	1.9459	168
node 19	-53.1164	-53.1164	-83.7397	24.7291	24.4102	1.2896	171
node 28	-53.1347	-53.1347	-83.7616	34.5534	33.5232	2.9815	163
node 37	-42.9097	-42.9097	-71.4916	42.1775	40.8119	3.2377	163
node 11	-59.1212	-59.1212	-90.9455	11.1476	10.9307	1.9457	168
node 20	-56.9778	-56.9778	-88.3733	24.7286	24.4097	1.2896	171
node 29	-56.7976	-56.7976	-88.1571	34.5534	33.5231	2.9818	163
node 38	-46.1065	-46.1065	-75.3278	42.1767	40.8111	3.2378	163
node 12	-54.9978	-54.9978	-85.9974	11.1466	10.9297	1.9459	168
node 21	-53.1157	-53.1157	-83.7389	24.7291	24.4102	1.2896	171
node 30	-53.1342	-53.1342	-83.7611	34.5535	33.5232	2.9818	163
node 39	-42.9097	-42.9097	-71.4916	42.1775	40.8119	3.2377	163

VITA

Graduate School
Southern Illinois University Carbondale

Joel Mondo Kisekini

Joel.kisekini@siu.edu

joelkisekini@gmail.com

John A. Logan College (JALC), Carterville, Illinois
Associate Degree of Science, May 2018

Southern Illinois University Carbondale
Bachelor of Science, Civil Engineering, May 2020

Special Honors and Awards:
- John A. Logan College Outstanding Student Award, 2018
- SIU Dean Scholarship Recipient, 2018
- SIU Dean’s List, 2018-2020
- SIU Academic Honors 2018-2020
- National Science Foundation SI, Energy Scholar 2018-2020
- SIU Chancelor Scholar Award 2018-2020
- SIU Honors Certificate (UHP), 2020

Thesis Paper Title:
Effect of Simultaneous Application of the Two Horizontal Orthogonal Ground Motion Components on the Seismic Behavior of Buildings (Case of Four-Story Steel Frame)

Major Professor: Dr. Jale Tezcan