Control of Seismic Response of Structure using Friction Pendulum Isolator with Viscous Damper

Thesis submitted in partial fulfillment of the requirements for the degree of

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in

Civil Engineering

(Structural Engineering)

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented in this report entitled "Control of Seismic Response of Structure using Friction Pendulum Isolator with Viscous Damper" in partial fulfillment of the curriculum of fourth semester of Master of Technology in structural Engineering, submitted in the Department of Civil Engineering, DTU is an authentic record of my own work under the supervision of Prof. Nirendra Dev, Department of Civil Engineering.

I have not submitted this matter for the award of any other degree or diploma.

Date: July 28,2014

Anjali Dhakar

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Prof. Nirendra Dev

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ABSTRACT

Some natural or man-made effects may be cause of minor or major create vibration on earth's surface. So a building resting on it will experience motion, which depends on magnitude of earthquake. This unpredictable earthquake motion has kinetic energy, which is also responsible for the generation of inertia force and if transmitted to structure, may cause damage of structure. So the knowledge about the earthquake, its behavior and their effects on structures grew with time and seismic resistant design procedures have been started.

Base isolation is the most widely used in seismic resistant systems used in building in earthquake prone areas. The object of this study is to reduce the base shear, story displacement and story drifts due to earthquake ground excitation, applied to the superstructure of the building by installing base isolation devices at the foundation level and then to compare the different performances between the fixed base condition and base-isolated condition (FPS) by using SAP2000v15 software. In this study, the 7-story symmetrical R.C.C. building is used as test model. Non-linear time history analysis is used on both fixed base and base isolated multistory buildings. There are two studies; one is comparative study of response of fixed base condition and base isolation (FPS) condition and the comparative study of performance by two different time histories LACC and Newhall T.H. Finally, base shear, displacement and acceleration are compared from two times histories analysis between fixed base conditions. It is found that the displacement is increased with time period of the isolated building.

FPS design parameters depend on the coefficient of friction. So in this study behavior of friction pendulum system is found out with variation of value of coefficient of friction, which depends on property of lubricating material. By use of isolator system we can decrease the acceleration, but the displacement at different stories is increase, and might collide with sidewalls or stoppers due to excessively severe ground motions. To control these response displacements of the base isolated structures by means of viscous damper with coupling mechanism. In this study, results of the software SAP2000v15, 7-story base isolated structure specimen is shown to investigate the performance the effectiveness of the proposed device.

Keywords: Base Isolation, friction pendulum isolator, time history, Viscous Damper, SAP2000.

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Chapter -1 Introduction

1.1 General

Base isolation is the one of the most wanted means of protecting structures resistant to earthquake forces. The term base isolation have two word 1^{s} is 'base' its meaning is a part that supports from underneath or perform as a foundation for a structure, and 2^{nd} is 'isolation' its meaning of the state of being disparate. Base isolation falls into general category of passive control device. In the passive Control system, adding some constituents into the structure modifies the mass or the stiffness or damping or a combination of any two or all. These constituents are actuated by the movements of the structure and impart control forces according to their dynamic properties. No external source of energy is required to actuate the structure. Base isolation is a passive control device, which is located between the base of superstructure and substructure of the building.

In buildings it insulates the structure from earthquake forces in two ways:

1) By deflecting the seismic energy and
2) By absorbing the seismic energy.

Making the base of the structure flexible in lateral directions, thereby increasing the fundamental time period of the structure deflects the seismic energy. As buildings with greater the time period, attract less seismic force, the isolation system deflects the seismic energy. In particular, high energy in the ground motions at higher mode frequencies are deflected. The isolator device because of its non-linear behavior to earthquake excitation absorbs the seismic energy. The force–displacement behavior of isolators under sinusoidal excitation manifests hysteretic behavior and, therefore, much of the input energy to the isolators is lost in the hysteresis loop. Because of these two properties of the isolators, they have become very attractive passive control devices to be used in the control of seismic response of structures, especially the building structures.

1.2 Principle of Base Isolation

The fundamental principal of base isolation system is to amend the response of the structure so that the ground can move below the structure without transferring these motions into the superstructure. In a perfectly ideal system for the flexible this separation would be total. But In the realistic world there is a need to be some contact between the super structure and sub structure.

A structure that is perfectly flexible means has an infinite time period. For the flexible type of structure when the substructure moves there will be zero acceleration influence in the structure, and the relative displacement between the super structure and substructure will be equal to the ground displacement between the super structure and ground will be equal to the ground displacement the structure will not move with the ground motion.

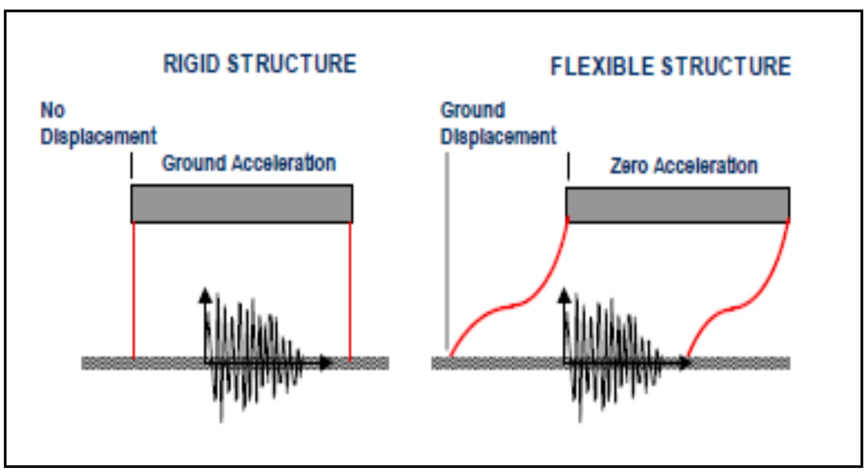


Fig -1.1 Transmission The Motion

A structure that is perfectly rigid will have a zero time period, when the ground moves the acceleration induced in the superstructure will be equal to the ground acceleration and zero relative displacement between the superstructure and substructure.

All the existing structures are neither perfectly flexible nor perfectly rigid, so the response to ground motion is between these two as shown in fig-1.2. For time periods between zero and infinity. The maximum acceleration and relative displacements to the ground is depends on the earthquake as shown in fig.1.2.

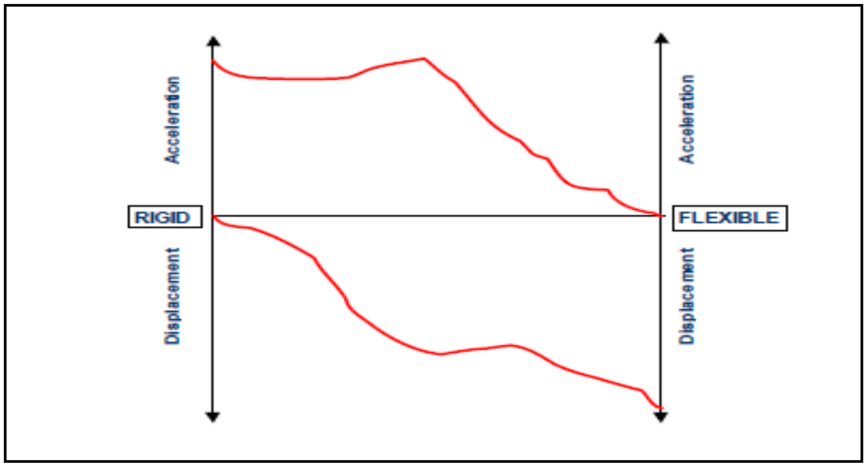


Fig 1.2 the acceleration and displacement for flexible and rigid structure

For most of the earthquakes there will be a range of time periods as which the acceleration in the system will be increase exceeding the maximum ground acceleration. The relative displacements will generally not exceed the peak ground displacement that is having infinite period displacement but there are some exceptions to this, particularly for soft site and site which are located close to the fault generating the earthquake.

1.3 Base Isolation System

Base isolation is a passive control device. There are generally two types of base isolation system; one is elastomeric bearing base isolation system and second is sliding bearing base isolation system. Lead rubber bearing, laminated rubber bearing(LRB), and New Zealand(NZ) rubber bearings are used extensively in practice in elastomeric bearing base isolation system. Elastic sliding bearings, friction pendulum systems (FPS), resilient friction systems (R-FBI), and pure friction (P-F) systems are used extensively in practice in sliding bearing base isolation system.

1.3.1 Friction Pendulum System

The friction pendulum base isolator system is shown in Figure 1.3.1 along with its characteristic force-displacement loop. It has a centering action, caused by the horizontal component of reaction in the dish to the vertical gravity force. This horizontal component increases with time period. There is an energy dissipation device due to the friction between the spherical surface and the articulated slider. This coefficient of friction, which is depends on the lubricating property can range from .03 to 0.09. The lower the coefficient of friction the better the centering action of the friction pendulum system. However, higher coefficient of friction is desirable to increase energy dissipation, which reduces dynamic displacement under earthquake. But higher friction increases the tendency to excite higher modes in the isolated structure due to the abrupt change in loading as the velocity reverses direction. The design of any friction pendulum base isolation system is always a compromise between the need for low friction to minimize residual offset and higher mode excitation, and the need for high friction to minimize dynamic displacement.

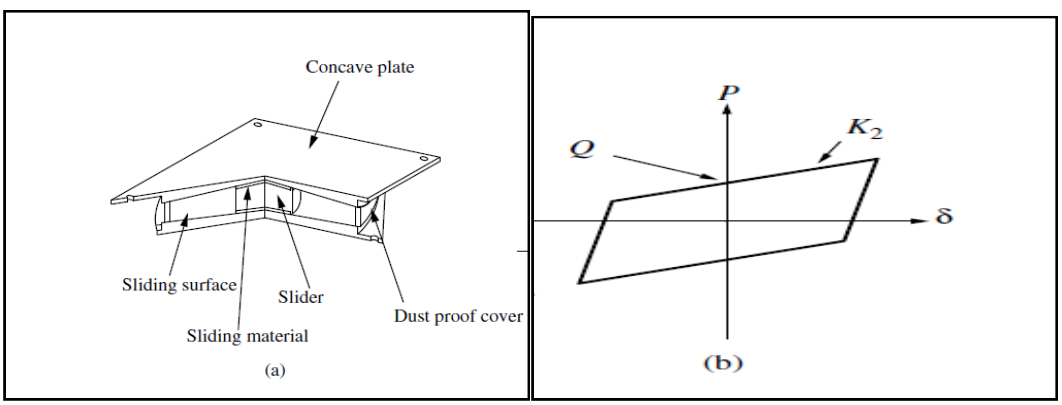


Fig 1.3 (a) & (b) friction pendulum isolator and force-displacement relationship for friction pendulum isolator

1.3.2 Laminated Rubber Bearing

The basic components of the LRB are steel and rubber plates built into alternate layers (Figure 1.4). Generally, an LRB system exhibits high damping capacity, horizontal flexibility, and high vertical stiffness. For low damping rubber bearings, a lateral force–deformation relationship is modeled as linear, as shown in Figure 1.5 (a). A temperature independent model for the lateral stiffness of the bearing is given

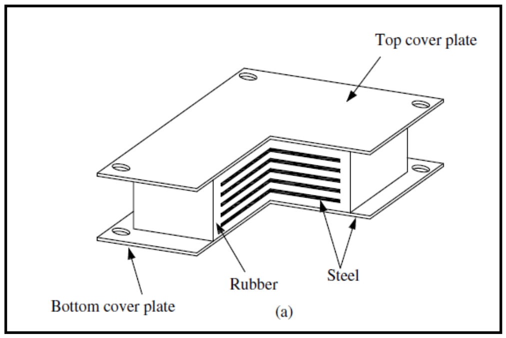


Fig 1.4 - Laminated rubber bearing isolator

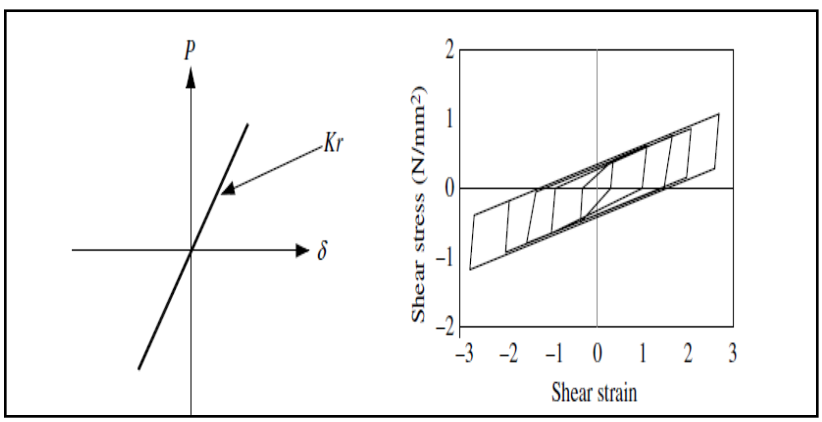


Fig 1.5- (a) & (b) Force-deformation relationship for linear and non-linear structure respectively

1.4 Objective of Study

The first objective of this research is to investigate the non linear analysis for fixed and base isolated 7-storey buildings designed to international building Code (2000), FEMA 273 1997, FEMA 274 1997, FEMA 751 2000 of Practice for Design of " Concrete Structures to the different isolation systems (friction pendulum isolator) and to consider the effects of foundation compliance during the different earthquakes. Non-linear time history analysis is used on both fixed base and base isolated multistory buildings. There are two studies; one is comparative study of response of fixed base condition and base isolation (FPS) condition and the comparative study of performance by two different time histories LACC and Newhall T.H. Finally, base shear, displacement and acceleration are compared from two times histories analysis between fixed base conditions. It is found that the displacement is increased with time period of the isolated building. And also investigate the seismic response of the structure for the different value of coefficient of friction (0.03-.10) in friction pendulum system.

Thus, the second objective of this research is to the objective of this study is to reduce coming into the structure due to base isolation systems used. These displacements sometimes reached beyond the desirable limits. Thus to restrict them a damping system is incorporated in a structure. This system not only hinders top story displacements but affects whole structure responses.

1.5 Scope of Study

Medium & high-rise structures are need of this century but security is also main issue. Shaking of earth cause the structures to respond abruptly. To keep the structures sound base isolation is a good technique but the responses generated are sometimes do not lie in permissible limits thus to maintain these responses dampers are now being used efficiently.

CHAPTER -2 LITERATURE REVIEW

2.1 Overview of Past Study

Peng-Hsiang, Charng

They proposed that, a dynamic study is carried out to investigate in detail the seismic responses for flexible and stiff 12-storey multi -story building to the various base isolation systems and to consider the effects of substructure compliance on their responses when subjected to different earthquakes. At the same time, an investigation of the seismic response of the recently suggested segmental buildings is carried out. The segmental building concept can be considered as an extension of the conventional base isolation technique with additional flexibility distributed in the superstructure. In inclusion to the conventional isolation system located at the base, the superstructure of number of buildings is further divided into number of segments, which are interconnected by additional isolation systems located in the upper stories.

In General, the increase of additional viscous damping in the structure may reduce dynamic displacement and acceleration responses of the structure. This study also desires to evaluate the effects of additional damping on the seismic response when compared with structures without additional damping for the different ground motions. In addition, analysis and design considerations for base isolated and number of structures are suggested to enable the designer to get a better understanding the design in the preliminary stage.

Norio Hori, Shuang Zou, Masahiro Ikenaga, Kohju Ikago & Norio Inoue

They stated that the application of the base isolation system in detached houses increased in Japan. However, the large base dynamic displacement of a base isolated detached house, exceeding the design limit. It was observed when the Great East Japan earthquake occurred on 11 March 2011. To avoid this damage caused by much more excessive displacement device for controlling seismic displacement of base isolated structures by introducing a friction damper with coupling mechanism. This device is a passive friction damper. In the case of moderate earthquakes, this damper is inactivated. When the deformation of the isolated story reaches the recommended length, the damper is activated with coupling mechanism to reduce the displacement.

They found experimental results shown that the proposed friction damper is effective for reduce the maximum response displacement of the each isolated story, with a slight increase of the response acceleration on the superstructure. But higher mode vibrations increase after coupling of the friction damper. Because these vibrations are attributed to the shock and the increased stiffness caused by the friction damper, suitable elastic stiffness and friction force should be studied

Vasant A. Matasagar and R.S. Jangid

They studied on the seismic response of multistorey base isolated building on various types of isolator system connected using viscous dampers to an adjacent dissimilar base isolated or fixed- base structure.in this study the multistoried buildings are modeled as a shear type building with lateral degree of freedom at each floor,which are connected at different floor levels by the viscous dampers. They concluded that connecting the two adjacent base isolated buildings with the viscous damper is helpful in controlling large bearing displacement in the base-isolated structures. They also found the connection of viscous damper to the structures are found to be most effective when;

1) The adjacent base- isolated and fixed- base buildings are connected.
2) Dissimilar isolation systems are used for the two adjacent buildings.
3) The time period of adjacent structures are well separated and
4) The superstructure flexibility is higher.

Saif Hussain, David Lee & Eloy Retamal

They proposed that Seismic Base Isolation could use elastomeric pads, sliding plates or inverted pendulums. every method can introduce an energy dissipation means, but only as some kind of hysteretic damping. Hysteretic damping has limitations in terms of energy absorption and may tend to excite higher modes in some cases.. It’s possible to avoid these problems with viscous dampers. Viscous damping adds energy dissipation through loads that are 90o out of phase with bending and shear loads so even with damping levels as high as 40% of critical adverse side effects tend to be minimal. They study presents basic theory of viscous damping, and also describes a sample project.

Nitish Takalkar & D. K. Paul

They proposed that in seismic base isolation system, flexibility is introduced between the superstructure and substructure, which decouples the superstructure from earthquake ground motion. They disclosed that the friction pendulum isolator system (FPS) could be a better alternative in the base isolation system to study the response of multi-storey building for earthquake ground motion. Their study includes modeling of friction pendulum isolator and analysis of multi-story buildings subjected to earthquake ground motion. The force-deformation characteristics of the isolation system are considered bi-linear. The suitability of friction pendulum isolator has been checked for medium rise RC buildings. They found that the friction pendulum isolator to be economical and suitable for medium rise multi-story buildings. The effect of isolation damping on the response of structure parameters has been analyzed with varying effective damping of FPS from 5% to 35% for five spectrums compatible time histories. They also done the, roof acceleration and variation of bearing displacement of isolated building is studied under different percentages of damping of the isolation system. They found their study is the roof acceleration decreases up to a certain isolation damping level and beyond that it increases because of the participation of higher modes & also Friction pendulum system is designed to increase the time period of the structure, which helps in reduction of response in the building subjected to strong ground motion.

Shashi K. Thakkar and Sarvesh K. Jain

They observed from their study that the isolation damping is efficient in reducing the dynamic displacement at level of isolation. Increase in the damping up to a definite level reduces top accelerations and story shears beyond which the increased participation of higher modes leads to increase in the response. Value of damping changes with the parameter of response. There subsists an optimum value of damping which gives low value of displacements without increasing the involvement of higher modes. The Optimum values of damping depend on the characteristics of ground motion and have low value for earthquake motions with high frequency contents. It is observed that in generally not more than 15% damping is required in the base isolation system.

Mohsen Kargahi and Chukwuma G.

They stated that this method of successfully utilizing viscous dampers to improve the seismic response of concrete moment frame buildings. An existing concrete moment frame building is used to illustrate the concepts. The properties of dampers are selected by performing an optimization to minimize the cost of structure, based on non-linear static analyses. By optimizing the properties of the dampers, they can be made efficient even at comparatively small displacements.

Viscous damper is very effective in enhance the seismic performance of concrete structure, when the damper properties are optimized to secure effective performance. Result from this study got reduction in displacement in order of 50%. The optimization processes also impart the engineer with the capability to minimize the cost of dampers for a particular project, while maximizing the profit to the structure.

Nonlinear static analyses tend to underappreciate the riposte due to earthquakes when compared with a non-linear time history analysis. However, the differences in between two analyses methods are small, and an enough to be satisfactory for use in performing the optimization for developing preliminary designs This method is proved that the efficient for a building of the size of the example building and with the chosen range of variation for damper properties.

Douglas Taylor, Philippe Duflot

They stated that to reduce deflections, the project team evaluated the improvements from adding dampers in parallel with the base isolation bearings The design group investigated adding 37% fluid damping to the 8% damping expected from the rubber bearings, for a total damping level of 45% critical. Higher damping levels were found to cause decreased deflections, but higher stress, so the 45% damping level was considered as optimal for both stress and deflection. The use of the fluid viscous dampers allowed bearing displacement to be reduced to only plus or minus 0,6 meters, a reduction so substantial that the project goals could be accomplished economically. One of these goals was to produce the most seismic resistant structure in the world, and this was achieved easily with fluid viscous dampers. A fluid viscous damper with nonlinear damping of $F = CV^{0.4}$ was selected the project work An additional advantage of the fluid viscous dampers was that the long period rubber bearings and fluid viscous dampers would be able to fully reset the building after a seismic event with no permanent offset.

Trevor E. Kelly

A viscous damper provides a damping force $FD = CV^{\alpha}$ where C is the damping coefficient, V is the velocity and α is the damper exponent, generally in the range of 0.4 to 1.0. The velocity is out of phase with displacement and so the damper force is a maximum at zero displacement and reduces to zero at maximum displacement.

This study has assessed the effectiveness of two devices, viscous dampers and buckling restrained braces, in reducing deformations in flexible frame structures. For relatively small reductions in deformations the BRBs tended to be more effective in terms of reduction in drift for a specified damping force. However, for larger reductions in drift the VDDs were more effective. The VDDs had a further advantage in that they reduced floor accelerations whereas the BRB increased accelerations. The VDDs also produced smaller increases in base shear forces and overturning moments than the BRB. Neither type of device has been widely enough used in New Zealand for definitive costs to be developed. However, U.S. anecdotal evidence is that the VDD is about 60% more expensive than the BRB for a given force level.

This suggests that the VDD would be more likely favored over the BRB in two situations:

1) Where it was required to reduce deformations in a flexible building by a large factor (one-half or less the drift of the non-strengthened building).

2) For buildings with high value contents, equipment or other acceleration-sensitive components where there would be advantages from reduced floor accelerations

2.2 Earthquake Resistant Design Techniques

The objective of design codes is to have structures that will behave elastically under earthquakes that can be expected to occur more than once in the life of the building. It is also expected that the structure would survive major earthquakes without collapse that might occur during the life of the building. To avoid collapse during a large earthquake, member must be ductile enough to absorb and dissipate energy by post-elastic deformations. Nevertheless, during a large earthquake the deflection of the structure should not be such as to endanger life or cause a loss of structural integrity. Ideally, the damage should be repairable. In some cases, the order of ductility involved during a severe earthquake may be associated with large permanent deformations and in those cased; the resulting damage could be beyond repair. Even in the most seismically active areas of the world, the occurrence of a design earthquake is a rare event. In areas of the world recognized as being prone to major earthquakes, the design engineer is faces with the dilemma of being required to design for an event, which has a small chance of occurring during the design life time of the building, the client will be faced with extra costs, which may be out of proportion to the risks involved. On the other hand, to ignore the possibility of a major earthquake could be construed as negligence in these circumstances. To overcome this problem, buildings designed to these prescriptive provisions would

1. Not collapse under very rare earthquakes;
2. Provide life safety for rare earthquakes;
3. Suffer only limited repairable damage in moderate shaking; and
4. Be undamaged in more frequent, minor earthquakes.

The design seismic forces acting on a structure as result of ground shaking are usually determined by one of the following methods:

1) Seismic analysis, using equivalent seismic forces obtained from response spectra for horizontal earthquake motions

2) Dynamic analysis, either modal response spectrum analysis or time history analysis with numerical integration using earthquake records.

2.2.1 Static Analysis

Although earthquake forces rare of dynamic nature, fo r majority of buildings, equivalent static analysis procedures can be used. These have been developed on the basis of considerable amount of research conducted on the structural behavior of structures subjected to base movements. These methods generally determine the shear acting due to an earthquake as equivalent static base shear. It depends on the weight of the structure, the dynamic characteristics of the building as expressed in the form of natural period or natural frequency, the seismic risk zone, and the type of structure, the geology of the site and importance of the building.

2.2.1.1 Linear Static Procedure

Under the linear static procedure (LSP), design seismic forces, their distribution over the height of the building, and the corresponding internal forces and system displacements are determined using a linearly elastic, static analysis. In the LSP, the building is modeled with linearly-elastic stiffness and equivalent viscous damping that approximate values expected for loading to near the yield point. Static lateral forces whose sum is equal to the pseudo lateral load represent design earthquake demands for the LSP. The magnitude of the pseudo lateral load has been selected with the intention that when it is applied to the linearly elastic mode of the building it will result in design displacement amplitudes approximating maximum displacements that are expected during the design earthquake. If the building responds essentially elastically ot the design earthquake, the calculated internal forces will be reasonable approximations of those expected during the design earthquake. If the building respond in-elastically to the design earthquake, as will commonly be the case, the internal forces that would develop yielding in the building, will be less than the internal forces calculated on an elastic basis.

2.2.1.2 Nonlinear Static Procedure

Under the nonlinear static procedure (NSP), a model directly incorporating inelastic material response is displaced to a target displacement, and resulting internal deformations and forces are determined. The nonlinear load-deformation characteristics of individual components and elements of the building are modeled directly. The mathematical model for the building is subjected to monotonically increasing lateral forces or displacements until either a target displacement is exceed or the building collapses. The target displacement is intended to represent the maximum displacement may be calculated by any procedure that accounts for the effects of nonlinear response on displacement amplitude.

Because the mathematical model accounts directly for effects of material inelastic response, the calculated internal forces will be reasonable approximations of those expected during the design earthquake. Results of the NSP are to be checked using the applicable acceptance criteria. Calculated displacements and internal forces are compared directly with allowable values.

2.2.2 Dynamic Analysis

2.2.2.1 Linear Dynamic Procedure

Under the linear dynamic procedure (LDP), design seismic forces, their distribution over the height of building, and the corresponding internal forces and system displacements are determined using a linearly elastic, dynamic analysis. The basis, modeling approaches, and acceptance criteria of the LDP are similar to those for the LSP. Modeling approaches, and acceptance criteria of the LDP are similar to those for the LSP. The main exception is that the response is carried out using either modal spectral analysis or Time-history (TH) analysis. Modal spectral analysis is carried out using linearly elastic response spectra that are not modified to account for anticipated nonlinear response. As with the LSP, it is accepted that the LDP will produce displacement that are approximately correct, but will produce internal forces that exceed those that would be obtained in a yielding building. Results of the LDP are to be checked using the applicable values. Calculated internal forces typically will exceed those that the building can sustain because of anticipated inelastic response of components and elements. These obtained design forces and alternative analysis procedures to account for anticipated inelastic response demands and capacities.

2.2.2.2 Non Linear Dynamic Procedure

Under the nonlinear dynamic procedure (NDP), design seismic forces, their distribution over the height of the building, and the corresponding internal forces and system displacements are determined using an inelastic response history dynamic analysis. The basis, modeling approaches, and acceptance criteria of the NDP are similar to those for the NSP. The main exception is that the response calculations are carried out using Time-history analysis. With the NDP, the design displacement are not established using a target displacement, but instead are determined directly through dynamic analysis using ground motion histories. Calculated response can be highly sensitive to characteristics of individual ground motions; therefore, it is recommended to carry out the analysis with more than one ground motion record. Because the numerical model accounts directly for effects of material inelastic response, the calculated internal forces will be reasonable approximations of those accepted during the design earthquake. Results of the NDP are to be checked using the applicable acceptance criteria. Calculated displacements and internal forces are compared directly with allowable values.

2.2.2.2.1 Modeling and Analysis Assumptions

1. General

The NDP shall conform to the criteria of this section. the analysis shall be based on characterization of the seismic hazard in the form of ground motion records. the modeling and analysis consideration set forth shall apply to the NDP requires time-history analysis of a nonlinear mathematical model of the building, involving of building response, using discretized recorded or synthetic earthquake records as base motion input.

2. Ground Motions Characterization

The earthquake shaking shall be characterized by ground motion time histories meeting the requirements

3. Time-History Method

Time-history analysis shall be performed using horizontal ground motion time histories prepared. Multidirectional excitation effects shall be accounted for by meeting the requirements may be satisfies by analysis of a three-dimensional mathematical model using simultaneously imposed pairs of earthquake ground motion records each of the horizontal axes of the building.

2.2.2.2.2 Acceptance Criteria for Nonlinear Procedure

1. Deformation-Controlled Actions

Primary and secondary components shall have expected deformation capacities not less than the maximum deformations. Excepted deformation capacities shall be determined considering all coexisting forces deformations.

2. Force- controlled actions

Primary and secondary components shall have lower bound strength not less than the maximum design actions. Lower-bound strength shall be determined considering all coexisting forces and deformations.

2.3 Design Criteria for Base Isolation Device

A complete design for friction pendulum isolator should ensure that the isolators can support the maximum gravity service loads of the structure throughout its life, and the isolators can provide the dual function of energy dissipation and period shifting to the isolated structure during earthquakes. In accordance with these design aims, the following design steps should be undertaken [Mayes and Naeim, 2001]:

1) Determine the minimum plan size required and locations of isolators under the maximum gravity loads.

2) Compute the dimensions of the isolators that will result in the desired period shift for reducing the earthquake forces.

3) Determine the damping ratio of the isolator such that the displacement of the structure can be controlled within the permissible limit under earthquake loads.

4) Check the performance of the isolators under gravity, earthquake, and other possible load conditions.

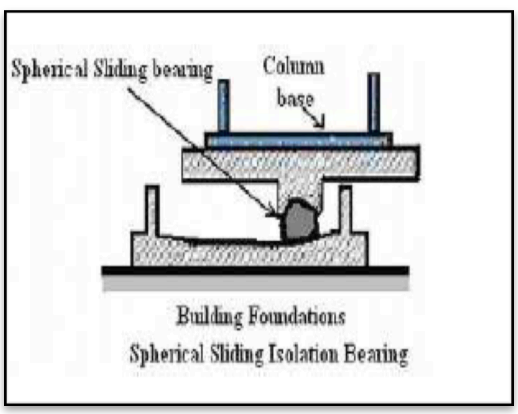
Chapter-3 Design of Friction Pendulum System

3.1 Friction Pendulum System

In this study friction pendulum isolator system design in which there are two plates made up of stainless steel, top plate is flat and bottom plate is concave in which articulated slider is moving in the duration of earthquake. Lubricating material is required between articulated slider and bottom plate. Teflon is considered, as a lubricating material, which has coefficient of friction, is 0.05. Behavior of friction pendulum isolator system is depending on the coefficient of friction.

Parts of friction pendulum isolator:

1. Top plate
2. Bottom plate
3. Articulated slider
4. Enclosing cylinder for lateral displacement restraint



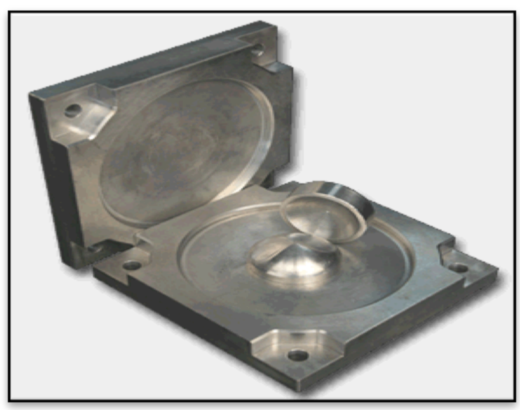


Fig-3.1 Friction pendulum isolator system

3.2 Design Model

Using SAP2000v15 performs the time history earthquake analysis. The natural and mode shapes of the building are obtained from the time history analysis. From the time history analysis, the time dependent responses of the building for the whole duration of the earthquake excitation, the displacement, shears, base shear, moments and axial loads of the elements at various amounts of earthquake ground motions have been determined. The understanding of seismic behavior of multistory building by isolators has been done by analysis methods such as- Time History analysis. As it mentioned earlier, large magnitude long-distance earthquakes generated LACC & Newhall is selected for Time History analysis to understand the seismic response of the multistory building.

3.2.1 Material and Structural Properties

Properties of Concrete:

Use grade of concrete= M30

Mass per unit volume = 2.5 KN

Weight per unit volume = 25 KN/M^3

Modulus of elasticity, Ec = 2.7x10^7 KN/m^2

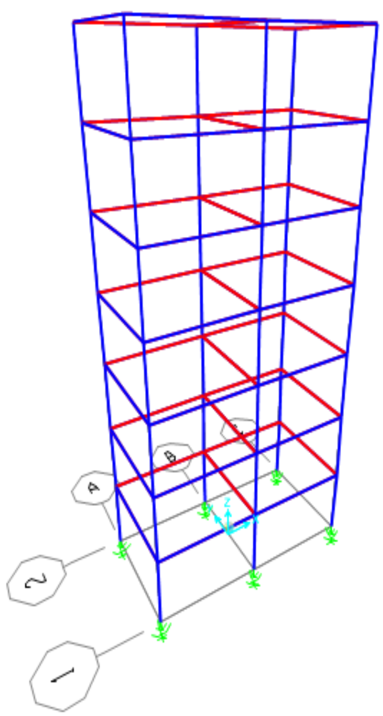
Damping ratio = 0.05

Poisson's ratio = 0.20

Shear modulus = 1500

Co-efficient of thermal Expansion = 5.5x10^ -6

The required material properties like weight density, mass, modulus of elasticity shear modulus and design values of the material used can be modified as per requirements.



Number of story =7

Storey height =3m

Beam size=300*500mm

Column size=500*500mm

Dead load =3.5KN/m^2

Live load =2.5KN/m^2

Superimposed load =1KN/m^2 at all storey and 1.5KN/m^2 at the roof

Fig 3.2 Design model

3.2.2 ASSIGNING LOADS

After having modeled the structural components, all possible load cases are assigned. These are as follows:

1) Dead load on the structure includes the self-weight of column, beams and slabs. The self-weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself. Live load on the structure over the area section is provided.

2) Earthquake loads on the structure according to the LACC & Newhall time history data.

3.2.3 TIME HISTORY DATA

1) LACC Time History

Figure 3.3 represnets the LACC earthquake data at 24389-s2775-94019.02 century city - LACC north at 90 degree
3000 points of acceleration data equally spaced at .020 sec. (Units: cm/sec/sec)

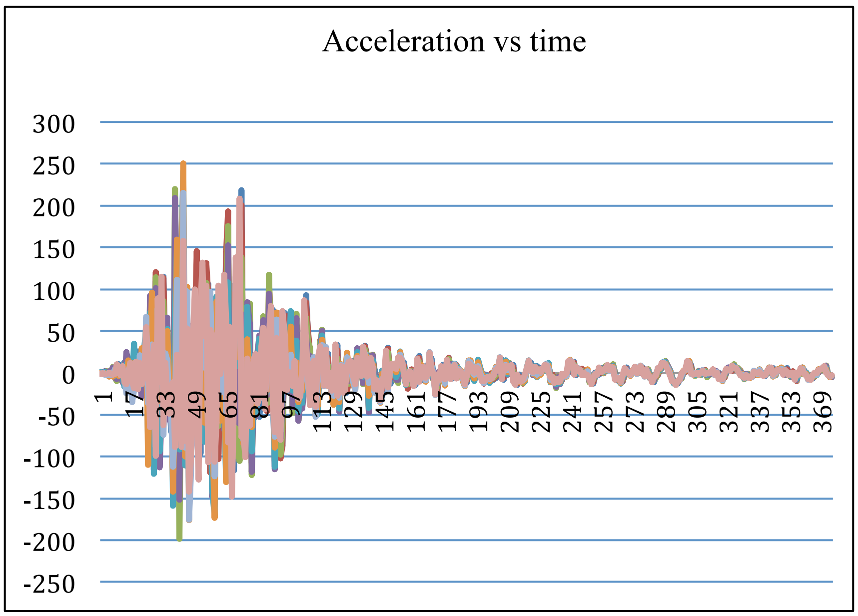


Fig- 3.3 Acceleration time histories for LACC

2) Newhall Time History

Figure 3.4 represents the 24279-s2499-94021.02 Newhall - La County fire station at 90 degree

3000 points of acceleration data equally spaced at .020 sec. (Units: cm/sec/sec)

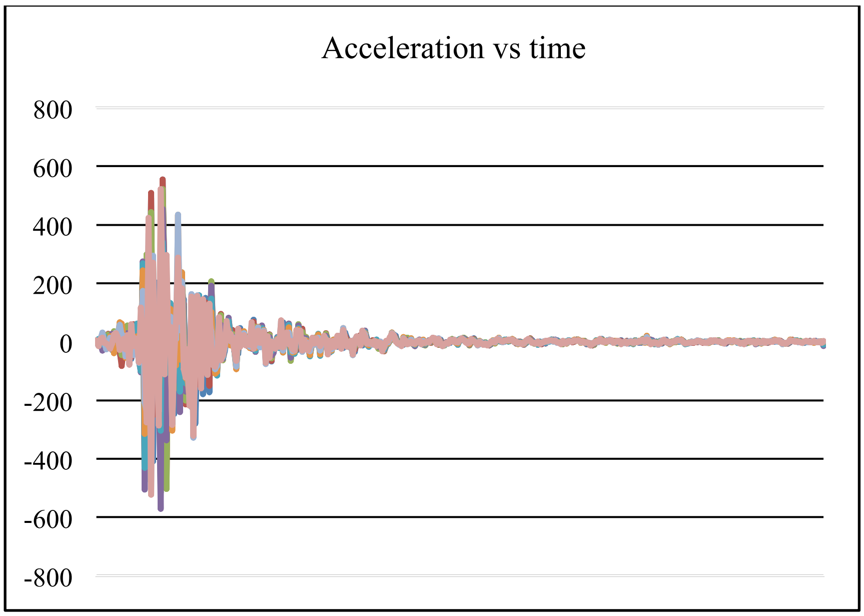


Fig- 3.4 Acceleration time histories for Newhall

Both time histories given above are used in our study as an earthquake forces applied on our model. Newhall acceleration time history data given in APPENDIX-II for 60 sec, 3000 points at 0.02 sec interval.

Chapter-4 Comparative Study of Fixed Base and Base Isolated Building

4.1 Time Period for Different Modes

Table 4.1 Time Period for different Modes

MODE SHAPE	TIME PERIOD (SEC.) FIXED BASE	TIME PERIOD (SEC.) FRICTION ISOLATOR
MODE 1	0.83834	5.26242
MODE 2	0.76427	3.40398
MODE 3	0.72875	1.17057
MODE 4	0.25351	1.00511
MODE 5	0.23256	0.61136
MODE 6	0.21935	0.59756
MODE 7	0.12962	0.30721

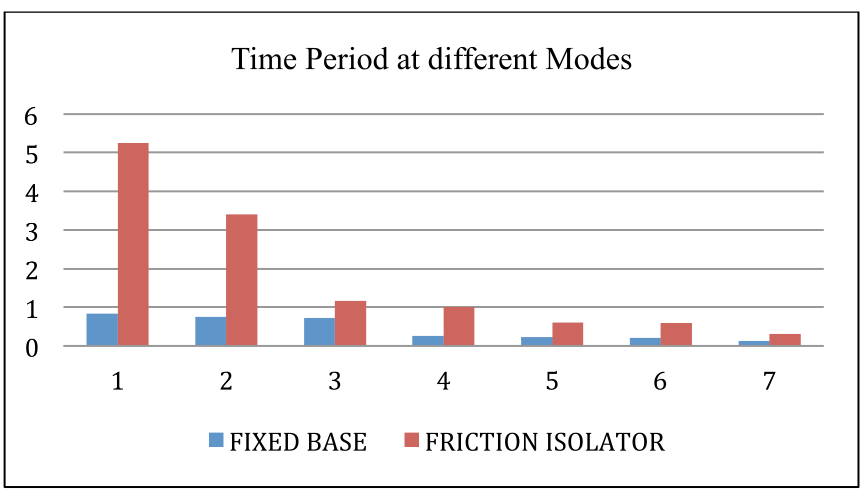


Fig- 4.1 Time period for fixed base & friction pendulum isolator system

From fig- 4.1 we can easily observed that base isolation system increase the lengthening time period of the structure. When we introduce flexibility in the structure then the time period of the structure is increased, but time period has proportional relation with displacement. So when we introduce flexibility by means of isolation system, time period increase and displacement is also increased (See Figure 4.2) in this study friction pendulum isolator system is used a base isolation system.

In table 4.1 we observed that by providing isolation system (friction pendulum isolator) time period at different modes is increased with time period of fixed base building.

4.2 Floor Displacement of Structure

Here we can see that from story drift analysis. Drift is less in fixed base building as compared to base isolated building. This is happen because of isolation in building we actually increase the lengthening of time period, and due to increase in time period displacement is also increase.

Table 4.2: Displacement for different Floors

LACC Time History Case:

FLOORS	Displacements (m) (Fixed Base)	Displacements (m) (Base Isolated)
1	0.00	0.00082
2	0.000772	0.000928
3	0.001142	0.001465
4	0.001463	0.00209
5	0.001716	0.002711
6	0.001908	0.003328
7	0.002054	0.003939
8	0.002141	0.004545

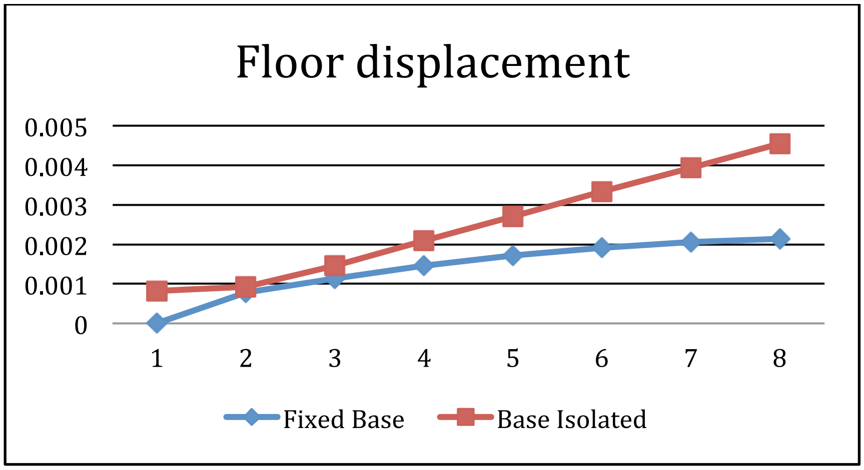


Fig 4.2 Displacement at each floor for fixed base & friction pendulum isolator system (LACC T.H.)

Table 4.3 Drift at each storey

STORY	Displacements (m) (Fixed Base)	Displacements (m) (Base Isolated)
1	0.00072	0.000108
2	0.000370	0.000537
3	0.000321	0.000625
4	0.000253	0.000621
5	0.000202	0.000617
6	0.000146	0.000618
7	0.000087	0.000626

Table 4.4 Floor Displacement Of Structure

Newhall Time-history case

Floor	Displacement (m) (Fixed Base)	Displacement (m) (Friction pendulum isolator)
1	0.00	0.002556
2	0.003270	0.003966
3	0.005193	0.006569
4	0.006672	0.009101
5	0.007871	0.01160
6	0.008823	0.01401
7	0.009519	0.01650
8	0.009919	0.01894

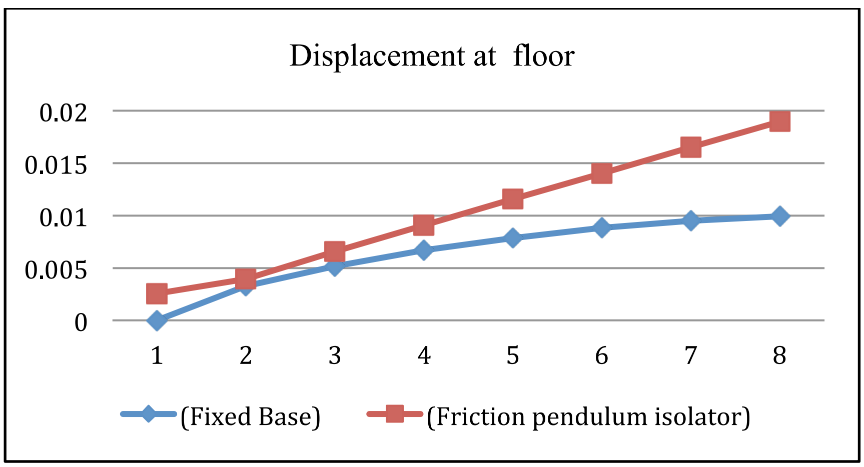


Fig 4.3 displacement at floor for fixed & friction pendulum isolator (Newhall T.H.)

4.3 Response Of Fixed Base And Friction Pendulum Isolator

Table 4.5 Response of structures

Kinds Of Response Of Structure	Time History		Fixed Base	Friction Pendulum Isolator	Reduction (%)
Base Shear X	LACC	Max	22.72	9.825	56.76
		Min	-28.70	-11.16	61.11
	Newhall	Max	134.2	48.42	63.9
		Min	-130.5	-35.59	72.7
Base Shear (Y)	LACC	Max	25.73	12.16	52.7
		Min	-27.21	-11.88	15.33
	Newhall	Max	67.48	36.22	46.32
		Min	-59.32	-39.20	33.91
Acceleration (X)	LACC	Max	0.1486	0.09668	34.94
		Min	-0.1789	-0.009600	94.63
	Newhall	Max	0.8911	0.3069	65.55
		Min	-0.7247	-0.3474	52.1

Kinds Of Response Of Structure	Time History		Fixed Base	Friction Pendulum Isolator	Reduction (%)
Acceleration (Y)	LACC	Max	0.2125	0.08400	60.47
		Min	-0.1569	0.1181	24.73
	Newhall	Max	0.4868	0.2812	42.22
		Min	-0.4071	-0.2690	33.92
Displacement (X) [Bottom]	LACC	Max	0.00	0.0008201	- 8.21
		Min	0.00	-0.0096	-9.6
	Newhall	Max	0.00	0.002556	-2.56
		Min	0.00	-0.003692	-3.6
Displacement (X) [Top]	LACC	Max	0.002141	0.004545	-49.21
		Min	-0.001686	-0.005375	-218.8

Kinds Of Response Of Structure	Time History		Fixed Base	Friction Pendulum Isolator	Reduction (%)
Displacement (X) [Top]	Newhall	Max	0.009919	0.01894	-48.62
		Min	-0.01049	-0.01987	-89.41
Displacement (Y) [Top]	LACC	Max	0.002305	0.004806	-108.5
		Min	-0.002362	-0.004527	-91.66
	Newhall	Max	0.004786	0.01395	-191.47
		Min	-0.005914	-0.01604	-171.22
Displacement (Y) [Bottom]	LACC	Max	0.00	0.0008710	-8.7
		Min	0.00	-0.0008925	-8.9
	Newhall	Max	0.00	0.002951	-29.51
		Min	0.00	-0.002703	-27.03

4.4 Sap2000 Results for Fixed Base and Friction Pendulum System

Following results shows in given figures are results of Fixed base structure and friction pendulum isolator structural system for base shear X, acceleration in X direction, modal damping, displacement in X direction and response spectrum curve obtained by modeling on SAP2000v15.

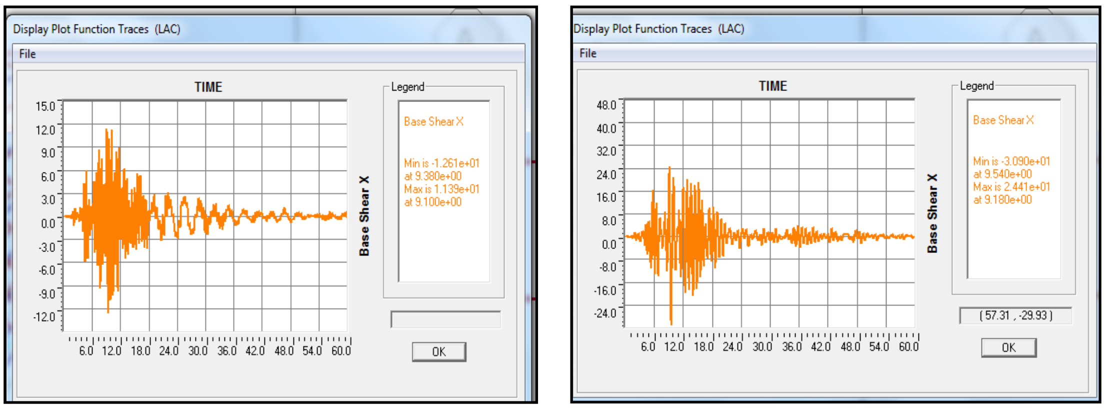
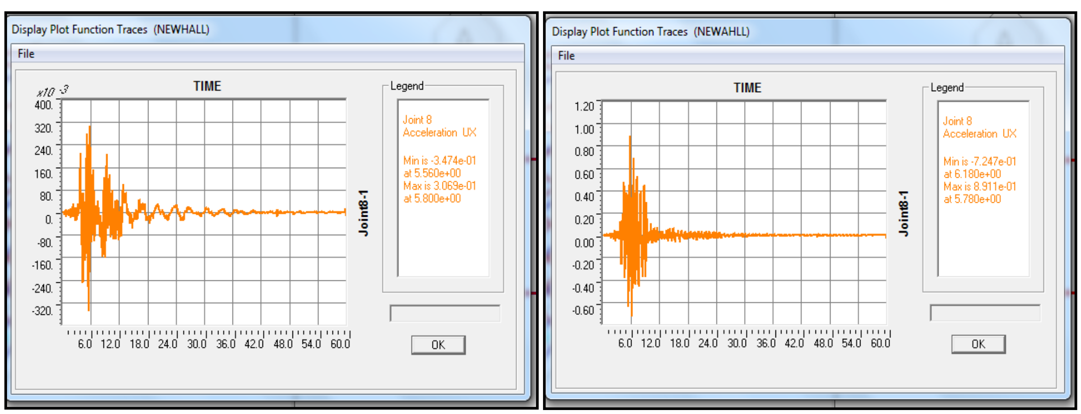
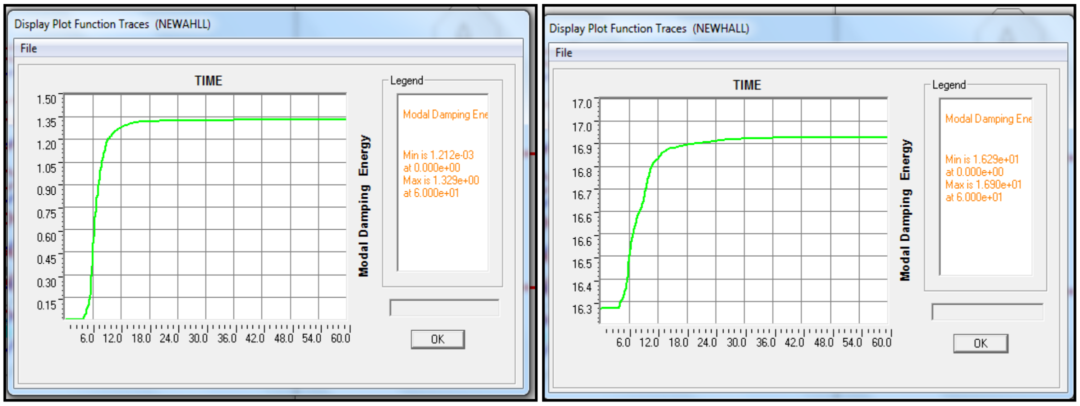


Fig- 4.4 (a) & (b) SAP2000 result of base shear X for fixed base & base isolated structure respectively



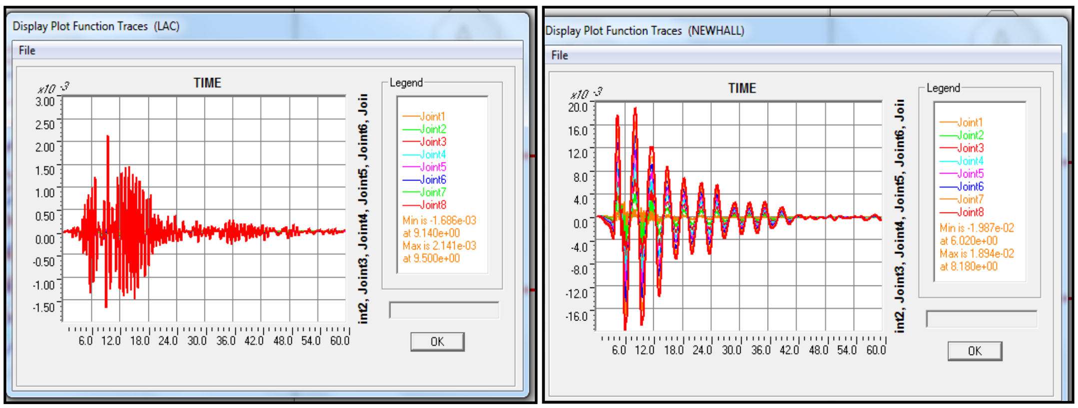
(a) (b)

Fig- 4.5(a) & (b) SAP2000 result of acceleration X for joint 8 for fixed base & base isolated structure respectively



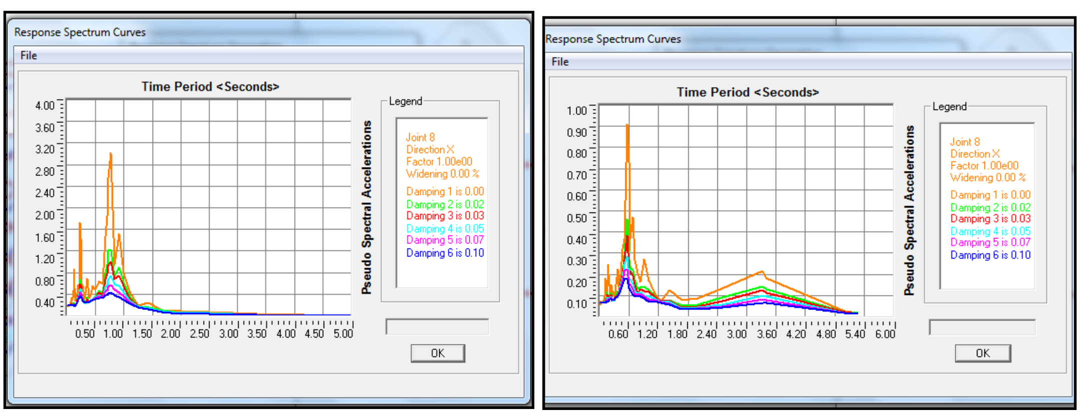
(a) (b)

Fig- 4.6(a) & (b) SAP2000 result of modal damping energy for fixed base & base isolated structure respectively



(a) (b)

Fig- 4.7(a) & (b) SAP2000 result of displacement X for fixed base & friction pendulum isolator system respectively



(a) (b)

Fig-4.8(a) & (b) SAP2000 result of response spectrum curve for fixed base & friction pendulum isolator respectively

Chapter-5 Parametric Study of Friction Pendulum Isolator

As earlier discussion we found that the coefficient of friction is important characteristics of friction pendulum system, that is depend on the property of the lubricating material. Our aim is to found out the behavior of base isolated structure with different value of coefficient friction. From the results of previous study in friction pendulum system the effective range of the coefficient of friction is 0.03 – 0.10.

5.1 Time Period for Different Value of Coefficient of Friction

Here, we can easy see that from fig 5.1, when we increasing the coefficient of friction, then time period of structure are reduce. This happen, because of when we increase the coefficient of friction then we actually create a more energy-dissipating device.

Table 5.1 Time periods with coefficient of friction

Coefficient of friction	Time period
0.03	5.68439
0.05	5.26242
0.06	4.92687
0.09	4.84346
0.1	4.29257

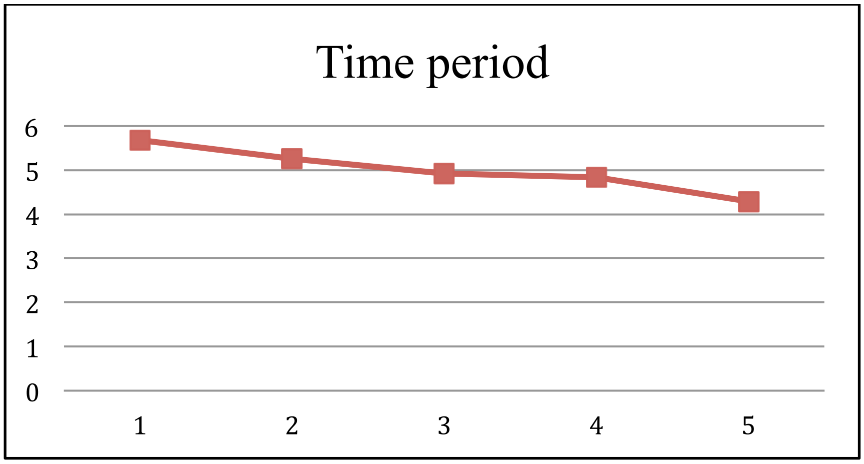


Fig. 5.1 Time period with coefficient of friction

5.2 Displacements for Different Value of Coefficient of Friction

In this section we obtained displacement for different values of coefficient of friction, we observed increasing the coefficient of friction displacement in first storey is decrease nearly straight but in top storey at some point decrease abruptly. It implies stiffness and damping of friction pendulum isolator is proportional to coefficient of friction.

Table 5.2 Displacement at 1 story with different coefficient of friction.

Coefficient of friction	Displacement (m) at 1st story
0.03	0.004080
0.05	0.003966
0.07	0.003678
0.09	0.003482
0.10	0.003044

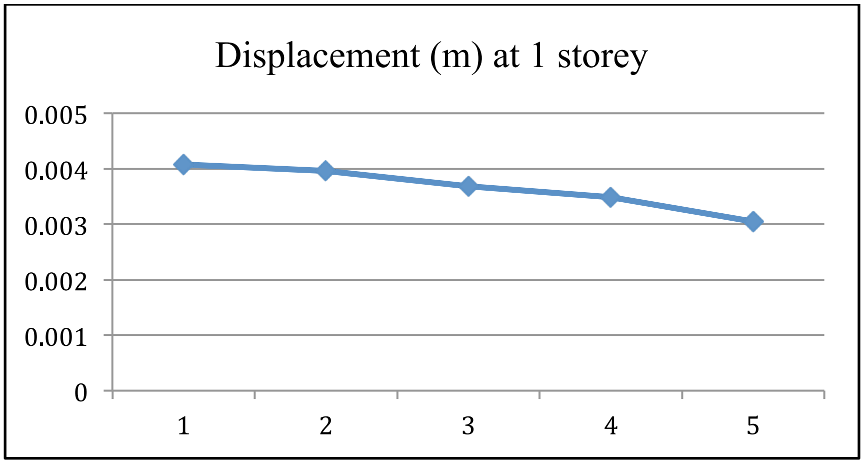


Fig-5.2.displacement at 1st story with different coefficient of friction

Table- 5.3 displacement at top story for different coefficient of friction

Coefficient of friction	Displacement (m)at top story
0.03	0.02271
0.05	0.01894
0.07	0.01748
0.09	0.01735
0.10	0.01048

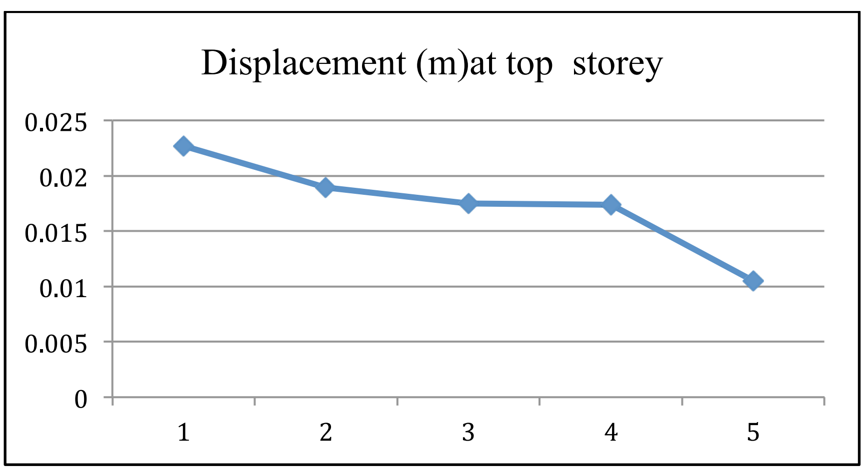


Fig-5.3 Displacement at top story with different coefficient of friction

5.3 Base Shear for Different Value of Coefficient of Friction

From the experimental work we found that the base shear in X- direction is increase with the coefficient of friction is increase. This happen because of the stiffness and damping of structure is depends on the coefficient of friction, when we increase the coefficient of friction then the stiffness and damping of structure is also increased, that means damping is increased, control of the dynamic displacement of structure but due to stiffness is increased this provided some kind of rigidity in structure so we found the base shear is increased. This happen up to 0.07 because of after this value damping is more increased as compared to the stiffness, so we get the base shear is increased up to 0.07, after this we get decreasing in base shear as shown in fig-5.4. So this study we get the efficient value of coefficient of friction is 0.1.

Table 5.4; Base shear in X- direction with different value of coefficient of friction for LACC & Newhall Time history.

Coefficient of friction	**Base Shear in X direction**			
	Lacc T.H.		**Newhall T.H.**	
	Max	**Min**	**Max**	**Min**
0.03	8.035	-8.397	49.25	-37.56
0.05	9.825	-11.16	48.42	-35.27
0.07	13.35	-13.10	50.18	-34.35
0.09	12.10	-12.23	48.98	-31.81
0.1	11.57	-11.08	35.67	-29.64

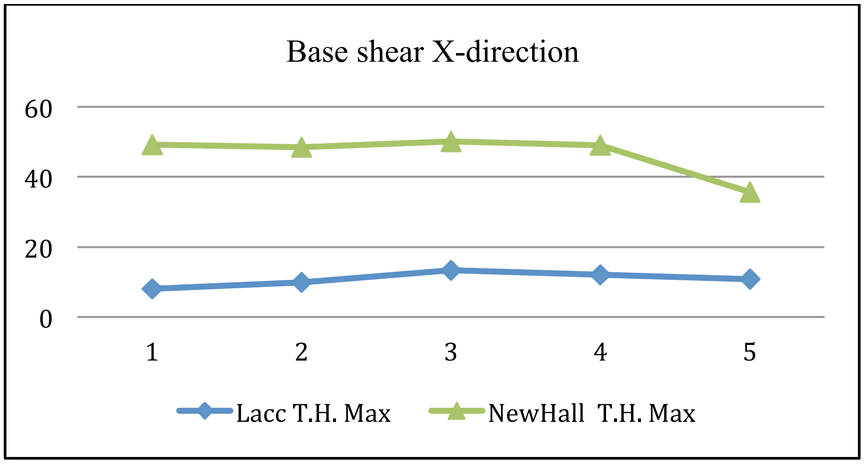


Fig-5.4 base shear X-direction with different value of coefficient of friction for LACC & Newhall Time history.

Table- 5.5 Base shear in Y- direction with different value of coefficient of friction for LACC & Newhall Time history

Coefficient of friction	**Base Shear in Y direction**			
	Lacc T.H.		**Newhall T.H.**	
	Max	**Min**	**Max**	**Min**
0.03	14.06	-12.64	32.49	-33.49
0.05	16.23	-16.56	36.22	-39.20
0.07	29.79	-29.81	46.77	-45.77
0.09	11.34	-12.11	35.68	-38.68
0.1	20.77	-22.41	38.95	-44.07

We clearly observed from figure 5.5 that base shear in Y direction is increased up to the value of coefficient of friction 0.07 reason is already mention in the base shear in X-direction case.

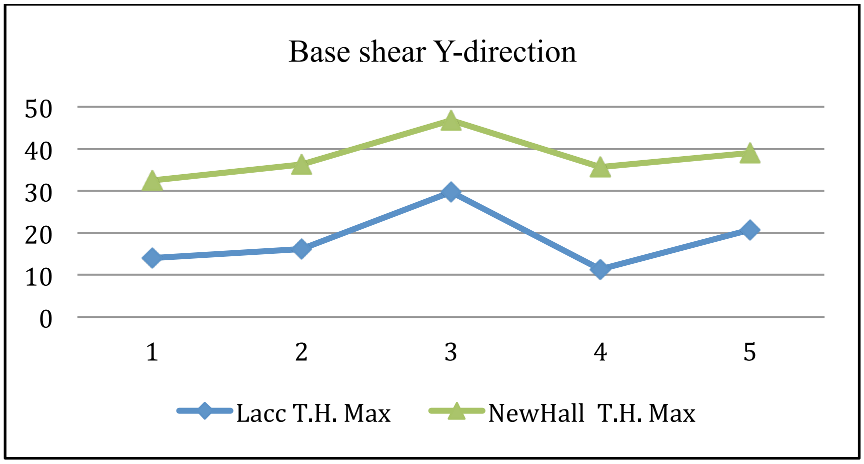


Fig-5.5 base shear Y- direction with different value of coefficient of friction for LACC & Newhall time history case.

5.4 Acceleration for Different Value Of Coefficient of Friction

Table- 5.6 Acceleration in X & Y direction for value of coefficient of friction

Coefficient of friction	**Acceleration in X direction**		**Acceleration in Y direction**	
	LACC T.H.	Newhall T.H.	LACC T.H.	Newhall T.H.
0.03	0.07410	0.2711	0.09359	0.2532
0.05	0.09668	0.3069	0.08400	0.2812
0.07	0.1173	0.3490	0.1904	0.3687
0.09	0.1180	0.3457	0.0912	0.2791
0.10	0.1076	0.2086	0.1739	0.3641

Chapter -6 Coupling Mechanism of Viscous Damper with Friction Pendulum Isolator

Base isolation system is increase the time period of building and it is also increase the displacement at each story. We are adopting viscous damper parallel friction pendulum isolator system with coupling mechanism.

6.1 Viscous Damper Model

The viscous damper for structures is an energy observer device. The damping fluid is silicone oil, which is inanimate, non-burnable, non-noxious, and stable for tremendously long periods of time as shown in figure 6.1.The sealant in the viscous damper is patented high technology designs, which is based on aerospace fluid elements, and provides totally drip free service. The action is of viscous damper provided by the fluid flow across the piston head. The piston head is made up of a conscious clearance between the outside of the head, and inside of the cylinder, which forms an annular orifice. The fluid flows through this orifice at a high speed as the damper strokes. The shape of the piston head determines the characteristics of damper.

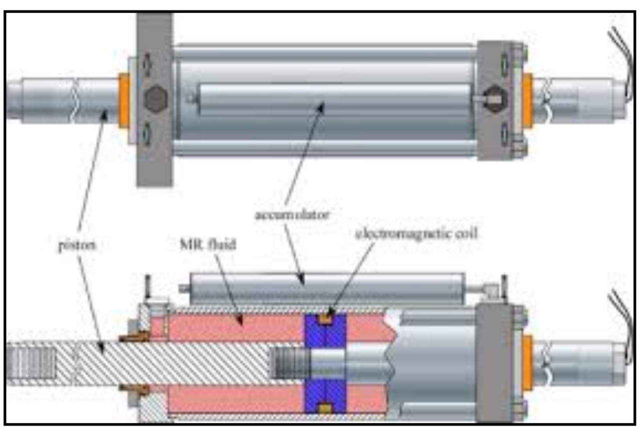


Fig- 6.1 viscous damper model

6.2 Characteristic of Viscous Damper

The force-velocity relationship for viscous damper can be characterized as $F=CV^n$, where F is the output force in KN, V is the relative velocity across the damper in meter per second, C is a constant determined by the diameter and the orifice area of damper, and n is a constant exponent .The damper with value of n=1, is called a linear viscous damper, in which the damping force is proportional to its relative velocity. The dampers with value of n>1 has not been seen generally in practical applications. The viscous damper with value of n<1 is called a non-linear viscous damper called a nonlinear viscous damper which is efficient in minimizing high velocity shocks. Figure 6.2 shows the force-velocity relationships all three types of viscous dampers.

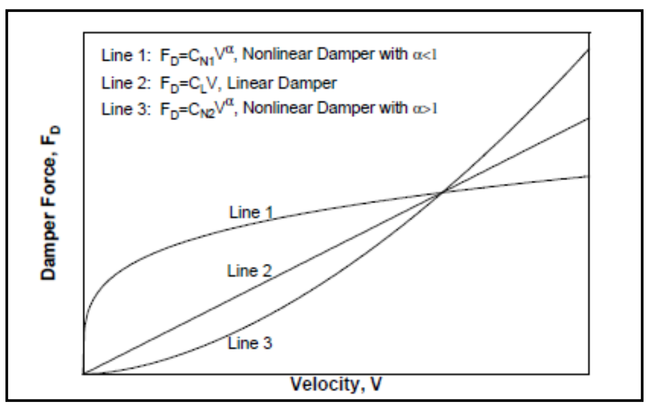


Fig-6.2 Force-velocity relationship for viscous damper

This Figure intimates the efficiency of non-linear dampers in minimizing the high velocity shocks. For a small value of relative velocity that is less than 1, the damper with a can give a larger damping force than the other two types of viscous dampers.

Figure 6.3 (a) shows the hysteresis loop of a pure linear viscous behavior. The loop is a perfect ellipse under this situation. There is absence of storage stiffness makes the natural frequency of a structure assimilate with the damper endure the same. This advantage wills clearly the design procedure for a structure with supplementation viscous devices. When the viscous damper develops restoring force then the loop will be changed from condition (a) to (b). In other words we can say that it turns from a viscous behavior to a viscoelastic behavior.

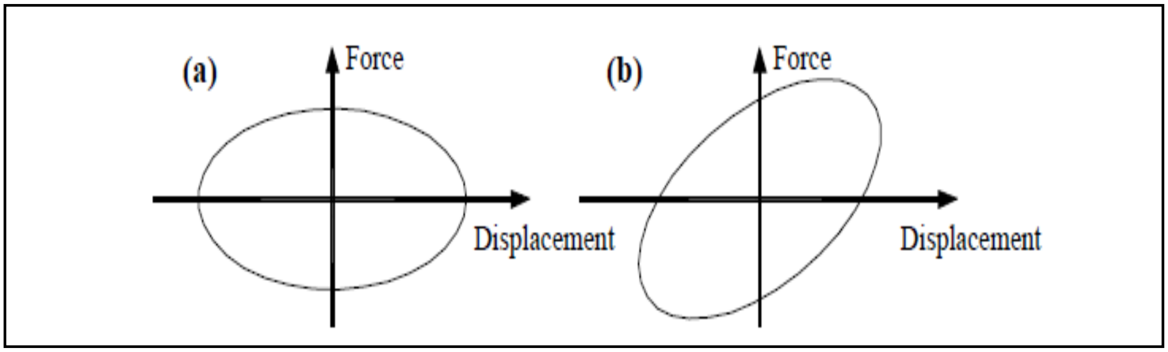


Fig-6.3 Hysteresis Loops of Viscous damper and Viscoelastic damper

The additional damping provided by the system, which is, increases the energy absorbed by the structure during earthquakes duration. Due to this energy absorber behavior there is a reduction of the displacements and forces induced in structural components. In addition, since dampers is a energy dissipating device in proportional to velocity not displacement, the damper forces are not in a state with the forces in other structural components

6.3 Comparison with or without Viscous Damper Base Isolation System

In this section we study structural characteristics of structure with or without viscous damper base isolation system

6.3.1 Time Period

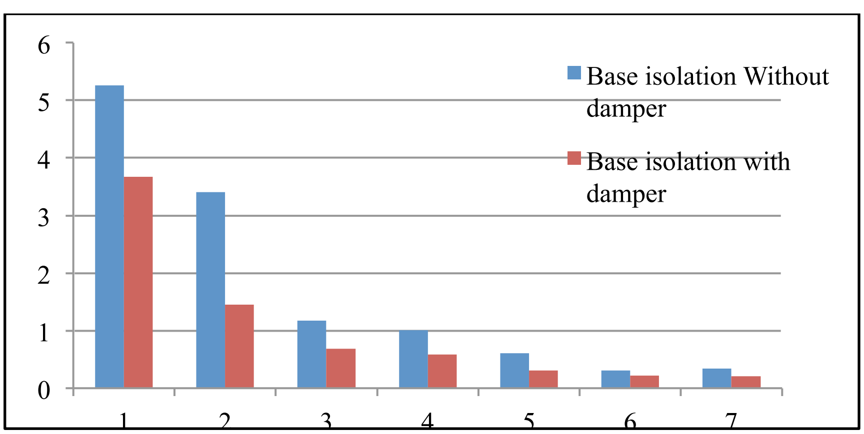


Fig-6.4 Time period for with or without damper of structure

Figure 6.4 shows time period of structure with damper is decreased because energy dissipiatating is increase when we provide viscous damper in structure. Table 6.1 shows time period with different modes for with or without viscous damper system.

Table- 6.1 Time period for with or without damper isolation system

Mode	Base Isolation Without Damper	Base Isolation With Damper
1	5.26242	3.66846
2	3.40398	1.45368
3	1.17057	0.68211
4	1.00511	0.58901
5	0.61136	0.31062
6	0.30721	0.22265
7	0.34281	0.20777

6.3.2 Displacements of Structure

Table 6.2 Floor displacements for with or without damper isolation system

Displacement at floors	Base isolation without damper (m)	Base isolation with damper (m)
1	0.002556	-0.007684
2	0.003966	-0.004990
3	0.006569	-0.002338
4	0.009101	0.0003258
5	0.01160	0.002979
6	0.01406	0.005646
7	0.01650	0.008325
8	0.01894	0.01101

6.3.3 Responses of Structure

Table 6.3 Response of structure of with or without damper isolation system

Kinds of response		**Base isolation without damper**		**Base isolation with damper**	
		Time history		**Time history**	
		LACC	**Newhall**	**LACC**	**Newhall**
Base shear X	Max	9.825	48.42	18.79	52.82
	Min	-11.16	-35.59	-17.09	-44.56
Base shear Y	Max	12.16	36.22	18.74	41.58
	Min	-11.88	-39.20	-15.89	-42.60
Displacement X Top	Max	0.004545	0.01894	0.003478	0.01101
	Min	-0.005375	-0.01987	-0.01126	-0.01231
Displacement Y Top	Max	0.004806	0.01395	0.004180	0.004280
	Min	-0.004527	-0.01604	-0.01737	-0.01025
Acceleration X top	Max	0.09668	0.3069	0.3166	0.3386
	Min	-0.009660	-0.3474	-0.1186	0.3570
Acceleration Y top	Max	0.08400	0.2812	0.3180	0.3188
	Min	0.1181	-0.2690	-0.1014	-0.2918

CHAPTER -7 RESULTS & DISCUSSION

Generally we seen that following results:

1. Friction pendulum isolator is designed to increase the time period of the structure, which helps in reduction of response in the structure subjected to earthquake. Participation of higher modes has been found to decrease as compared to fixed base buildings.
2. Friction pendulum isolator introduces high non-linearity in the structure, hence non-linear time history analysis of three different time histories cases has been performed with different value of coefficient of friction and it is observed that bearing displacement tends to decrease as the coefficient of friction increases but the rate at which it decreases slows down at higher value more than 0.1 and its response also depends on earthquake motion.

3 Acceleration at the top, response of the structure highly depends on earthquake ground motion. Roof acceleration decreases up to a certain isolation damping level and beyond that it increases because of the participation of higher modes.

4. Acceleration at the top, response of the structure also depends on flexibility of the structure. Participation of higher modes has been found to increase as the building flexibility increases.
5. This study indicates that the safety of building is substantially increased with the help of friction pendulum system. Friction pendulum isolator is found to be suitable and economical for medium rise multi-story buildings. It has been concluded that effective damping of friction pendulum isolator should be properly chosen to optimize the performance of the building.

7.1 Comparative Study of Fixed Base & Friction Pendulum Isolator System.

Friction pendulum isolator has proved to be a reliable method of earthquake resistant design. The success of method is largely attributed to the design of isolation devices and proper planning and placing the isolators.

The results of the study show that using friction pendulum isolator can dramatically reduce the response of the structure

1. The base shear in X-direction is reduced by 56.76% & y- direction is reduced by 52.73%in LACC time history, when it is compared to that of fixed base structure
2. The base shear in X-direction is reduced by 63.69 % & Y- direction 46.32 % in Newhall time history, when it is compared to that of fixed base.
3. It is found that the reduction in base shear in X- direction is more in Newhall time history analysis and reduction in Y- direction is more in LACC time history analysis.
4. The reduction in acceleration at roof in X- direction 34.93% & Y- direction is reduced by 60.47% in LACC time history analysis when it is compared to that of fixed base structure.
5. The reduction in acceleration in at roof in X-direction 65.55% & Y -direction is reduced by 42.23% in Newhall time history analysis.
6. The results of the displacement show that the displacements are increased with the time period and with the story height in the friction pendulum system building. The displacement at top is increased by 90.9% in Newhall time history analysis.

7.2 Parametric study of friction pendulum isolator

The lower the coefficient of friction has the better the centering action of the friction pendulum isolator system. However, the higher coefficient of friction is desirable to increase energy dissipation, which reduces dynamic displacement at each floor under ground shaking. But higher value of coefficient of friction increases the propensity to exhilarate higher modes in the base isolated structure due to the sudden change in loading as the velocity reverses direction. The design of the friction pendulum isolator system is always a understanding between the need for low coefficient of friction to minimize residual offset and higher mode excitation, and the need for high coefficient of friction to minimize the displacement at each story.

Result from experimental study we found that the base shear, displacements, acceleration and time period all the results are depends on the coefficient of friction as discussed below-

1. Time period of the structure is reduced with increasing the coefficient of friction.
2. Displacement at top and bottom floor is reduced with increasing the coefficient of friction.
3. Base shear in x direction is increase with coefficient of friction.
4. Base shear in y direction is also increase with coefficient of friction.
5. Acceleration in x direction increase with the coefficient of friction.

7.3 Effect of viscous damper on base isolated structure

As earlier study we found out the displacement is increased due to friction pendulum isolator or base isolation system and in this study it is found 90.9% .so use of viscous damper with friction pendulum isolator displacement at roof is reduced by 41.86%, and also other effects on building as given below

1. Time period of structure is reduced as compared to without damper isolation system.

2. Base shear in X & Y direction is increased as compared to the without damper isolation system.

3. Acceleration at top in Ux & Uy direction is also increased as compared to the without damper isolation system.

4. This results shows that the proposed viscous damper is effective for suppressing the maximum response displacement of the isolated story, with an increase of the response acceleration on the superstructure.

7.4 Response time history of two different time history

In this section we discussed time history response of building for different earthquake. We want to compare response due to earthquakes on structures for verify that higher amplitude earthquake give more structural response than lower amplitude earthquake.

Figure 8.1, 8.2 and 8.3 shows that structural response acceleration, base shear and displacement with the function of time, respectively. It indicates the response in Newhall T.H. is more as compared to LACC Time History case

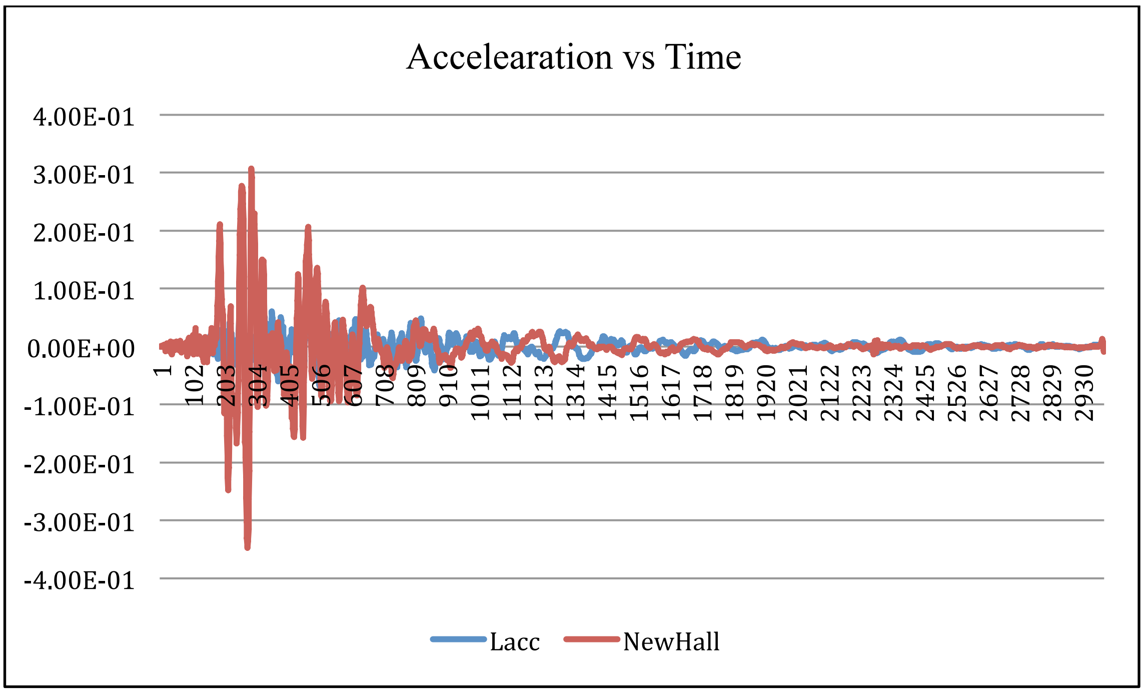


Fig- 8.1Time history analysis for acceleration along friction pendulum isolator in X-direction

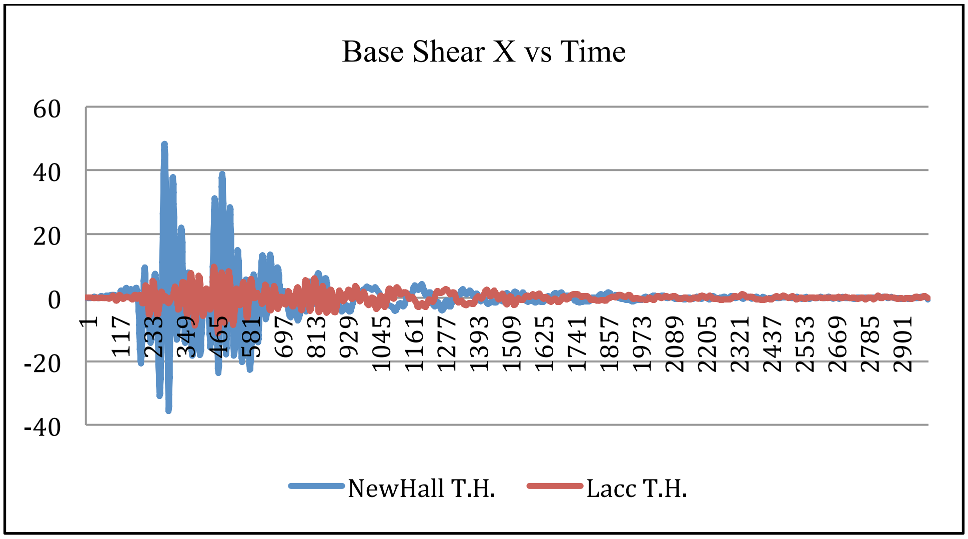


Fig- 8.2 Time history analysis for base shear along friction pendulum isolator in X-direction

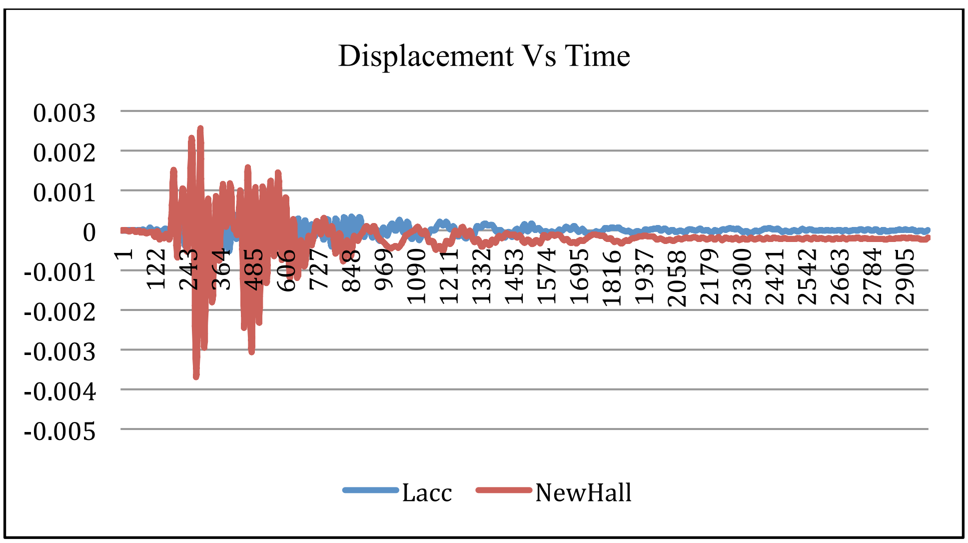


Fig- 8.3time history analysis for displacement along friction pendulum isolator in X-direction

Chapter -8 Conclusion

Friction pendulum system is very promising and effective, alternative technique for medium rise multistory buildings. The Base isolation approach is based on lengthening the time period of the structure. Additional flexibility provided by friction pendulum isolator that is required to increase the time period of the base-isolated building results in large base & top displacements requiring large seismic gap at the isolation level. Amount of damping in isolation structure plays a very salient role in controlling the structural response of the base-isolated building, particularly the base displacement. Large amount of damping is necessary for near earthquake field to control the extravagant displacements but it may allow energy to be transmitted to the superstructure subsequently skeptically affecting the aim of providing human comfort and protecting the parts of the structure. Thus it is obvious that heavily damped seismic base isolator is not solution. In this analytical study, role of isolation damping is studied for medium rise multistory base-isolated buildings in controlling their seismic response under different types of earthquake motions. Reinforced concrete framed buildings are considered for this study. In order to study the effect of earthquake characteristics, 2 real earthquake motions are considered. It is observed that the choice of damping in isolators is crucial as their larger values of coefficient of friction may result in increased forces and accelerations. Optimum value of isolation damping is also dependent upon the characteristics of input base motion and has low value for motions with high frequencies only. Displacement is reduced by the use of viscous damper with friction pendulum system. The cost of an isolation system containing viscous dampers is often less than the cost of a similar isolation system without dampers. The reason for this is that the addition of viscous dampers reduces the dynamic displacement by as much as 41.23% is this study, which greatly reduces the cost and size of the isolator parameters.

REFERENCES

[1] Shirule. P. A, Jagtap. L. P, Sonawane. K. R, Patil. T. D, Jadwanir. N And Sonar. S. K. 'Time History Analysis Of Base Isolated Multi-Storyed Building' International Journel Of Earth Science & Engineering, August 2012, P.P. 809-816.

[2] ATC 40 [1996] Seismic Evaluation And Retrofit Of Concrete Building Vol.1. Applied Technology Council, Seismic Safety Commission, State Of California.

[3] Mario Pazz 'Structural Dynamics Theory And Computation'

[4] A.K.Chopra ' Dynamic Of Structure, t

[5] IS 456-2000 Indian Standard Plain And Reinforced Concrete.

[6] CSI computer And Structure.Inc.Sap 2000. Linear & Non-Linear Static And Dynamic Analysis Of 3d-Structure.

[7] W. F. Chen ' Earthquake Engineering Hand Book'.

[8] IBC 2000 'International Building Code'

[9] Nitish Takalkar 'Seismic Response Of Friction Pendulum Isolated Medium Rise Multistory Buildings' International Journal Of Engineering Science And Technology (IJEST).

[10] Garevski, M. & Jovanovic, M. (2008). "Influence Of Friction Pendulum System On The Response Of Base Isolated Structures". 14th World Conference On Earthquake Engineering, Beijing, China, October 12-17.

[11] T. K. Dutta ' Structural Dynamics'

[12] Saif Hussain, Saif Hussain & Eloy Retamal 'Viscous Damping For Base Isolated Structures'

[13] Nikolay Kravchuk, Ryan Colquhoun, And Ali Porbaha, 'Development Of A Friction Pendulumbearing Base Isolation System For Earthquake Engineering Education'.

[14] D.-G. Lee & H.S. Kim (2001) Efficient Seismic Analysis Of High-Rise Buildings Considering The Basements At Nzsee 2001 Conference Dept. Of Architectural Eng., Sungkyunkwan Univ., Suwon, Korea.

[15] Habib Sadid 'Low-Cost Base Isolation Devices For Residential Buildings'

[16] Sj Thurston 'Base Isolation Of Low Rise Light And Medium-Weight Buildings' 2006.

[17] J. C. Ramallo1; E. A. Johnson, A.M.Asce2; And B. F. Spencer Jr., M.Asce (2002) - ‘‘Smart’’ Base Isolation Systems - 10.1061/~Asce!0733-9399~2002!128:10~1088!

[18] FEMA 273[1907] NEHRP Guidelines for the Seismic rehabilitation of buildings. Report No. FEMA 273, Federal Emergency Management Agency, October.

[19] Leif O. Nielsen, Imad H. Mulla and Yuuichi Iwai ‘Seismic Isolation with a new Friction –Viscoelastic Damping System. 13th World Conference on Earthquake Engineering Vancouver,B.C. , Canada. August 1-6,2004 Paper No. 249.

[20] Mohsen Karaghi and Chukwana G. Ekwukeme ‘Optimization of Viscous Damper Properties for Reduction of Seismic Risk in Concrete Buildings’ 13th World Conference on Earthquake Engineering Vancouver,B.C. , Canada. August 1-6,2004 Paper No. 1027.

[21] Trevor E Kelly, S.E. ‘Base Isolation of Structure Design Guidelines’ Holmes Consulting Group Ltd.

[22] Charalampos Iliadis ‘ Friction-based Control System for Seismic Energy Dissipation with Isolated stories’

[23] Mahmood Sayed- Ahmed ‘Building with Base Isolation Techniques’ AEIC 2012 December 25-27,2012.

[24] Peng-Hsiang, Charng ‘ Base Isolation for Multistorey Building Structures’ Engineering Library TH 1095 C483.

[25] Jenn-Shin Hwang ‘ Seismic Design of structures with Viscous Damper’ international Training Programs for Seismic Design of Building Structures Hosted by National Center for Reserch on Earthquake Engineering Sponsored by Department of International Programs, National Science Coucil.

[26] Christian Bucher ‘Optimal friction pendulum systems for seismic isolation’ proceedings of the 8th international Conference on Structural Dynamics, EURODYN 2011.

APPENDIX-I

1. Mathematical Calculation of Friction Pendulum System

Total vertical load on the isolator = 1750 KN

Fix time period of the building= 0.075(h)^75

= 0.075(21)^75 = .736 sec

Use time separation of 3 is considered for the base isolated structure, that is,

T_D= 3T = 2.21 sec

Let the friction coefficient of the spherical sliding surface of the FPS be 0.05(0.03-1.10) and the assume design horizontal displacement *D* be 20 cm from fig

1. Determine the size of the FPS. The radius of curvature of the spherical sliding surface of the isolator is [FEMA 273].

$$R_{fps} = g\left(\frac{T_D}{2\pi}\right)^2 = 1.21 \text{ m}$$

2. The minimum stiffness of the isolator [FEMA 273]

$$K_{min\ Keff} = \frac{W}{g} \times \left(\frac{2\pi}{T}\right)^2 = 1441 \text{ KN/m}$$

3. But the total stiffness of isolator is depends on the coefficient of friction that is given by [Wai-Fah Chen & Charles Scawthorn] ;

$$\sum K_{eff} = \frac{W_T}{R_{fps}} + \frac{\mu W_T}{D} = 1984\ KN/m$$

μ = friction coefficient = 0.03-1.10, taken μ = 0.05 for Teflon as a lubricating material

4. The effective damping ξ_{eff} provided by the isolator is given by [Wai-Fah Chen & Charles Scawthorn] can be computed as:

$$\xi_{eff} = \frac{2}{\pi}\left(\frac{\mu}{\mu+\frac{D}{R}}\right) = 0.147 = 14.7\%$$

5. Check for design displacement D_D:

$$D_D = \left(\frac{g}{4\pi^2}\right)\left(\frac{S_d T b}{B_D}\right); \qquad S_d = \frac{S_a T_b^2}{4\pi^2}$$

B_D = damping coefficient corresponding to ξ_{eff} = 14.7 % for FPS isolation system. [IBC 2000 table 1623.2.2.1]

Taken B_D = 1.341

D_D =0.163 < .2 m Hence OK

6. Estimate of the vertical displacement[[Wai-Fah Chen & Charles Scawthorn]

$$Бv = \frac{D^2}{2R_{fps}} = 0.0165 \text{ m}$$

Use depth Б=2cm

Use diameter d = 0.45 m for the disk of the FPS (>2D**)**

7. CHECK

$$\frac{{d/_2}^2}{2R_{fps}} = 0.0209\text{m} \geq 0.0165 \text{ m} \qquad \text{(Hence it's O.K.)}$$

Dimensions for the FPS:

Radius of the curvature of the spherical surface, R_{fps}=1.21m

Depth of the disk, Б=2cm

Diamenter of the disk, d=45cm

APPENDIX-II

Time Acceleration history for Newhall for 60 sec, 3000 points at 0.02 sec.

.257	-.644	-1.941	-1.902	-.561	.711	.919	1.493
2.504	-1.622	-6.294	-4.908	-4.176	-6.419	-9.788	-4.763
7.330	19.106	25.132	16.786	-.439	-14.661	-12.107	-2.327
1.406	3.412	5.106	6.896	6.636	15.773	21.282	10.153
-14.787	-21.948	-30.097	-16.381	31.572	42.018	14.470	-9.572
-16.404	-18.085	-10.658	5.970	17.642	12.022	9.638	22.635
23.343	14.255	2.044	-12.136	-32.383	-23.094	10.612	16.291
13.307	6.952	7.144	2.955	6.958	18.148	12.725	-6.271
-21.088	-8.205	11.380	25.121	35.675	35.730	24.298	2.532
-3.534	-9.666	-8.106	-4.431	-5.832	-6.698	.687	3.340
13.276	21.180	4.325	-11.166	-17.412	22.077	57.943	63.659
34.740	7.845	-10.489	-34.489	-49.210	-10.110	27.715	26.935
23.921	10.303	14.627	10.127	9.483	15.346	9.534	-20.383
-46.346	-21.838	29.242	59.227	46.199	33.297	11.091	-44.639
-83.792	-55.202	-6.489	25.258	34.550	59.808	68.835	56.187
44.277	37.711	34.332	3.709	-17.841	-45.608	-53.585	-33.165
-13.406	-7.262	-4.847	8.503	47.456	72.320	70.809	63.153
57.146	68.895	84.665	91.972	68.669	-.112	-30.162	-52.508
-60.062	-60.512	-27.738	41.616	71.391	105.550	87.891	77.014
66.545	49.685	45.569	47.973	46.957	35.114	24.273	5.458
-7.844	-22.110	-41.059	-85.220	-66.545	14.169	71.254	87.803
75.917	59.761	38.563	19.214	19.917	18.186	2.786	-9.097
-11.366	-9.406	-8.161	-23.067	-75.740	-140.786	-187.163	-225.676
-257.810	-285.837	-324.555	-378.141	-444.535	-482.883	-501.775	-457.062
-360.159	-257.415	-170.669	-89.845	-34.001	-25.523	-53.174	-103.528
-141.517	-91.480	7.162	101.605	169.181	127.210	19.946	-93.046

-143.152	-162.499	-185.669	-144.387	22.098	171.977	332.281	487.510
578.193	534.389	466.532	455.018	227.226	-40.962	-245.665	-367.315
-417.960	-327.760	-117.674	64.652	178.597	232.994	251.129	210.228
237.240	208.003	146.295	127.055	109.902	127.717	128.949	127.893
133.579	164.393	204.967	235.248	251.768	228.140	231.398	179.124
93.473	37.009	-99.441	-248.570	-384.773	-471.963	-518.079	-541.569
-530.045	-510.898	-502.880	-490.248	-453.438	-420.925	-406.691	-379.748
-337.628	-284.069	-214.964	-83.938	167.535	461.879	573.862	510.890
477.694	473.484	470.550	488.638	494.311	500.247	520.273	514.590
542.393	523.453	406.380	309.083	175.145	67.482	-23.033	-180.420
-391.088	-506.668	-481.188	-340.430	-92.889	111.735	217.520	241.112
174.762	60.103	-51.709	-186.502	-246.802	-245.154	-229.346	-220.053
-257.440	-311.807	-275.441	-125.506	4.428	89.137	154.460	198.291
210.953	150.802	51.555	-54.975	-159.029	-142.228	-31.246	92.476
185.081	166.913	92.449	45.259	-11.276	-80.347	-125.948	-151.223
-170.191	-183.666	-166.409	-101.082	-10.762	85.032	146.389	183.559
200.062	192.347	176.533	152.692	114.019	74.976	-5.846	-108.578
-120.662	-88.306	-49.521	-13.830	71.627	146.926	175.494	207.172
215.701	210.978	200.388	163.498	70.122	-14.010	-64.501	-98.990
-115.843	-97.621	-61.021	-48.310	-72.605	-128.896	-168.892	-178.579
-160.181	-98.588	-18.362	28.181	15.638	-56.590	-108.524	-118.822
-110.651	-63.564	2.671	40.818	32.432	-4.210	-49.552	-91.454
-127.139	-146.069	-147.272	-134.223	-119.280	-107.277	-84.459	-59.465
-52.493	-42.848	-17.591	-3.987	-7.890	-23.663	-57.994	-100.486
-126.414	-144.694	-139.556	-94.314	-37.696	26.956	96.355	163.282
175.839	160.108	98.119	-15.672	-90.636	-125.500	-128.478	-84.504
-11.704	74.335	122.435	118.647	121.394	126.173	143.146	186.833
223.910	256.618	283.060	292.261	273.750	164.197	51.943	-16.600
-74.344	-139.630	-195.648	-221.463	-217.065	-230.415	-315.127	-308.051
-254.948	-130.609	-21.138	19.824	61.521	77.415	119.373	163.609

212.755	243.607	281.068	310.108	335.618	352.349	367.717	317.375
122.391	-29.856	-120.176	-216.149	-297.806	-350.006	-342.313	-380.902
-318.603	-211.515	-155.826	-93.065	-51.866	-20.455	-2.774	24.016
60.468	101.179	111.771	98.689	63.001	32.371	.998	-25.556
-29.605	-14.686	1.684	2.147	-7.715	-27.932	-47.655	-51.485
-47.953	-49.583	-59.045	-71.803	-74.513	-46.599	-.024	50.224
84.578	94.782	91.427	80.577	71.204	58.807	49.880	54.511
65.399	66.224	52.721	24.737	1.745	-8.155	-3.235	10.290
21.731	23.819	14.927	5.785	7.965	22.919	40.383	52.043
54.746	47.454	30.054	14.539	5.091	4.155	12.505	27.233
40.891	46.515	44.743	40.634	36.142	31.294	29.326	29.483
26.414	16.858	5.304	-8.721	-16.943	-18.788	-13.896	-.909
14.498	22.272	18.937	11.090	1.685	-1.849	-.758	.227
-1.513	-5.920	-12.730	-25.640	-37.542	-41.118	-21.535	7.528
21.110	19.614	1.329	-22.330	-43.482	-52.783	-48.652	-30.635
-10.076	-3.307	-6.431	-22.909	-50.230	-77.852	-105.487	-126.672
-139.120	-146.611	-146.921	-142.306	-121.814	-85.744	-47.233	-19.685
-7.538	-2.926	-5.931	-11.967	-18.769	-18.479	-13.147	-4.791
-.691	.470	1.070	.701	-.660	-1.657	-2.280	-3.220
-2.805	-.798	7.844	16.545	25.992	32.273	35.657	40.066
44.091	43.877	33.884	20.107	10.552	10.145	19.938	39.775
61.471	76.070	82.448	81.403	80.576	80.503	83.580	89.628
97.806	105.798	108.329	95.070	49.289	5.191	-14.500	-21.305
-18.542	-11.329	-3.011	3.052	4.453	-1.155	-8.352	-14.418
-22.111	-30.187	-40.652	-48.946	-53.320	-52.991	-51.282	-51.354
-54.310	-63.539	-72.675	-81.797	-89.018	-86.852	-76.511	-63.369
-53.432	-48.990	-48.490	-46.326	-38.267	-27.099	-13.845	-.171
11.394	18.264	19.640	17.505	12.076	4.896	.236	-.921
.315	.939	1.337	-2.054	-8.932	-15.346	-18.721	-18.548
-15.087	-8.003	-5.973	-3.840	2.640	14.367	29.236	41.231
48.665	50.920	46.058	35.801	26.163	21.099	23.793	31.904

41.655	49.183	52.862	49.029	42.612	34.682	23.495	11.928
.592	-7.228	-13.013	-16.239	-14.151	-4.940	9.572	24.767
38.054	47.059	51.740	49.493	39.681	18.296	-4.428	-21.232
-35.248	-44.448	-46.689	-35.922	-21.345	-10.733	-4.695	-2.364
.725	4.671	8.342	11.245	10.413	8.350	10.427	16.815
24.541	31.903	36.395	36.736	28.904	14.186	-3.535	-19.357
-30.029	-32.541	-25.264	-11.474	2.381	11.724	16.664	16.756
13.925	10.954	7.502	2.678	-4.326	-19.119	-37.006	-47.157
-48.645	-40.997	-24.682	-8.886	2.337	8.013	9.102	8.201
3.822	-8.260	-22.266	-37.075	-49.322	-50.877	-41.172	-28.404
-20.591	-20.875	-26.719	-31.782	-34.965	-32.403	-23.762	-9.881
4.561	16.156	27.918	41.090	54.123	64.041	68.135	63.896
52.227	34.811	12.601	-3.215	-8.292	-5.850	5.130	19.561
29.386	28.154	17.552	-3.106	-23.975	-40.843	-47.581	-39.155
-24.148	-13.005	-7.592	-6.819	-11.141	-10.570	-5.371	2.626
8.010	9.105	4.995	-1.030	-5.124	-5.952	-4.895	.292
7.867	15.113	19.861	21.660	19.575	12.798	6.902	2.337
.339	-1.565	-1.909	-.256	6.018	13.857	17.714	21.925
24.736	24.492	24.105	24.729	25.795	23.851	20.955	15.737
11.914	7.318	-4.965	-18.561	-32.996	-45.311	-48.919	-39.399
-23.042	-8.139	.080	-1.006	-3.933	-3.993	2.956	14.342
24.718	29.637	24.007	5.929	-19.846	-38.173	-47.809	-50.703
-47.587	-42.188	-34.919	-26.273	-14.586	-5.018	1.174	1.906
-4.215	-11.416	-15.609	-14.245	-4.970	11.856	29.533	41.495
44.848	41.663	34.370	25.612	18.130	12.738	9.567	4.951
1.037	-.929	-3.863	-7.049	-11.334	-15.040	-15.736	-12.615
-8.181	-6.580	-8.114	-12.312	-15.123	-12.975	-6.016	2.206
8.788	11.909	8.988	2.144	-4.478	-10.060	-11.420	-5.738
4.985	16.210	27.122	33.361	33.499	27.833	18.185	3.784
-11.524	-23.507	-30.741	-31.196	-26.681	-18.192	-8.666	-.971

1.549	-1.437	-5.759	-10.798	-16.045	-17.431	-16.420	-13.983
-11.524	-11.954	-14.264	-16.052	-16.749	-15.652	-13.261	-11.072
-12.224	-15.902	-14.434	-4.754	10.189	25.919	37.881	42.523
40.168	33.314	21.979	10.833	3.244	-1.516	-.167	6.084
14.168	20.185	21.422	18.660	13.994	7.645	3.409	1.993
4.188	6.922	7.137	6.800	4.053	2.770	2.424	1.559
-2.008	-8.708	-16.735	-21.259	-18.271	-7.896	6.308	17.877
21.958	18.262	12.724	7.765	1.266	-6.924	-13.651	-17.860
-20.479	-17.637	-11.490	-4.553	2.702	6.265	7.098	6.568
2.767	-6.848	-17.427	-26.480	-29.655	-23.805	-12.550	-1.139
8.565	12.362	9.939	6.168	1.756	.918	4.339	10.398
15.996	22.538	27.959	29.165	24.550	16.238	8.842	4.604
7.492	16.369	27.203	33.993	37.463	38.756	38.496	35.976
30.802	22.861	13.435	6.495	1.774	-.349	-2.078	-1.480
-.276	1.631	1.437	-1.003	-4.540	-10.762	-16.994	-22.929
-26.155	-25.938	-21.345	-14.674	-8.991	-5.571	-7.970	-15.496
-24.669	-32.210	-35.301	-34.415	-30.226	-24.333	-17.519	-12.196
-8.725	-6.363	-6.184	-8.025	-8.694	-8.636	-7.594	-8.123
-9.019	-10.736	-10.109	-6.286	-2.128	3.033	6.435	4.975
-3.209	-13.672	-23.493	-28.667	-28.044	-23.798	-17.039	-11.554
-9.029	-8.755	-8.312	-8.532	-10.505	-11.681	-10.985	-8.371
-2.980	2.765	6.939	9.811	10.181	8.778	6.699	6.157
5.399	6.541	9.923	12.616	15.270	16.614	16.746	14.204
9.889	4.423	-1.667	-8.025	-9.575	-9.438	-7.563	-2.778
1.726	6.149	6.798	5.276	1.947	2.162	4.858	10.182
16.062	19.198	15.694	6.279	-2.380	-8.142	-9.509	-7.532
-3.193	.770	2.999	2.916	2.342	3.006	3.319	3.031
3.515	2.002	1.510	3.767	7.740	12.415	16.971	21.408
24.720	24.883	22.133	19.633	16.932	11.705	5.185	-1.926
-10.469	-16.747	-16.976	-12.873	-6.163	.340	3.651	5.956
7.771	9.602	10.269	9.481	6.864	2.374	.044	1.268

5.716	11.845	15.841	18.052	17.414	12.257	5.295	-1.765
-7.348	-9.466	-9.841	-9.993	-10.741	-12.777	-13.627	-12.197
-10.363	-10.700	-13.419	-17.664	-17.878	-14.660	-11.390	-10.148
-11.125	-12.766	-13.719	-12.034	-9.917	-9.116	-9.909	-9.756
-9.198	-7.644	-4.150	.100	4.583	8.049	9.355	9.701
7.158	3.511	-.794	-4.090	-4.155	-2.408	2.205	4.060
1.307	-3.536	-9.870	-13.890	-13.734	-10.195	-3.473	4.037
12.024	17.638	19.830	17.101	9.680	1.390	-6.982	-9.309
-6.933	-1.148	5.840	10.394	12.498	12.710	10.647	8.712
7.438	4.522	1.951	1.513	2.555	4.511	4.096	1.308
1.245	1.693	3.399	2.717	1.944	3.168	5.332	10.193
15.759	19.889	22.006	20.646	19.656	18.618	16.563	12.886
8.350	4.800	3.017	5.887	9.302	11.954	11.414	6.940
.430	-4.317	-9.264	-11.514	-12.069	-10.822	-6.341	-.872
3.013	1.784	-2.544	-9.553	-13.679	-14.614	-13.169	-10.357
-9.670	-9.033	-11.087	-11.435	-10.089	-9.481	-7.348	-6.831
-7.557	-8.988	-9.571	-10.997	-12.284	-13.507	-15.526	-17.390
-17.767	-15.830	-10.118	-5.882	-3.697	-3.414	-7.684	-13.644
-17.180	-16.114	-11.909	-7.762	-6.286	-5.416	-4.431	-3.494
-1.755	-1.547	-2.855	-7.039	-11.239	-12.214	-12.158	-8.934
-4.686	2.029	6.298	10.298	9.895	6.041	1.671	-1.529
-2.039	-.744	3.272	7.921	11.117	11.528	11.468	7.327
3.811	.926	2.063	6.275	11.324	15.287	16.036	12.646
7.622	2.891	-1.087	-1.689	-2.340	.093	3.972	9.382
13.506	17.422	20.207	23.185	25.752	27.124	27.229	25.847
23.470	19.761	16.914	12.754	8.203	2.951	-.190	-3.331
-6.812	-9.612	-10.777	-9.613	-6.521	.121	6.379	10.679
12.889	11.138	8.197	5.818	4.892	3.736	1.960	-.828
-2.431	-4.038	-5.347	-6.884	-8.069	-10.122	-10.791	-11.014
-9.783	-7.229	-4.756	-2.148	-2.963	-4.564	-7.933	-10.621

-13.352	-12.884	-12.953	-12.073	-11.313	-10.313	-8.476	-8.119
-8.384	-10.322	-12.435	-13.804	-13.750	-13.364	-12.101	-11.026
-9.836	-8.364	-6.589	-5.929	-5.823	-6.317	-7.090	-6.915
-6.381	-6.143	-4.227	-1.080	1.800	5.723	6.347	6.618
5.592	3.079	3.079	3.627	5.938	9.295	12.563	14.617
16.250	17.660	17.642	15.513	8.966	2.827	-3.857	-8.538
-9.946	-9.292	-7.727	-6.348	-3.671	-1.268	1.951	5.220
8.212	9.444	10.773	10.623	10.418	10.713	11.300	11.157
11.500	12.091	11.920	10.664	9.160	9.183	8.028	8.865
9.352	9.454	8.382	6.893	5.060	4.608	6.003	5.491
4.579	2.437	-.761	-3.477	-5.831	-7.772	-9.181	-11.137
-13.429	-13.886	-12.141	-9.539	-8.224	-8.344	-10.478	-11.695
-12.005	-10.754	-8.170	-7.073	-5.993	-5.995	-6.278	-5.694
-5.684	-4.892	-4.791	-6.319	-8.322	-11.022	-11.848	-11.286
-9.666	-6.638	-3.782	-3.003	-3.194	-5.809	-9.205	-8.884
-4.989	.222	7.179	11.735	14.701	14.868	12.690	9.797
7.357	6.970	5.831	4.628	2.317	.914	-.086	-1.830
-1.712	-3.260	-4.640	-4.626	-3.777	-2.339	-1.210	-.072
-1.695	-2.415	-4.274	-4.493	-4.158	-3.153	-2.614	-4.735
-7.267	-9.962	-10.705	-10.532	-10.865	-8.891	-7.675	-5.065
-2.842	-1.475	-.005	1.569	3.630	5.022	7.910	8.158
8.115	7.900	7.644	7.631	7.123	6.929	5.536	4.749
5.097	6.988	9.795	11.766	12.100	10.245	7.248	2.221
-1.657	-4.835	-5.482	-3.329	.340	3.278	5.788	6.682
4.774	2.746	.622	-.379	-2.258	-3.476	-3.506	-4.645
-4.824	-4.986	-5.824	-7.663	-8.716	-7.743	-5.202	-.552
3.513	9.655	14.020	14.914	14.331	10.679	6.707	2.802
.621	1.522	5.011	7.053	8.701	8.638	7.290	5.782
3.996	4.332	3.527	4.561	4.401	4.139	4.564	2.454
1.601	1.466	1.425	2.908	5.057	6.383	6.598	4.318
-.205	-2.166	-4.811	-5.411	-5.885	-5.777	-4.229	-5.272

-3.832	-3.576	-.624	1.824	2.838	3.361	2.984	3.367
3.273	3.490	3.760	4.432	4.163	4.114	4.060	2.320
.473	-1.885	-5.778	-8.010	-9.905	-11.587	-12.151	-13.752
-13.197	-10.694	-7.672	-6.190	-5.919	-6.530	-7.428	-6.431
-5.794	-3.843	-3.346	-5.827	-7.225	-7.508	-8.703	-8.674
-7.134	-5.607	-4.758	-3.282	-1.855	-.211	.556	.978
.265	-.957	.483	2.446	5.018	6.996	7.764	7.502
6.267	4.130	3.467	3.584	4.039	2.930	.692	-1.638
-4.247	-6.120	-5.003	-1.927	.802	1.919	.839	-2.059
-3.883	-6.174	-6.520	-6.573	-6.996	-5.837	-5.344	-4.216
-4.156	-3.845	-3.732	-4.334	-3.791	-1.368	.581	2.309
3.185	2.631	1.872	2.689	3.864	3.829	4.224	3.680
4.088	3.546	3.482	5.080	6.786	9.764	10.417	11.404
10.085	8.941	8.216	5.404	3.685	1.880	.566	-.611
-.221	-1.152	-1.122	-.343	.446	1.136	2.056	2.596
1.818	1.729	2.051	3.279	2.510	2.780	1.452	.823
.969	2.040	3.292	.845	-1.618	-3.741	-6.413	-7.198
-6.861	-4.601	-2.547	-3.423	-6.266	-9.923	-12.394	-13.699
-11.996	-8.348	-3.631	-1.347	-.278	.713	-.538	-3.578
-5.971	-7.220	-7.243	-6.116	-5.179	-5.236	-5.216	-7.215
-8.884	-8.939	-7.989	-6.562	-6.730	-5.461	-2.528	.049
2.725	3.953	4.003	3.280	1.753	1.050	1.986	4.105
6.764	9.570	11.328	11.932	10.847	8.588	7.022	8.520
8.519	10.324	12.414	14.365	15.949	14.554	12.953	10.472
8.020	6.623	6.583	6.568	6.547	6.633	6.655	6.610
6.647	6.798	8.816	9.263	8.990	6.531	3.053	-.168
-1.010	-.697	-1.009	-.506	-2.368	-3.748	-4.821	-5.600
-4.218	-2.345	-1.513	-1.960	-3.501	-4.175	-4.959	-3.868
-1.962	-1.520	-1.352	-2.073	-2.073	-3.972	-4.289	-5.380
-7.243	-6.803	-6.103	-5.882	-5.334	-4.894	-4.405	-3.494

-4.253	-2.503	-.961	-1.562	-2.605	-4.091	-6.330	-6.125
-4.094	.022	5.310	9.350	9.680	5.035	.039	-3.300
-1.740	1.678	4.912	5.544	2.216	-2.415	-4.392	-3.503
-1.386	-.732	-.574	-1.242	-2.401	-.822	1.104	1.981
1.760	1.717	-.270	-.733	-1.327	-.525	1.197	3.241
4.378	3.492	1.715	-1.479	-2.581	-3.243	-1.576	-.570
-.712	-.002	-.771	-.895	-.627	.078	1.206	.331
-.604	-1.077	-2.726	-3.752	-5.788	-6.425	-7.135	-6.523
-4.955	-1.937	.838	1.737	2.977	3.650	4.173	3.912
4.172	3.898	4.183	1.548	-.373	-2.331	-3.307	-3.256
-2.315	-1.239	-1.027	1.105	1.383	1.075	-.358	-2.048
-5.093	-6.191	-6.298	-5.451	-3.766	-3.095	-2.814	-2.560
-3.880	-6.323	-8.425	-9.181	-7.509	-5.866	-4.040	-3.671
-3.496	-3.849	-4.811	-4.017	-1.759	-1.133	-.624	-2.200
-3.671	-3.296	-3.733	-2.045	-.940	.903	2.014	1.513
.738	-.825	-2.087	-3.566	-3.211	-1.331	-1.607	-.251
1.058	2.458	4.052	5.008	5.863	6.136	6.936	7.003
7.700	8.013	9.005	9.040	7.463	5.956	4.032	2.548
1.870	2.921	3.418	3.635	3.904	4.278	6.543	6.860
7.149	4.126	.183	-2.031	-3.193	-.912	1.319	1.872
1.153	1.508	2.021	3.013	3.863	3.312	2.368	1.762
.442	-1.346	-.284	-.333	-.039	1.043	1.003	1.585
1.942	2.623	3.792	3.881	3.967	3.450	2.129	.435
-.356	-.396	-.704	-.640	-.514	-.250	-.184	1.073
.731	1.191	1.678	3.196	3.831	3.142	2.734	1.451
1.878	.816	-.201	-1.815	-3.621	-2.866	-1.914	-.511
.649	-.012	-.481	-1.762	-3.625	-5.142	-6.697	-7.164
-6.428	-5.071	-5.072	-4.821	-3.902	-3.686	-2.296	-1.410
-.905	.410	.080	.661	1.332	2.136	2.432	2.164
1.349	.341	1.060	.033	-.683	-1.713	-2.593	-2.762
-2.310	-.801	1.331	2.578	2.653	3.894	3.678	1.471

-.027	-2.309	-4.859	-3.454	-2.128	1.196	3.888	3.343
2.701	3.426	4.298	1.417	2.800	2.776	1.280	1.208
1.280	.426	-.217	-.487	-1.194	-2.369	-4.102	-5.084
-5.123	-4.648	-6.527	-6.962	-6.266	-5.669	-4.070	-3.562
-3.679	-4.163	-6.056	-4.843	-5.052	-4.788	-2.895	-2.565
-1.912	-1.728	-1.863	-2.379	-2.014	-1.466	-3.312	-4.918
-6.937	-7.486	-6.522	-6.543	-5.034	-2.728	-2.309	-2.636
-2.526	-2.444	-1.904	-1.353	-1.278	1.205	3.398	4.195
5.297	5.421	6.118	5.473	3.909	2.705	2.740	3.615
4.042	4.157	5.015	4.280	1.914	.994	1.302	2.631
4.455	5.533	6.148	7.222	7.832	7.981	6.381	3.595
1.778	.016	-.302	-.089	-.736	-1.866	-2.392	-1.621
-1.392	-1.346	-2.706	-4.188	-6.032	-8.723	-11.128	-11.552
-3.816	11.954	29.674	42.676	43.968	20.912	-12.065	-32.713
-40.408	-28.900	2.624	26.392	29.080	14.336	-8.817	-24.929
-26.164	-15.760	-2.775	5.906	6.086	3.349	3.873	5.836
7.767	8.842	6.198	.507	-5.135	-7.982	-9.021	-6.852
-2.984	-.065	.971	.789	-.696	-2.817	-5.926	-6.441
-5.710	-2.378	2.234	5.230	5.985	3.467	-.032	-1.653
-1.075	-.007	2.220	1.202	-1.158	-4.313	-3.741	-.261
4.555	7.210	5.940	1.203	-3.700	-4.595	-3.786	-.902
1.587	3.220	2.366	.713	-1.323	-2.243	-2.087	-.856
-.714	-2.068	-1.522	-.561	2.894	5.517	6.682	6.451
2.233	-1.983	-3.749	-3.808	-2.086	1.100	3.934	5.847
7.014	8.029	7.445	5.622	4.566	2.981	2.116	.784
.369	1.597	2.205	3.989	4.242	3.628	2.015	-.157
-1.790	-3.511	-4.553	-3.529	-2.066	1.840	4.333	4.748
4.658	3.211	1.323	-.868	-.255	-.562	.929	1.691
1.567	2.081	3.004	1.337	-1.074	-3.050	-5.434	-5.939
-6.849	-5.844	-3.438	-2.593	-1.926	-1.458	-.863	.983

1.388	2.178	2.589	1.157	-1.377	-3.631	-5.312	-5.948
-5.962	-6.523	-7.339	-6.667	-6.205	-5.398	-3.265	-2.071
-.846	-1.175	.051	-.276	-.647	-1.569	-2.883	-3.470
-3.360	-3.491	-2.251	-.792	-.943	-1.314	-3.293	-4.260
-5.754	-5.490	-5.532	-3.999	-2.646	-1.046	1.424	2.801
4.329	4.284	3.961	4.832	6.674	8.273	9.466	9.784
9.263	8.110	6.134	3.380	1.793	1.629	1.370	2.020
4.230	4.187	5.192	5.569	5.114	6.313	5.475	4.838
3.822	3.007	1.257	-.151	.927	.957	1.804	1.834
2.786	2.523	1.615	1.689	1.295	.632	-.950	-.069
-.183	.323	.532	-.617	-1.778	-2.867	-2.139	-1.438
-1.538	-.557	-.361	-1.409	-1.883	-2.844	-4.340	-6.122
-6.389	-6.434	-6.356	-6.838	-7.427	-6.897	-6.278	-7.307
-7.078	-6.708	-6.443	-6.267	-6.520	-6.125	-5.835	-6.535
-5.975	-5.497	-4.940	-3.693	-4.124	-4.095	-4.627	-3.954
-1.423	1.525	3.096	4.327	4.754	4.056	4.037	4.811
4.798	4.026	3.772	3.470	4.297	3.981	3.692	2.364
1.186	.092	-.171	1.550	3.289	4.442	4.953	3.918
2.076	1.843	1.248	.464	-1.495	-1.844	-1.582	.645
3.876	6.003	6.752	6.831	6.478	5.545	5.586	4.605
3.819	3.609	1.030	-1.046	-2.209	-1.765	-.058	.400
1.931	2.627	2.908	2.377	1.565	.722	.604	.785
.380	.817	.941	.765	.700	-1.205	-2.070	-3.257
-6.062	-7.148	-7.306	-6.509	-5.640	-4.780	-3.267	-1.649
-1.269	-.539	-.454	-1.614	-2.727	-3.613	-4.628	-4.035
-2.713	-1.796	-.619	-1.359	-1.462	-1.958	-2.365	-.741
.207	2.005	3.057	3.432	1.739	.117	.006	.089
1.993	2.440	1.983	.361	-1.199	-1.786	-.243	.662
1.792	2.305	2.222	2.283	2.227	2.769	3.426	3.294
3.049	3.268	3.174	3.098	2.656	4.040	3.345	2.220
2.142	1.942	2.031	2.354	2.083	2.033	1.897	.912

-1.531	-2.665	-2.079	-2.848	-1.698	-1.381	-2.371	-2.900
-3.063	-1.308	.079	-.400	-.258	-1.013	-2.200	-2.785
-3.172	-3.440	-4.498	-3.704	-3.508	-3.759	-4.234	-5.452
-6.566	-8.218	-8.984	-9.240	-8.915	-6.587	-3.391	1.464
5.804	7.083	7.028	5.605	2.443	-.488	-1.712	-1.755
.539	2.457	3.313	4.722	4.083	3.346	2.646	-.045
-1.609	-1.809	-.056	3.340	7.566	9.692	10.326	9.219
5.989	3.252	1.370	.895	.599	1.095	2.459	3.413
3.137	3.602	2.559	.045	-1.331	-2.220	-1.806	-1.536
-.465	.461	-.178	-2.228	-3.852	-4.247	-4.836	-5.701
-5.683	-5.778	-6.233	-5.201	-4.460	-3.701	-3.999	-4.038
-4.103	-4.541	-4.119	-3.484	-3.911	-2.692	-1.725	-1.514
-1.199	-2.278	-3.126	-4.020	-4.881	-4.074	-2.225	-1.311
-.618	-.159	.724	1.114	.913	.580	.757	-.349
-.447	.448	.800	.621	.355	.464	.391	.806
1.733	3.087	2.562	2.168	1.240	.652	1.041	1.824
2.252	2.806	3.436	2.280	1.329	.166	.998	3.450
6.438	8.588	6.448	1.832	-2.252	-3.094	-.163	4.536
7.821	7.102	3.947	2.027	2.229	3.868	3.875	2.858
.777	-1.264	-.799	1.847	3.985	3.536	.491	-1.614
-1.429	1.631	4.547	6.516	5.190	.846	-1.556	-2.480
-1.152	-.232	-1.327	-2.332	-2.755	-2.937	-2.142	-2.644
-2.415	-2.136	-2.462	-2.028	-1.967	-2.442	-1.266	-.242
.799	2.274	1.870	1.055	-.308	-.681	-.024	.037
1.285	1.612	.671	-.671	-1.911	-1.495	-1.587	-1.834
-2.400	-2.837	-2.247	-2.444	-.944	.003	1.104	2.207
2.758	3.112	2.842	2.628	1.854	.812	-.927	-2.793
-4.787	-4.178	-3.491	-3.428	-2.113	-1.543	-1.469	-1.506
-1.129	.387	1.962	3.257	3.038	2.831	1.225	.013
-.762	-.655	.778	1.084	1.039	.217	-.816	-1.309

-1.107	-.953	-.909	-1.843	-1.971	-1.160	-1.045	-.610
-1.520	-.985	-.464	-.976	.054	-.073	-.010	-.345
-.978	-1.618	-1.675	-1.139	-.228	-.562	-1.174	-.877
-1.094	-.864	.362	1.039	.959	.813	-.856	-.507
-.749	-.703	.420	.555	.769	.047	.613	-.309
-1.182	-1.836	-1.230	.693	1.270	4.137	5.841	4.084
2.708	1.845	-.711	-2.803	-1.193	.544	1.468	1.713
.951	2.670	1.910	-1.197	-1.783	-.407	.617	.803
1.240	1.504	.065	-.280	-.159	-1.042	-1.224	-1.492
-.230	-.736	.068	.879	1.360	1.850	1.396	1.601
2.021	2.149	.456	-.867	-.326	.211	1.581	2.720
1.470	1.241	.856	1.406	2.642	3.803	4.326	4.356
4.036	2.220	-.243	-3.886	-5.997	-7.281	-9.537	-13.339
-18.684	-24.208	-29.745	-27.043	-16.139	5.819	32.014	42.883