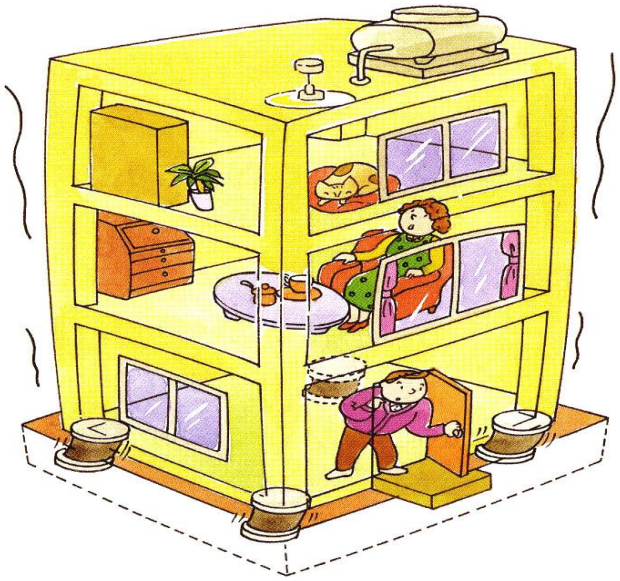
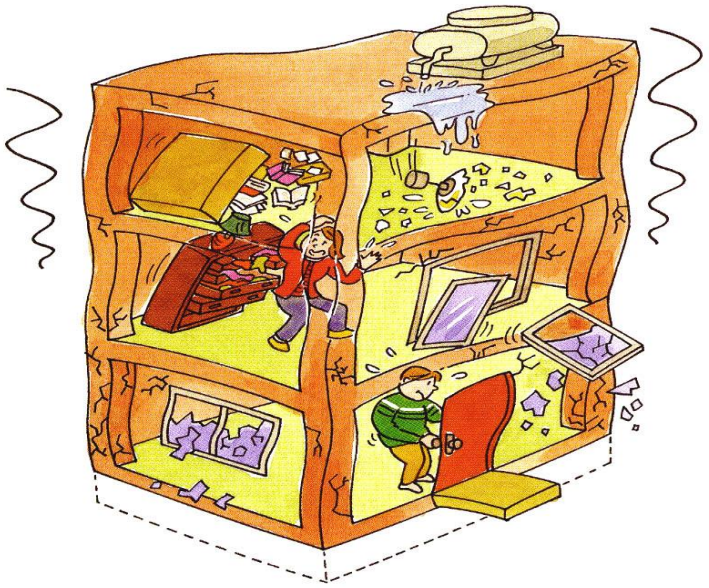


Building with Seismic Isolation



Common Building

Experimental & Analytical Evaluation of Base Isolated Building Structure

Smt. S. R. Patel Engineering College, Dabhi, Unjha

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Principal, SRPEC

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Mr. Varshil Parikh,
Multimedia Consultants Pvt. Ltd.

- ***Presented By:-***

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Contents:

- *Basics of Earthquake*
- *Causes of Earthquake*
- *Effects of Earthquake*
- *Earthquake Protection System*
- *Base Isolation*
- *Objectives of Base Isolation System*
- *Application of Base Isolation System*
- *Base Isolators*
- *Friction Pendulum System*

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- *Types of FP bearings*
- *Models of DCFP bearings parts of DCFP bearings*
- *Models of building structure*
- *Analysis of isolation system*
- *Analytical simulation*
- *Experimental setup*
- *Other Equipments for setup*
- *Modelling of building with FPS in SAP2000*
- *Behavior of DCFP bearing*
- *Conclusion*
- *Patent Report*
- *Work plan*
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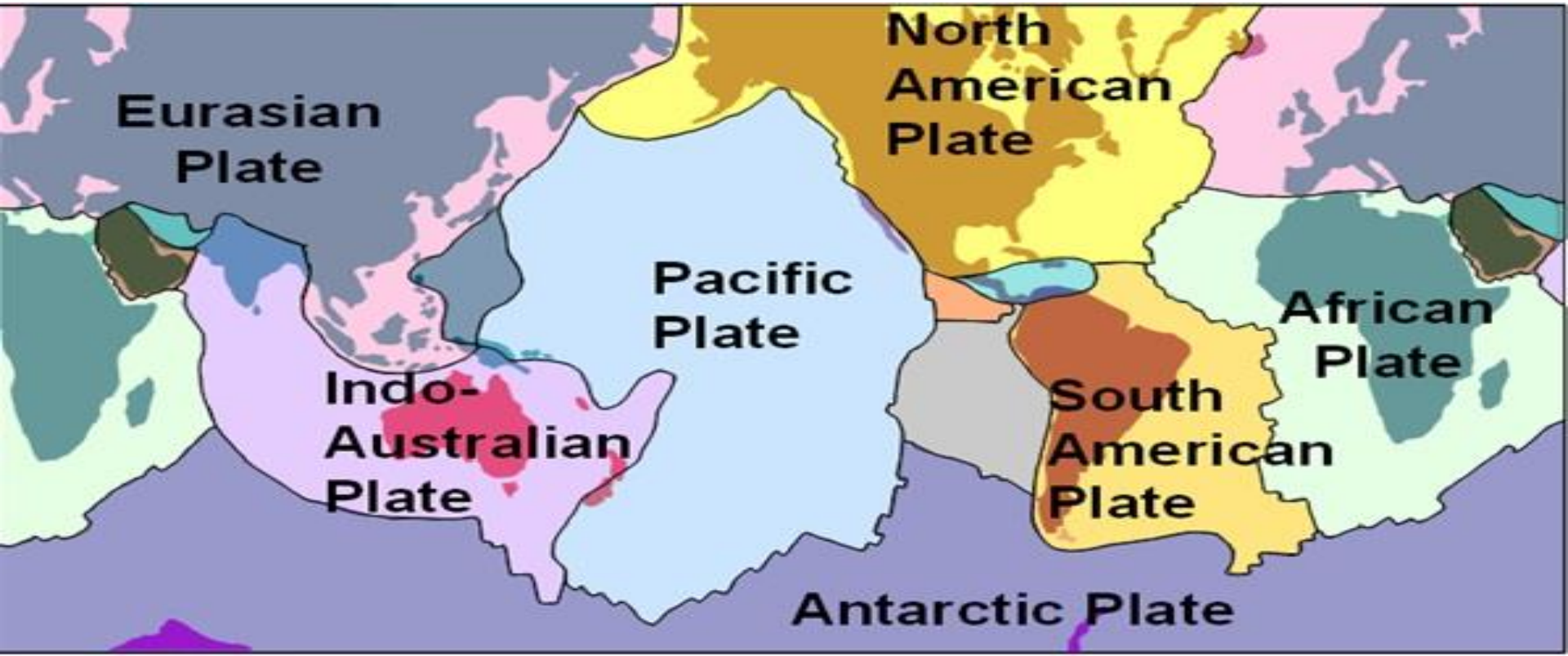
Basics of Earthquake

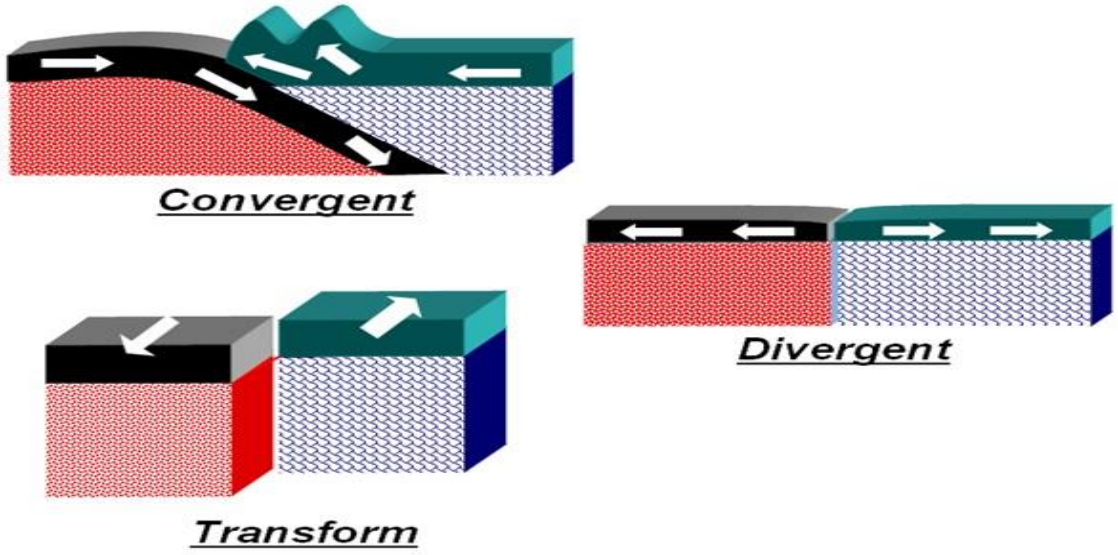
- **Definition:**

  Momentary shaking of the ground or vibrations or oscillations of the ground caused by the slip or by volcanic or magnetic activity or other sudden stress changes in the earth are called earthquake.

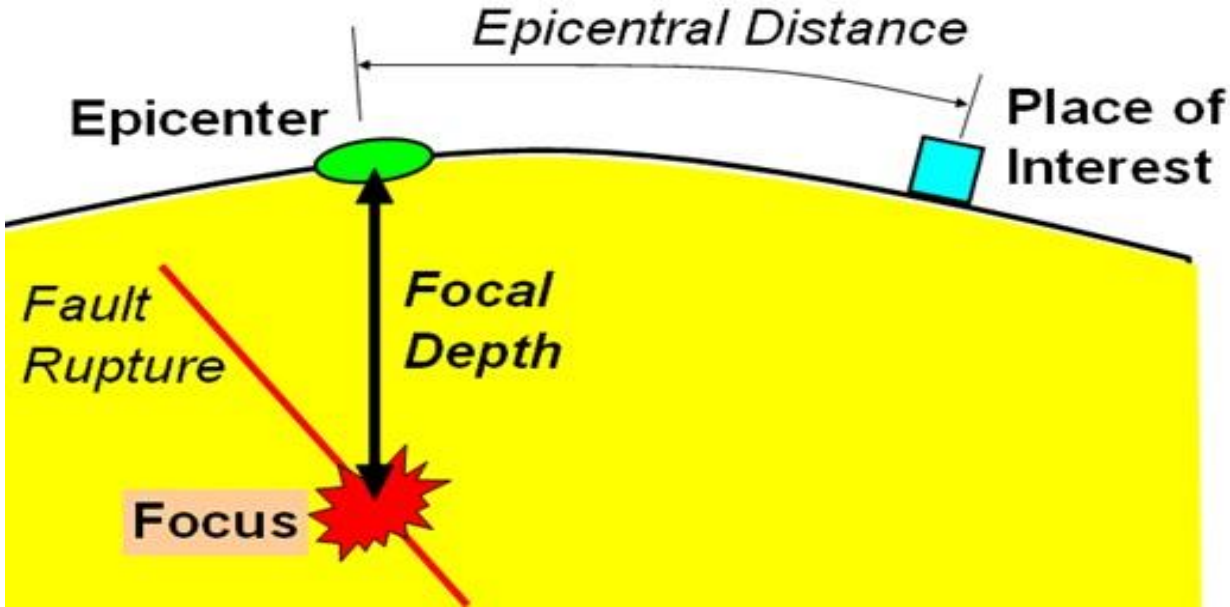
- **Plate Tectonics:**



- **Inter-Plate Boundries:**



- **Terminology:**



Causes of Earthquake:

Natural Sources

- Tectonic Earthquakes
- Volcanics Earthquakes
- Plutonic Earthquakes
- Land Slides
- Collapse of cavity

Man-made Sources

- Controlled Sources
- Reservoir induced earthquake
- Mining induced earthquake
- Cultural noise (Industry, traffic, etc)

Types of Earthquake Waves

- Seismic waves are generated by the release of energy during an earthquake. They travel through the earth like waves travel through water.
- Two types of seismic waves are generated at the earthquake focus:

  1. Body waves

  2. Surface waves

- **Body waves** spread outward from the focus in all directions.

Types of Body Waves:

- **Primary Wave (P wave):**

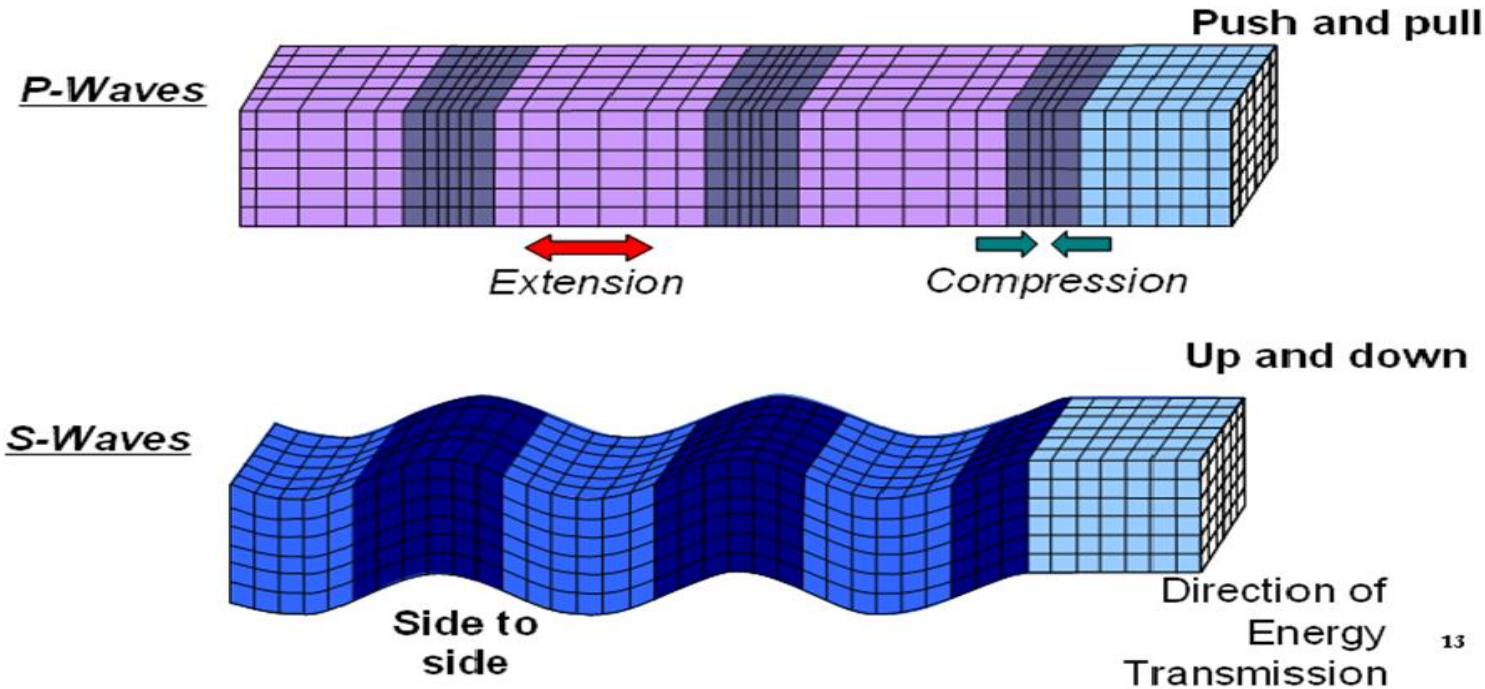
  Compressional wave (travels in the same direction the waves move).

  - Very fast (4-7 km/second)
  - Can pass through a fluid (gas or liquid)
  - Arrives at recording station first

- **Secondary Wave (S wave):**

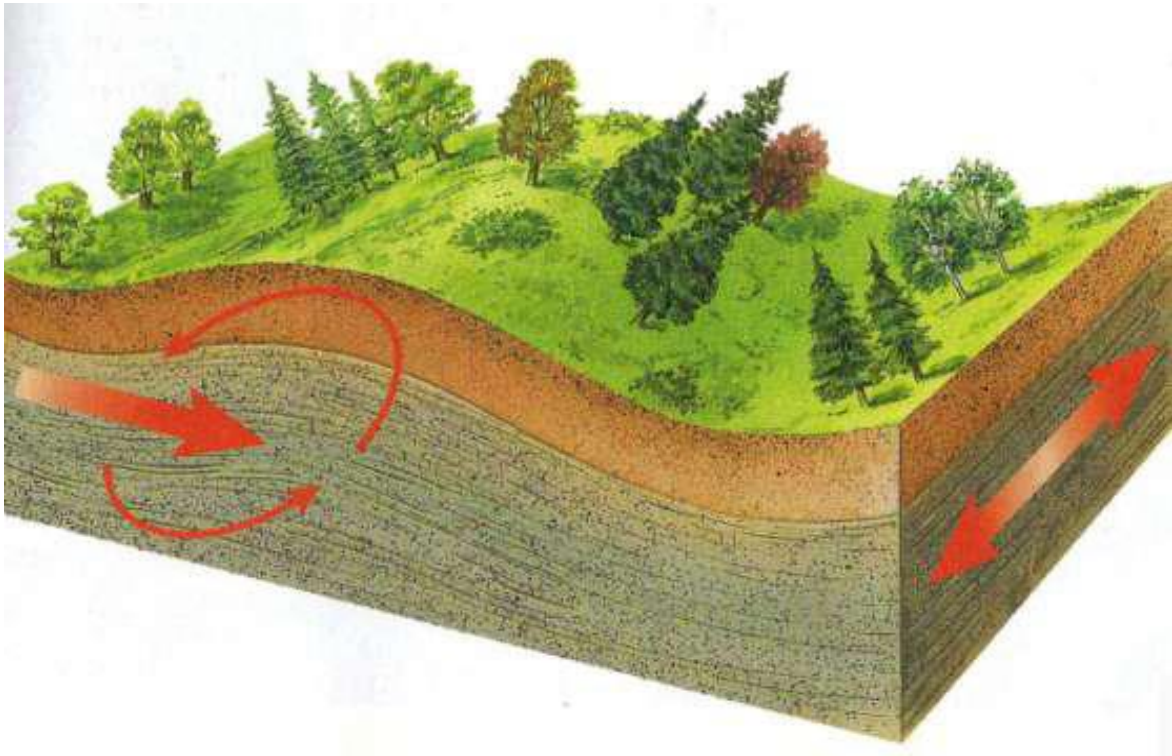
  Transverse wave (travels perpendicular to the wave movement).

  - Slower moving (2-5 km/second)
  - Caused by a shearing motion
  - Cannot pass through a fluid (gas or liquid)



Surface Waves:

- **Surfaces waves** are produced when earthquake energy reaches the Earth's surface.
- Surface waves moves rock particles in a rolling and swaying motion, so that the earth moves in different directions.
- These are the slowest moving waves, but are the most destructive for structures on earth
- Types of Surface Waves:
  - **-Rayleigh Waves**
  - **-Love Waves**



❑*Rayleigh waves:*

- This waves makes a material particle oscillate in an elliptic path in the vertical plane with horizontal motion along the direction of energy transmission.
- These waves are similar to waves produced when rock is thrown in a pond.

❑*Love waves:*

- In this wave particle motion is in horizontal plane and transverse to the direction of wave propagation.
- These waves generally tend to create shearing or breaking ruptures.

Effects of earthquake

- **Primary Effects:** Effects realated with origin of earthquake are known as Primary Effects.

✓ Change in topography

✓ Formation of new hills

✓ Change in direction of existing water course

✓ Formation of new water course

✓ Wrapping of strata

✓ Formation of sand dyke

✓ Change in under ground water level

- **Secondary Effects:** Effects caused due to passage of seismic waves and are associated with ground shaking.

✓ Destruction of human lives

✓ Destruction of multistoried buildings

✓ Destruction of dams and bridges

✓ Landslides and mudslides

✓ Uprooting of trees

✓ Psychological effect on human beings

✓ Worst effect on communication system

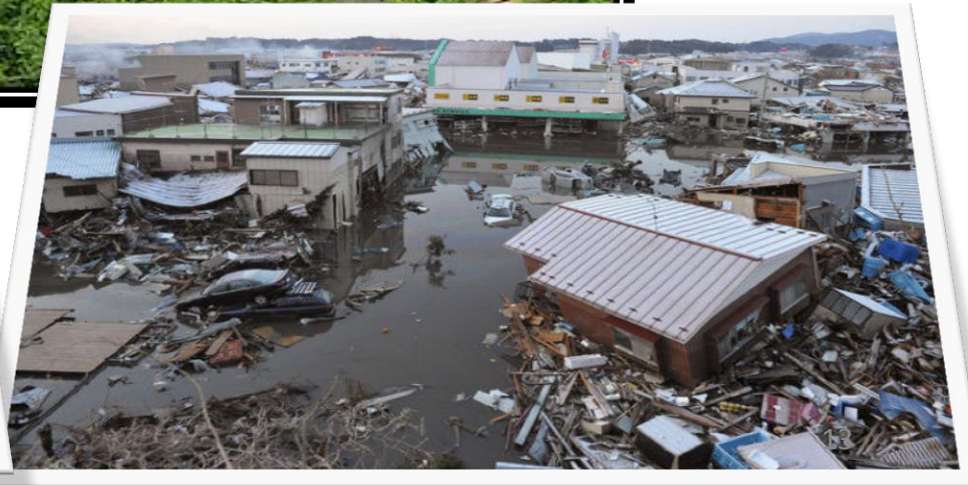
✓ Damage to roads and railway lines

✓ Destruction of telephone or T.V. tower

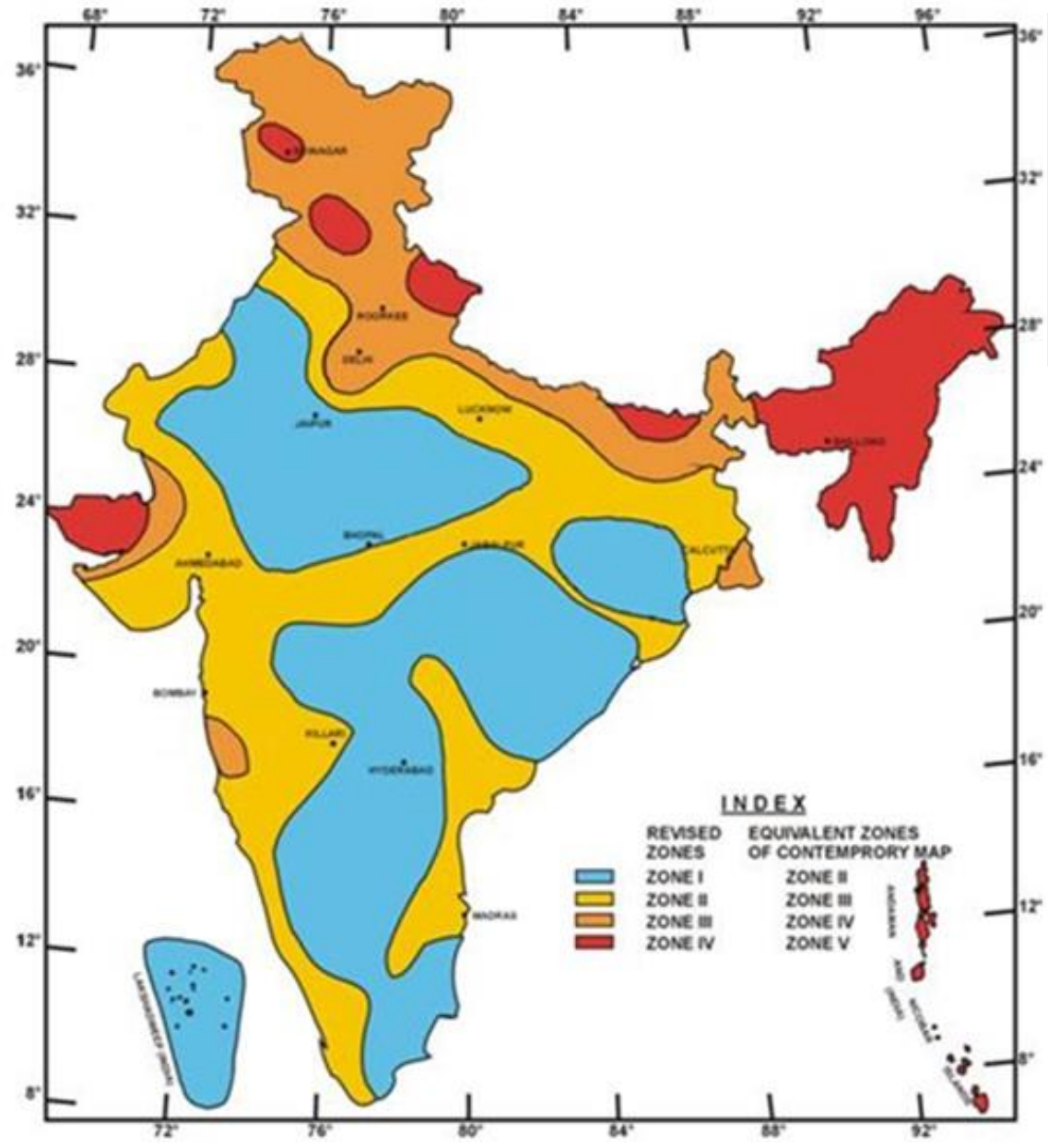
✓ Huge waves in the sea **(tsunamis)**

✓ Liquefaction of soil and sinking of structures

✓ Fire by damaging gas lines



Seismic Zone Map of India



About **59 percent** of land area of India is liable to seismic hazard damage

Structural Control for reducing earthquake effect

- The dynamic interation between the structure and earthquake ground motion can be modified in order to minimize structural damage and to control structural response. The structural response control system are also known as **Earthquake Protection System**.

Passive Systems	*Active Systems*	*Hybrid Systems*
• Base Isolation • Energy Dissipation • Tuned Mass Damping	• Active Mass Damping • Active Bracing • Active Control	• Active Isolation • Semi-active Isolation • Semi-active Mass Isolation

- **Passive Control System:** It includes base isolation, mechanical dissipators, tuned mass damping etc. This systems have significant applications to buildings, bridges and industrial plants.

- **Active Control System:** In this systems mechanical devices are incorporated into the building, which actively participate in the dynamic behavior of the building in response to the measurements of its behavior during the earthquake ground motion.

- **Hybrid Control System:**

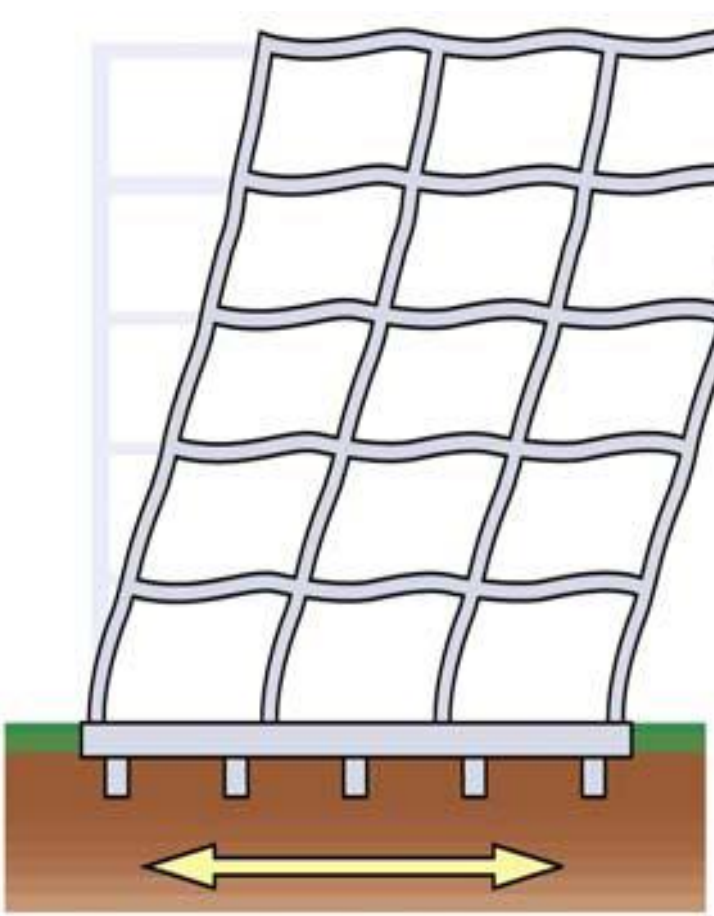
- Hybrid systems are systems implying the combined use of passive and active control systems. For example, A base isolated building is equipped with actuators, which actively control the enhancement of its performances.
- It requires less power as compared to active control systems for modifying mechanical properties of the system.

Base Isolation

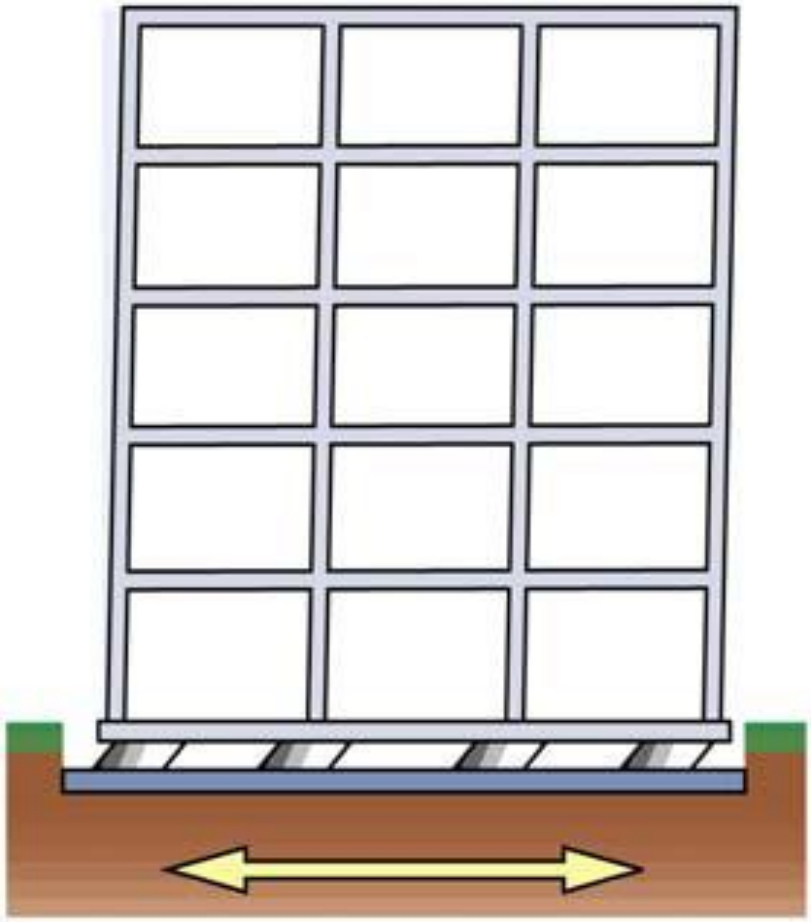
- It is a technique of controlling structural response in which the building or structure is ***decoupled*** *from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and its foundation.*

- The concept of base isolation is **most effective for low-rise**, relatively **stiff(rigid) buildings** located on hard grounds and with large mass. *It is not suited for use in high rise buildings because of large overturning moments.*

Behavior of building structure with Base Isolation system



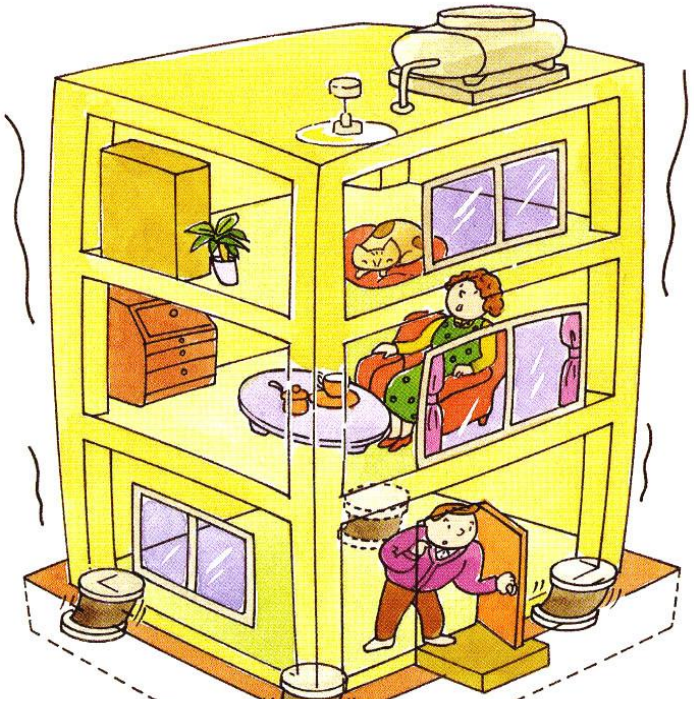
Conventional Structure



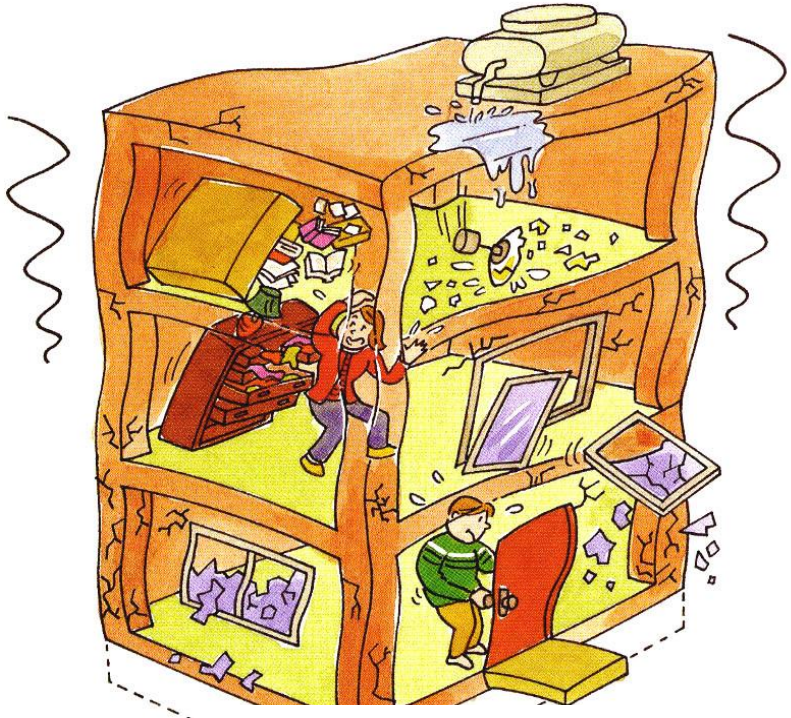
Base-Isolated Structure

Effects of Base Isolation System

- Improvement for Safety of Building
- Keep for Function of Building
- Preservation for Property



Building with Seismic Isolation



Conventional Building

Building with Seismic Isolation

Common Building

Objectives of Seismic Isolation System

- Minimizing interruption of use of facility

  (*e.g., Immediate Occupancy Performance Level)*
- Reducing damaging deformations in structural and nonstructural components
- Reducing acceleration response to minimize contentsrelated damage
- Lowering down the displacement

Application of Base-isolated Structure

1）Government and Municipal Office,
Fire Station, Police Station,
Broadcasting Station

2）**Hospital**, Social welfare facilities

3）Laboratory

4）Computer Center

5）**Museum**, Gallery, Library

6）Apartment House

7）Cultural Asset, Historic Structure

8) **Airports**

Base Isolators

- The various devices using in base isolation systems are known as **Seismic Base Isolators**.
- ***Seismic Base Isolators Types:***

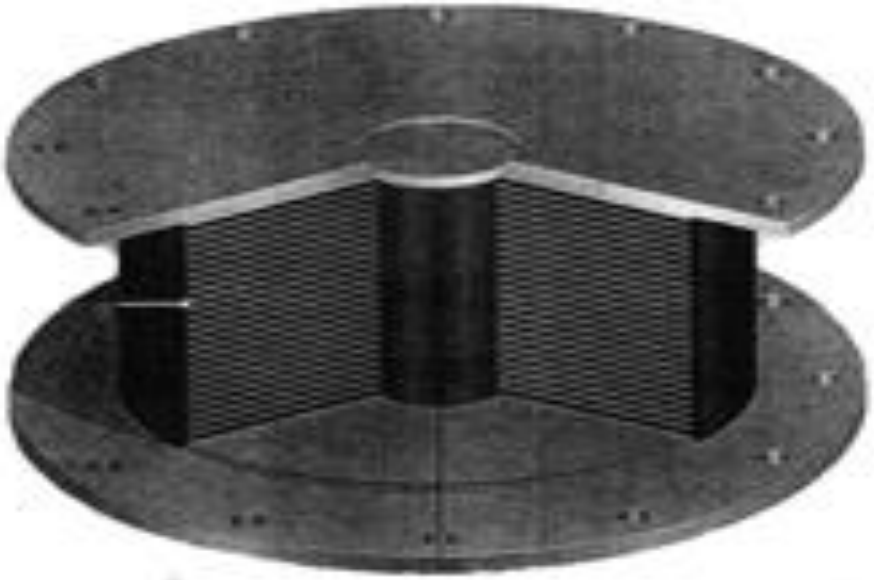
❖ **Elastomeric Bearings**

- Laminated Rubber Bearing
- Lead Rubber Bearing

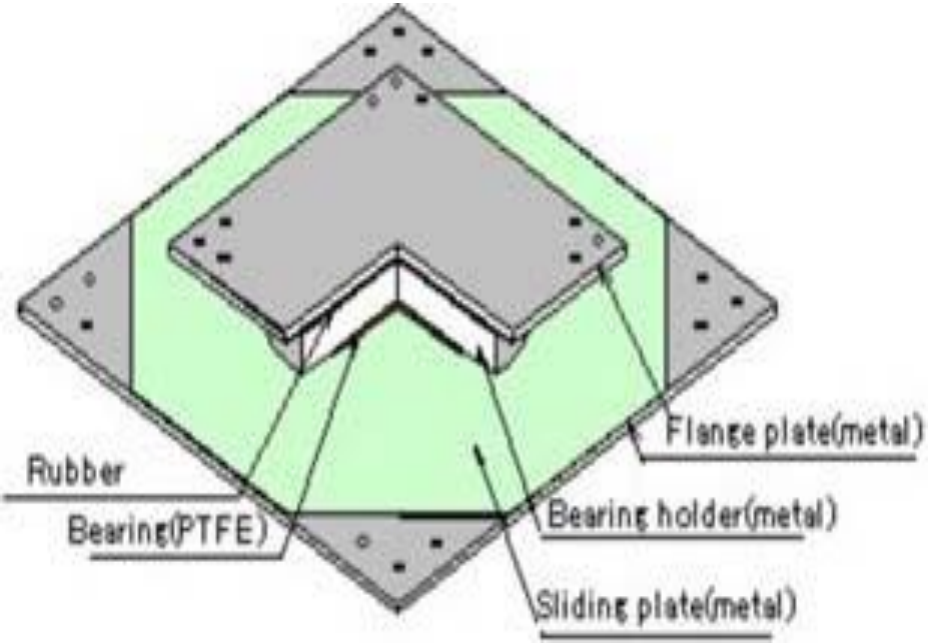
❖ **Sliding Bearings**

- Flat Sliding Bearing
- Spherical Sliding Bearing (Friction Pendulum System)

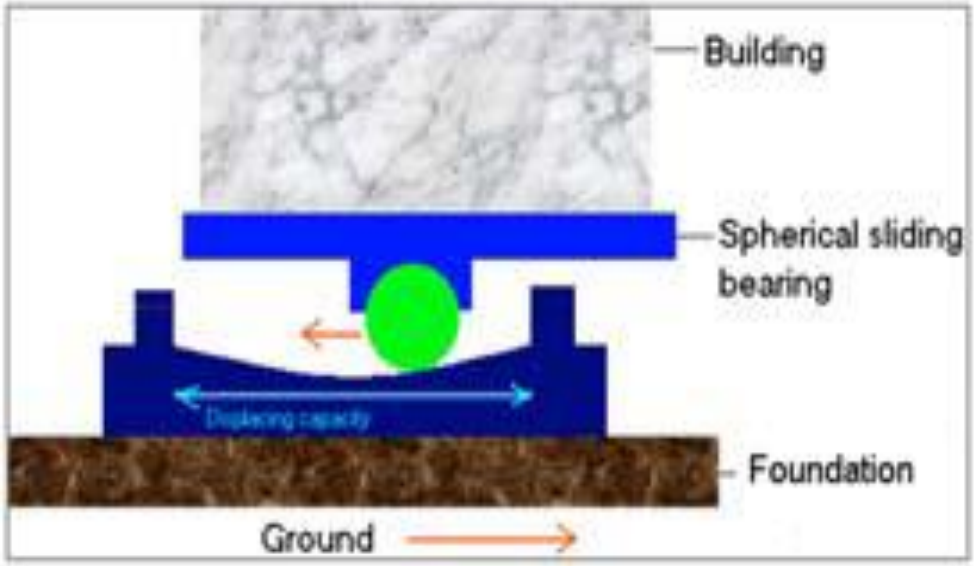
Laminated Rubber Bearing



Lead Rubber Bearing



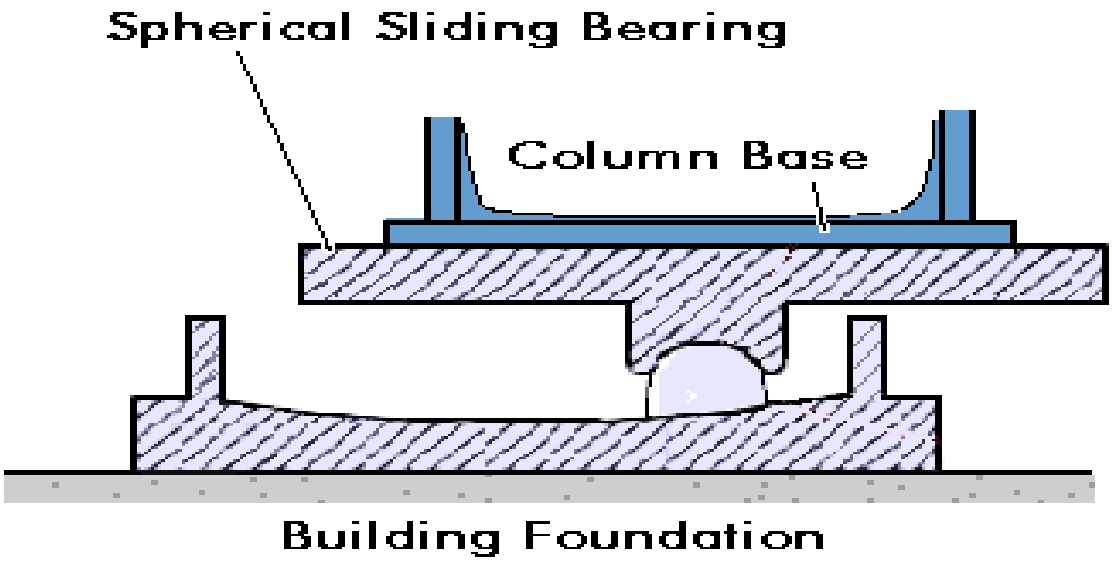
Flat Sliding Bearing

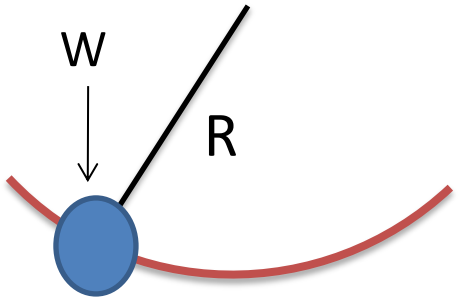


Spherical Sliding Bearing (FPS)

Friction Pendulum System Concept:

- Friction Pendulum Bearings work on the same principle as a simple pendulum. When activated during an earthquake, the articulated slider moves along the concave surface causing the structure to move in small simple harmonic motions, as illustrated in following fig.
- The friction pendulum bearing provides strength and stability.





- The Friction Pendulum Bearing is a seismic isolation system, with a mechanism based on its concave geometry and surface friction properties.

- The supported structure is administered into a pendulum motion as the housing plate simultaneously glides on the concave dish and dissipates hysteretic energy via friction.

- Seismic isolation bearings are structural joints that are installed between a structure and its foundation support columns.

- The purpose is to minimize damage caused by large lateral displacements observed during earthquakes.

Advantages of FPS

- F.P. systems can accommodate much larger levels of displacements than rubber bearings.
- F.P. systems offer more space efficiency (and are shorter) than rubber bearings with the same displacement capacity.
- By increasing the sliding period, the base shear is reduced and displacements are increased.
- Offer very predictable performance (particularly over rubber bearings).
- The isolator period is independent of the mass of the supported structure.

First Implementation of Seismic Isolation

- **FoFirst Implementation of Seismic Isolationothill Community Law and Justice Center, Rancho Cucamonga, CA**

- Application to *new building in 1985*
- 12 miles from San Andreas fault
- Four stories + basement + penthouse
- Steel braced frame
- Weight = 29,300 kips
- 98 High damping **elastomeric bearings**
- 2 sec fundamental lateral period
- 0.1 sec vertical period
- +/- 16 inches displacement capacity
- Damping ratio = 10 to 20% (dependent on shear strain)

BHUJ HOSPITAL COMPLETED WITH EARTHQUAKE RESISTANT HOSPITAL 1st in INDIA

- The 300-bed Bhuj hospital replaces the building that claimed 176 lives when it collapsed during the major January 2001 Gujarat earthquake. This is the first new building in India to be fitted with the earthquake resistant NZ developed base-isolation technology using rubber bearing.
- The hospital's base isolation design and bearings have been provided with the assistance of Earthquake Engineering NZ members.

Examples of Friction Pendulum Systems

Seismic Isolation of San Francisco Airport International Terminal

Pasadena City Hall, California

Friction Pendulum Bearings

SINGLE-PENDULUM BEARINGS:

- The single concave friction pendulum bearing is the original Friction Pendulum System described by Zayas et al. [1987] and represents the first manufactured sliding-bearing to make use of the pendulum concept.

- This bearing consists of an articulated slider resting on a concave spherical surface. The slider is coated with a woven PTFE (polytetrafluoroethylene) composite liner, and the spherical surface is overlain by polished stainless steel.

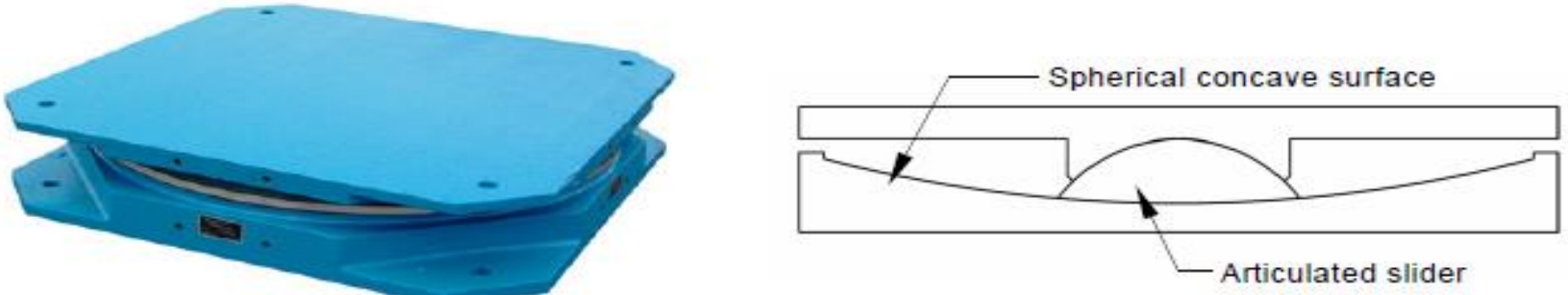


Figure 1: Photo (left) and section (right) of a typical FP bearing

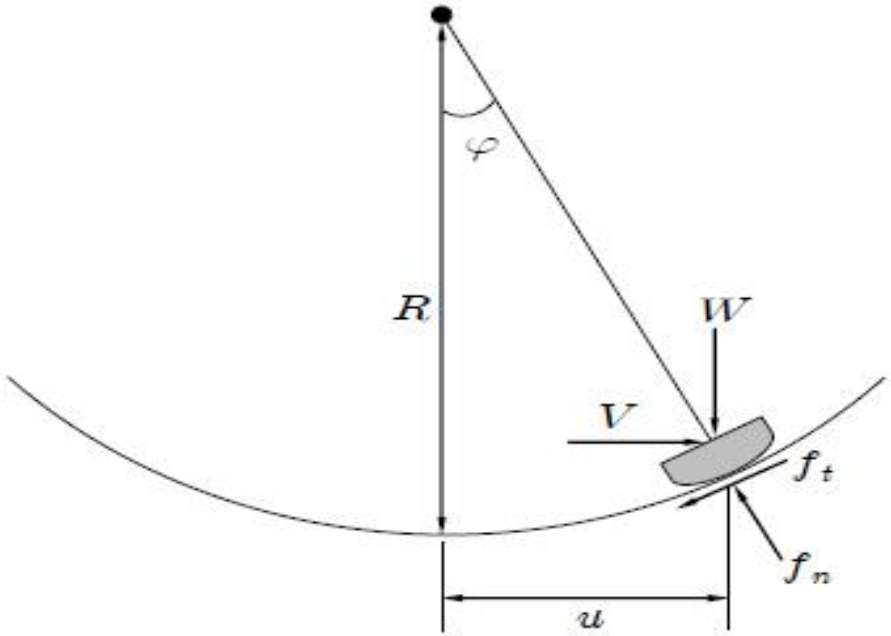


Figure 2: Idealized equilibrium of slider in displaced configuration

DOUBLE PENDULUM BEARING

- Recent developments in the design and manufacturing of FP bearings have centered on the use of multiple pendulum mechanisms.
- Whereas the single concave FP bearing has two key parameters that characterize cyclic behavior (*R and μ), a multi-stage FP bearing has greater* design flexibility because the pendulum length and friction coefficient are specific for each independent pendulum mechanism.
- In the case of a double-concave FP bearing, shown below in Figure, the parameters characterizing the cyclic behavior are (*R1, μ1) for one concave* sliding interface, (*R2, μ2) for the other, and* (*h1,h2) for the kinematic relation between the* position of the two sliding surfaces.
- The behavior of the double pendulum (DP) bearing has been described by Fenz and Constantinou [2006].

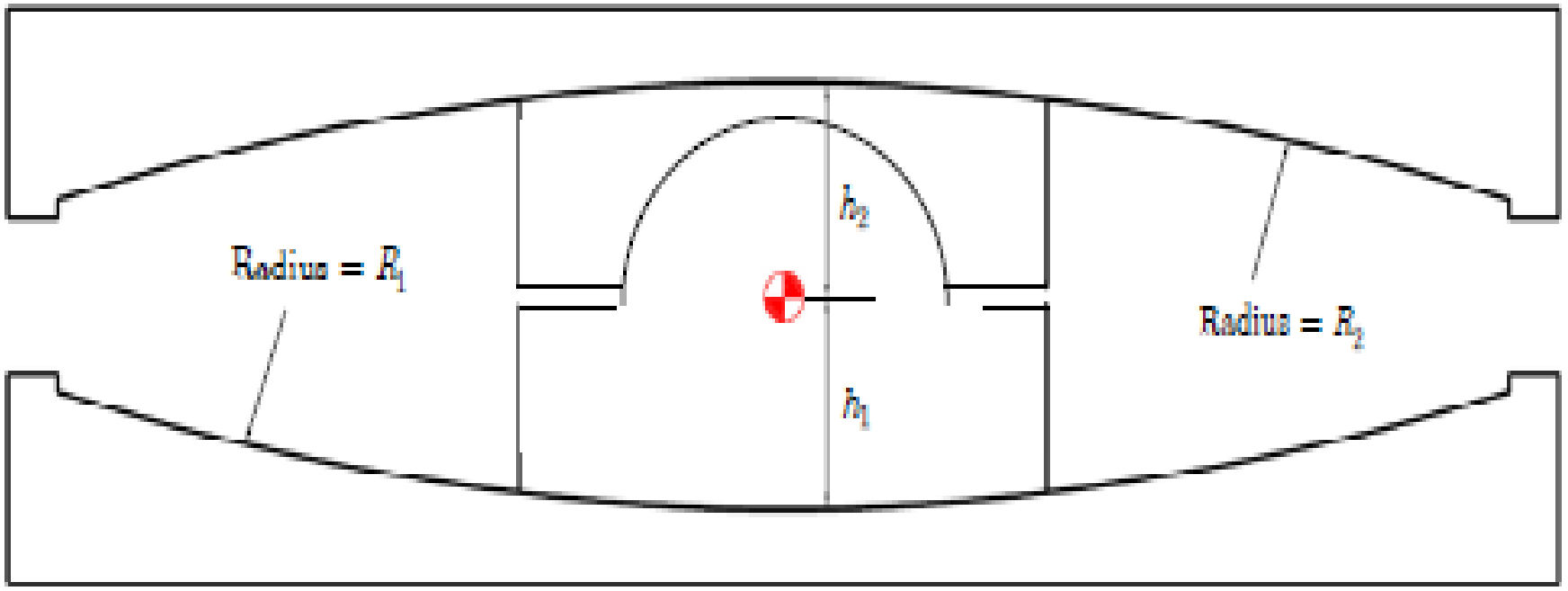
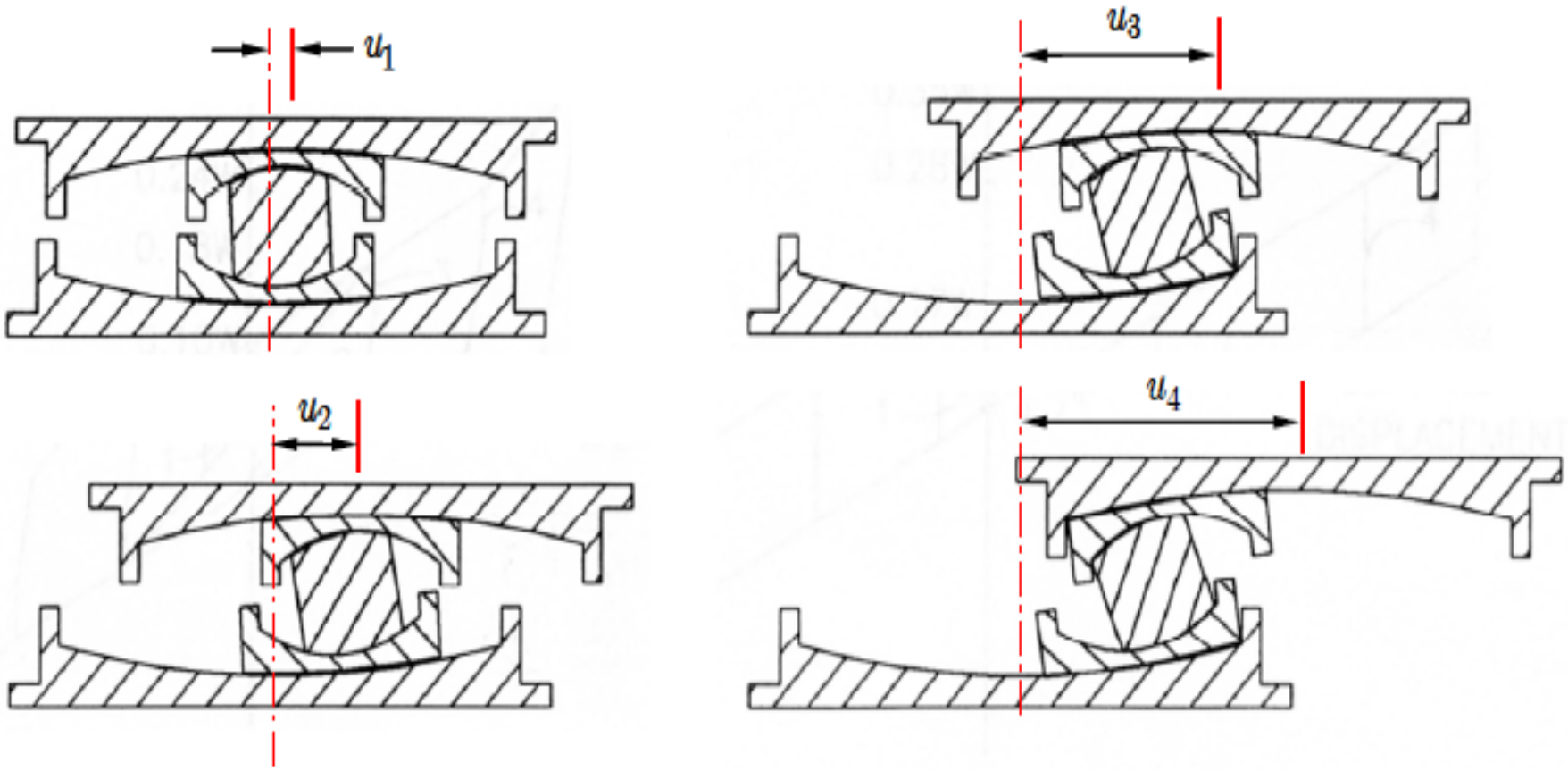


Figure 3 : Section through a typical DP bearing

TRIPLE PENDULUM BEARINGS

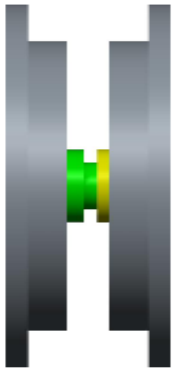
- The triple pendulum bearing introduced by EPS, Inc., consists of **four concave surfaces** and **three independent pendulum mechanisms**. The outer slider consists of concave surfaces on either side of a cylindrical inner slider with a low-friction interface on both ends.
- The outer slider also consists of sliding interfaces between top and bottom outer sliders and the major spherical surfaces of the bearing. The bottom sliding surface is in contact with a spherical surface of a particular radius of curvature, forming the second pendulum mechanism.
- A schematic description of each sliding mechanism as the TP bearing is subjected to increasing displacement demand in shown in next figure. In that figure, the **friction coefficient on the lower major spherical surface is less than the friction coefficient on the upper major spherical surface.**

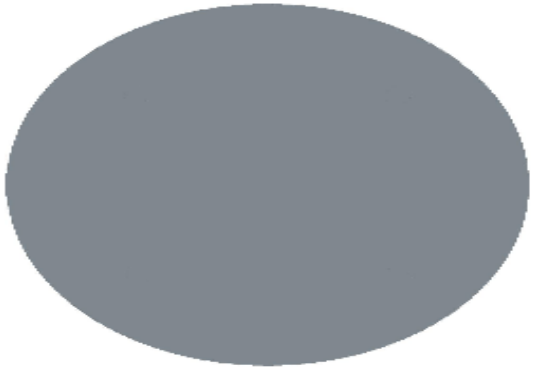


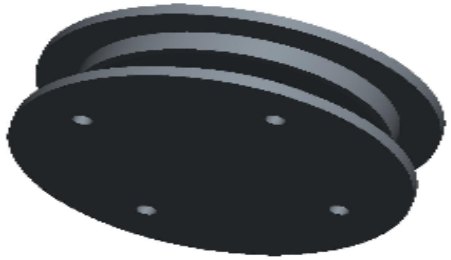
Schematic description of sliding mechanisms for TP bearing, where $u_1 < u_2 < u_3 < u_4$ (adapted from figure courtesy of EPS, Inc.)

Models of Double Concave FP bearing

DCFP Model (1)

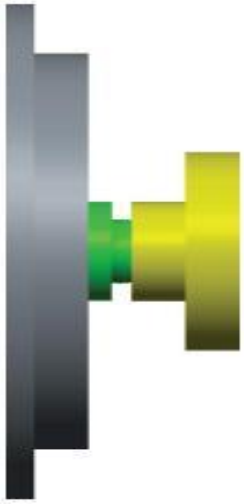


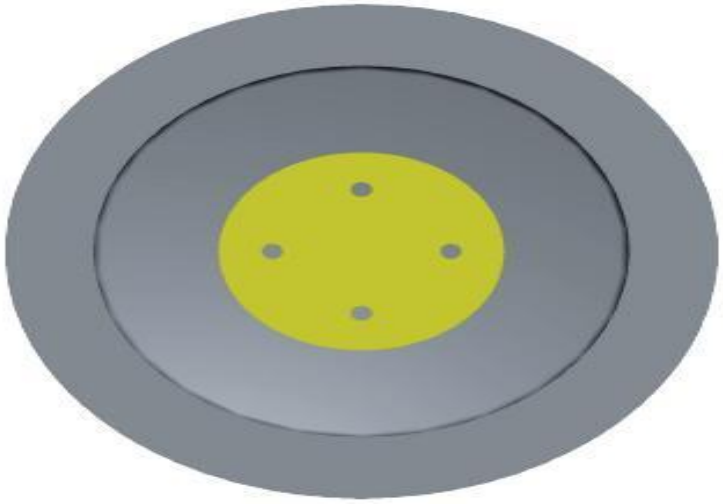


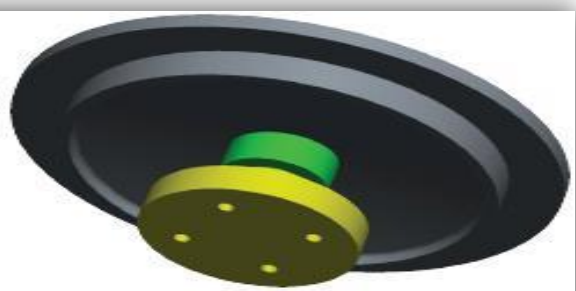


Bearing

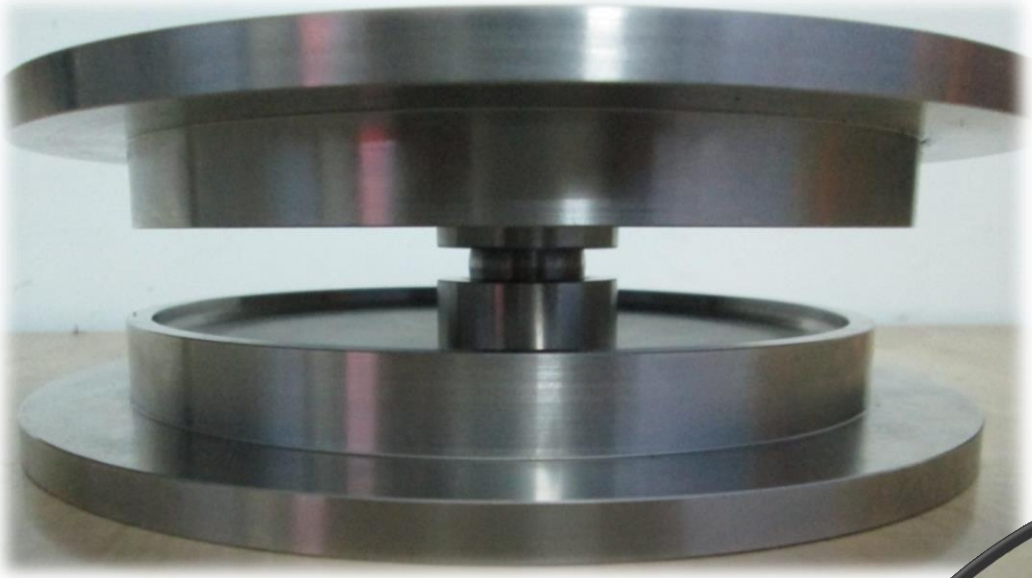
DCFP Model (2)

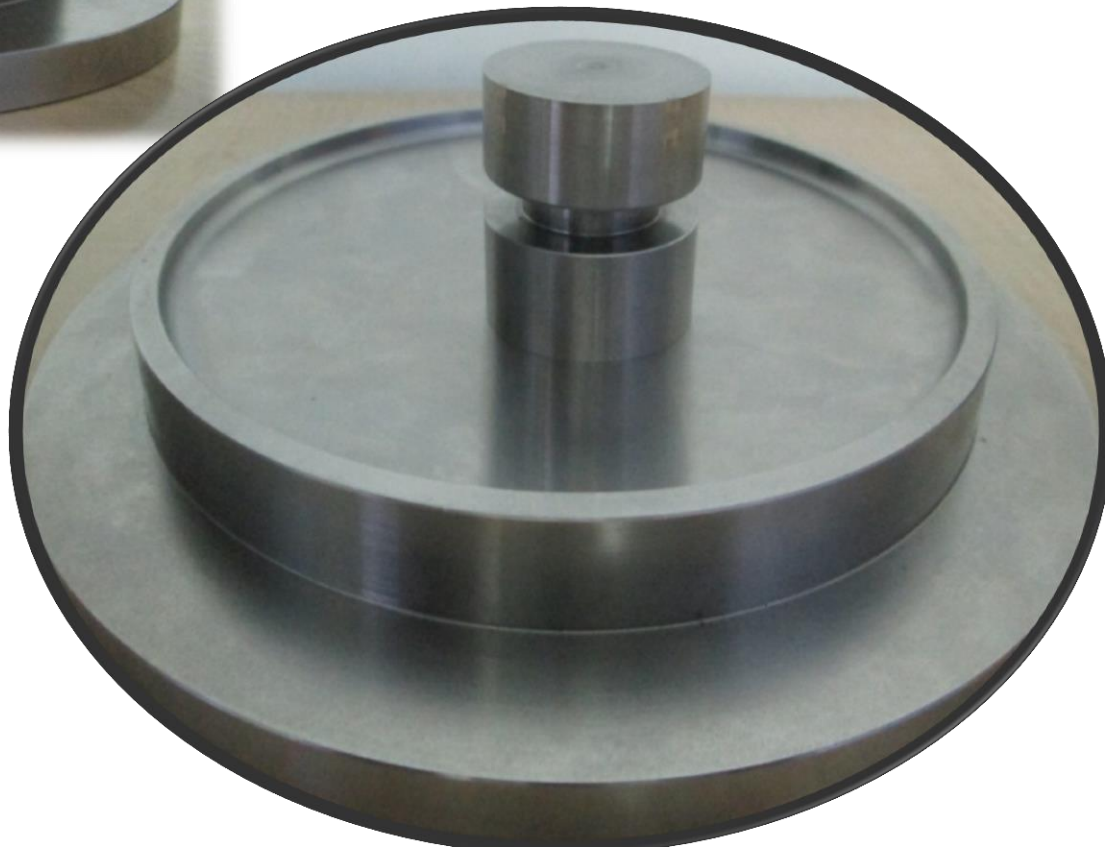






Actual Images of DCFP:

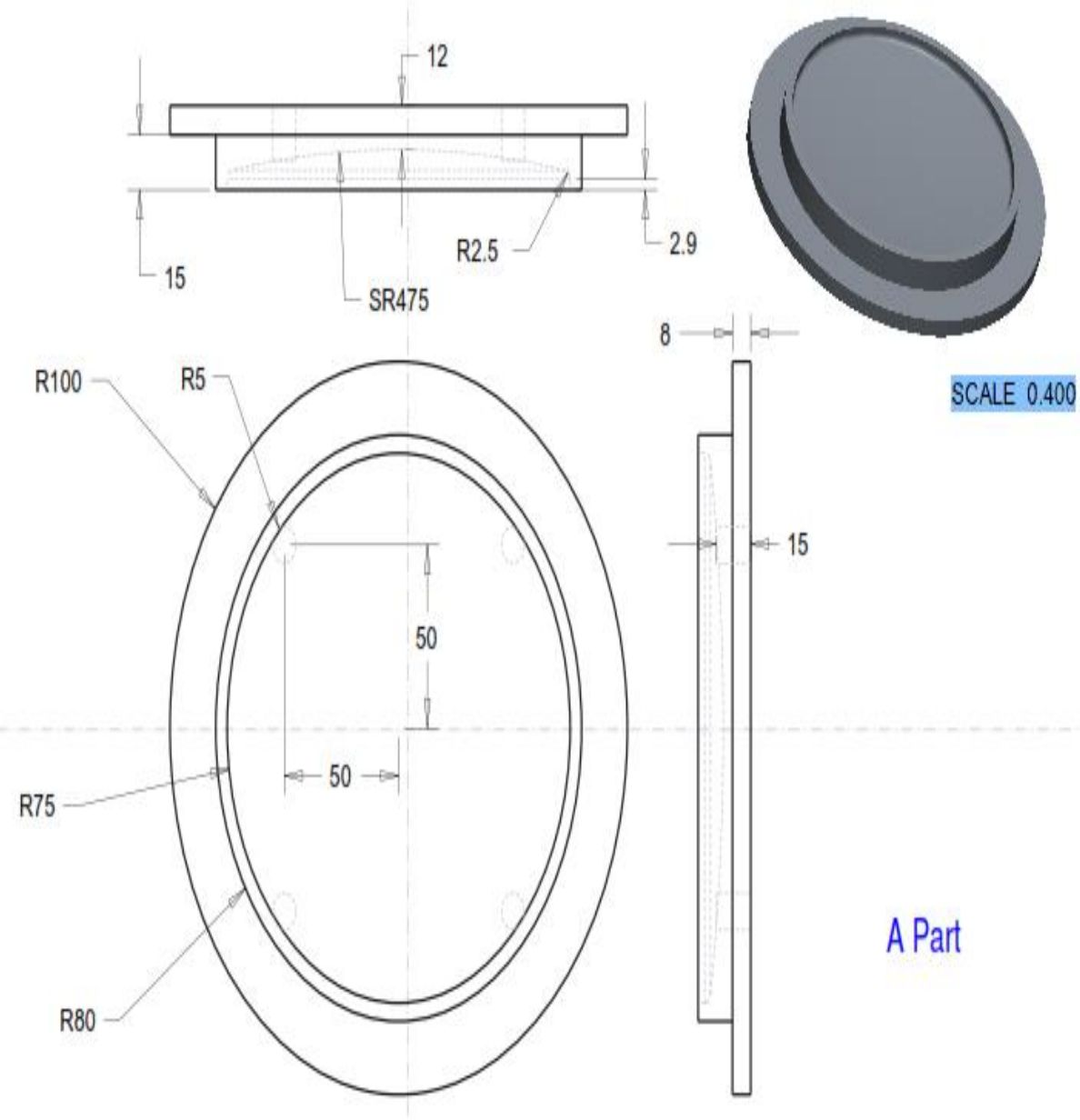




- The Friction Pendulum Bearings are stainless steel seismic isolators consisting of a concave surface, an articulated slider, and a cover plate. The slider is coated with self- lubricating composite liner (e.g. Teflon).

- Experimental and analytical results on the behaviour of a system having concave surfaces of equal radius and equal coefficients of friction at the top and bottom sliding surfaces were presented.

Parts of DCFP Bearing



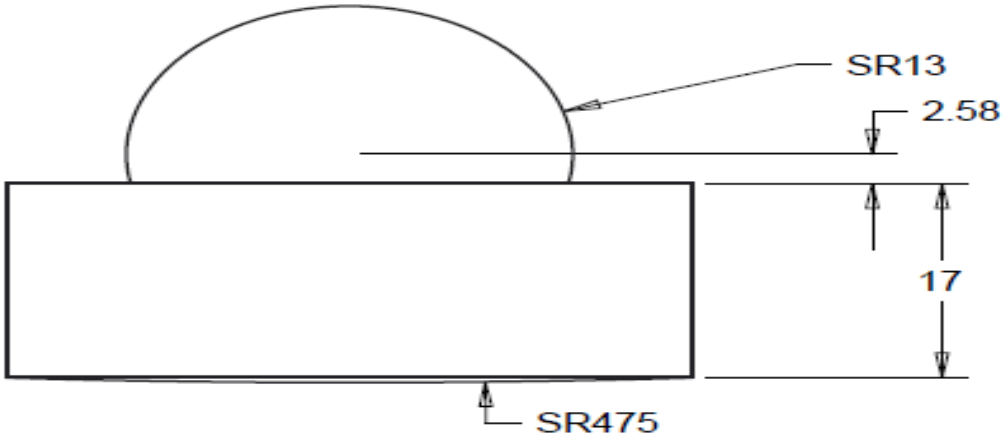
- ***Part A:***

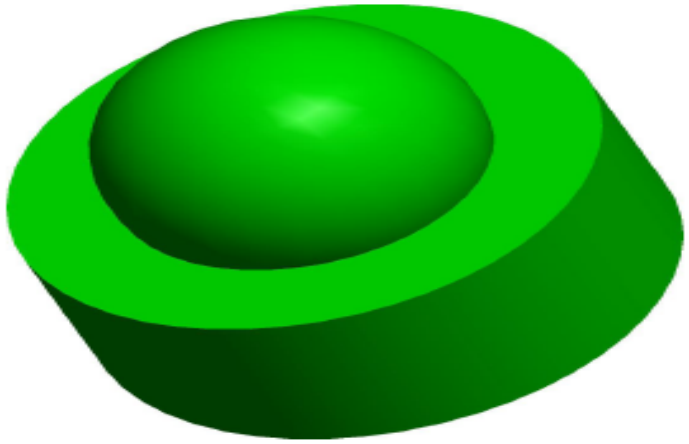
This part is putting one side of bearing as upper and lower plate.

In this plate, inner side having the curvature concave surface which have the *friction co-efficient of 0.02 to 0.08*.

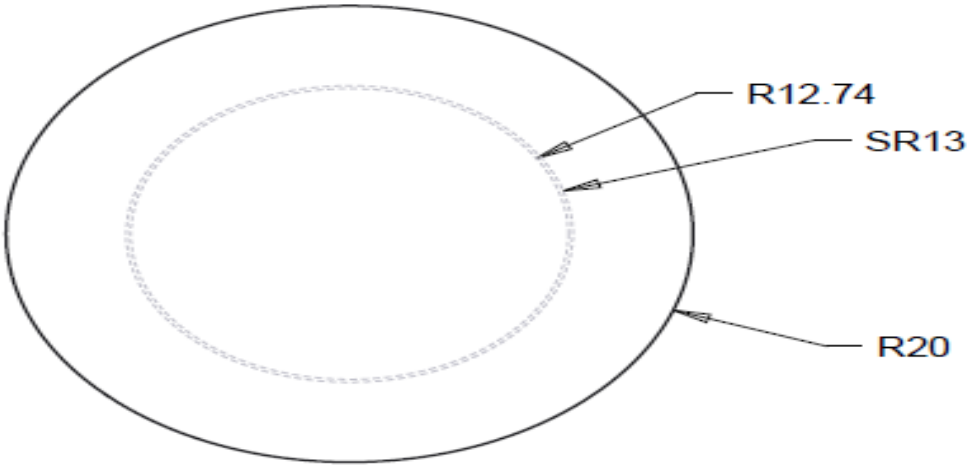
The coefficient of friction is dependent on the contact pressure between the Teflon-coated slider and the stainless steel surface.

Part B: Articulated Slider

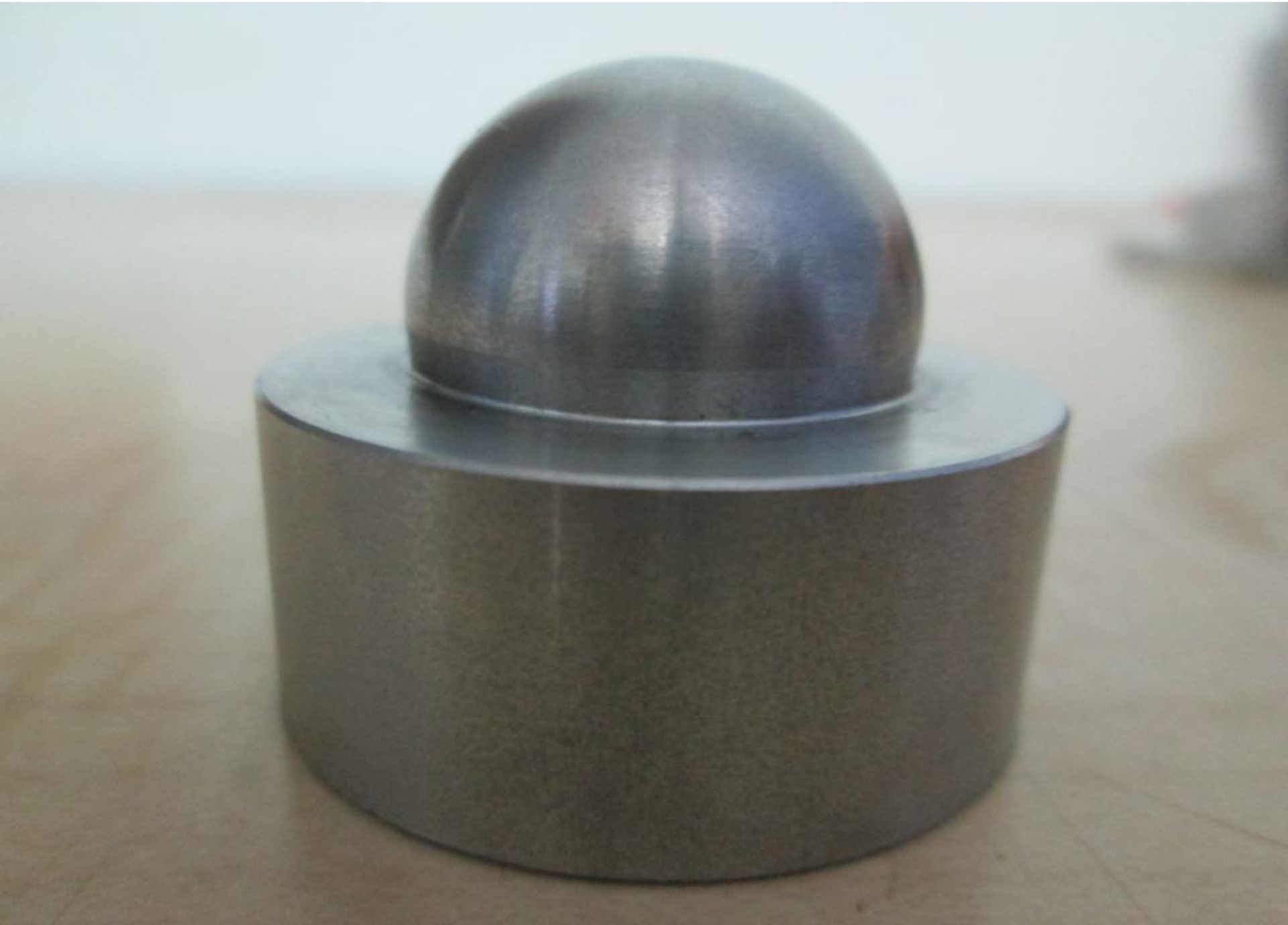




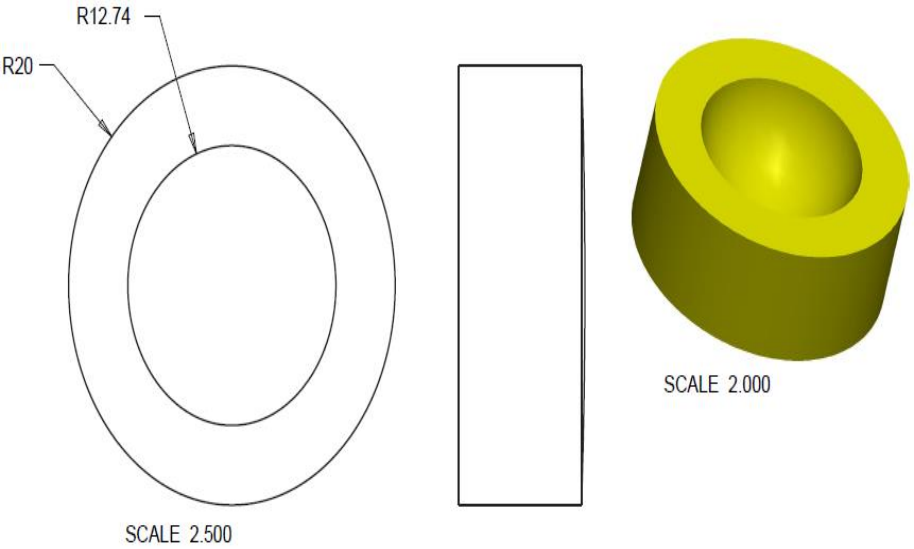
SCALE 2.000



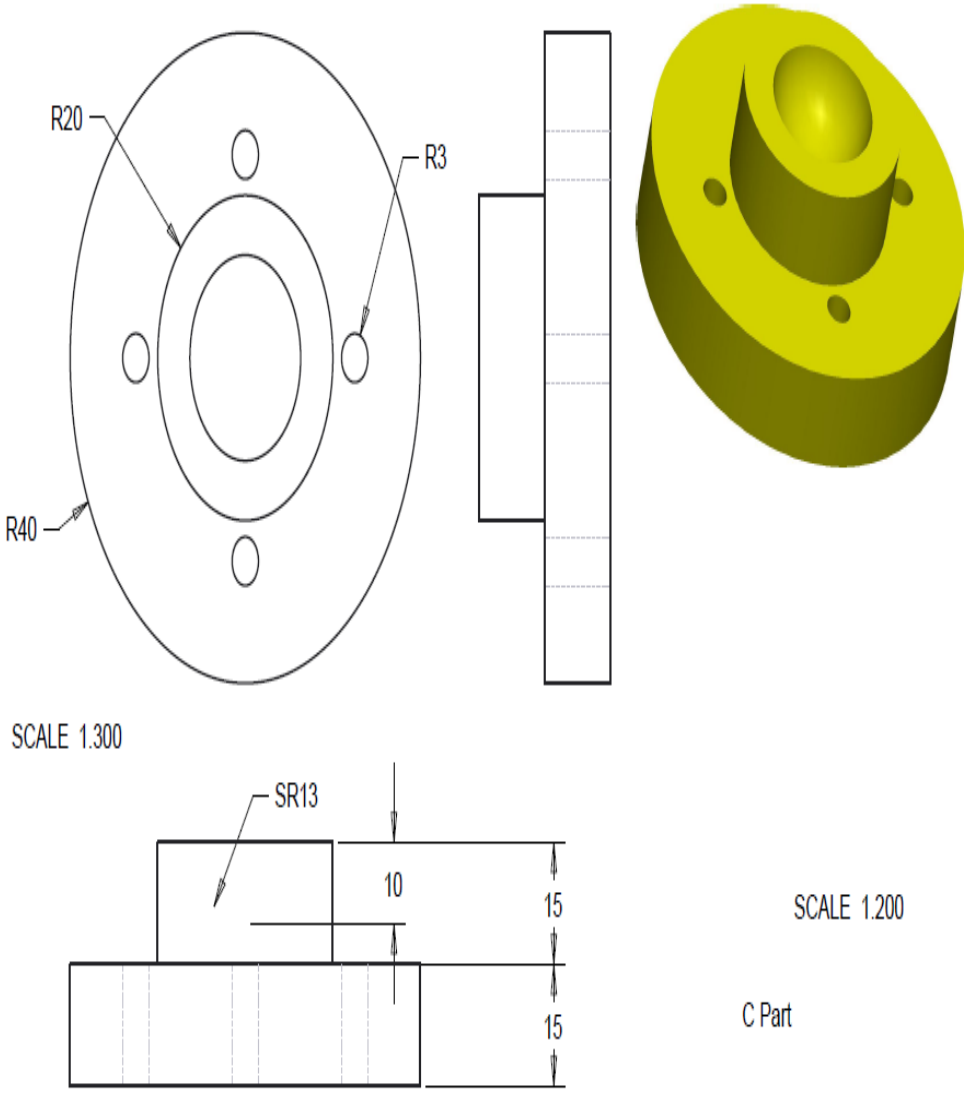
B Part

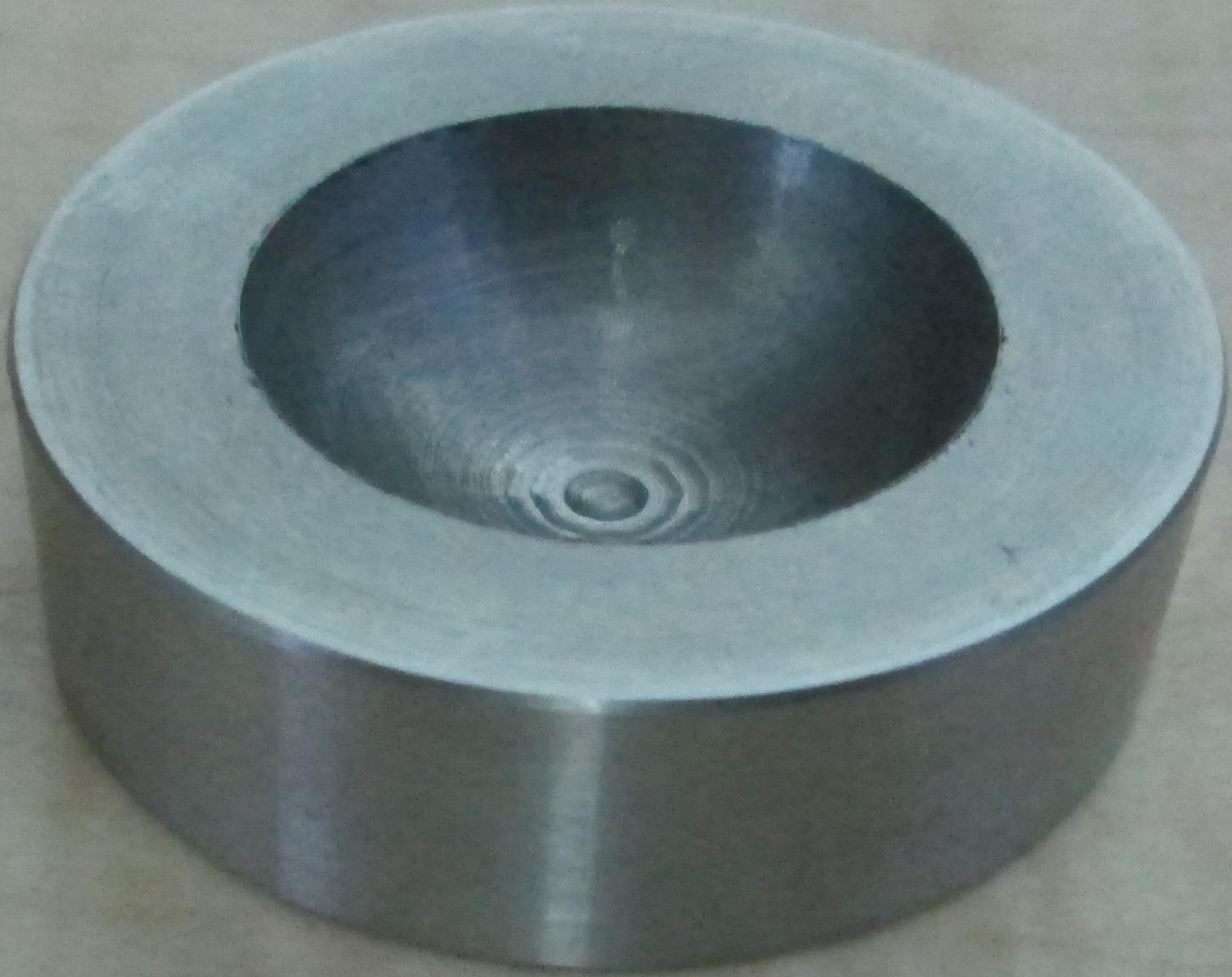


Part C: (For model 1)

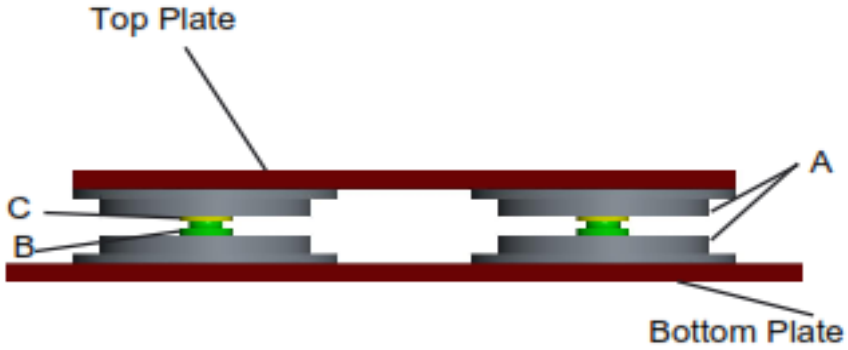


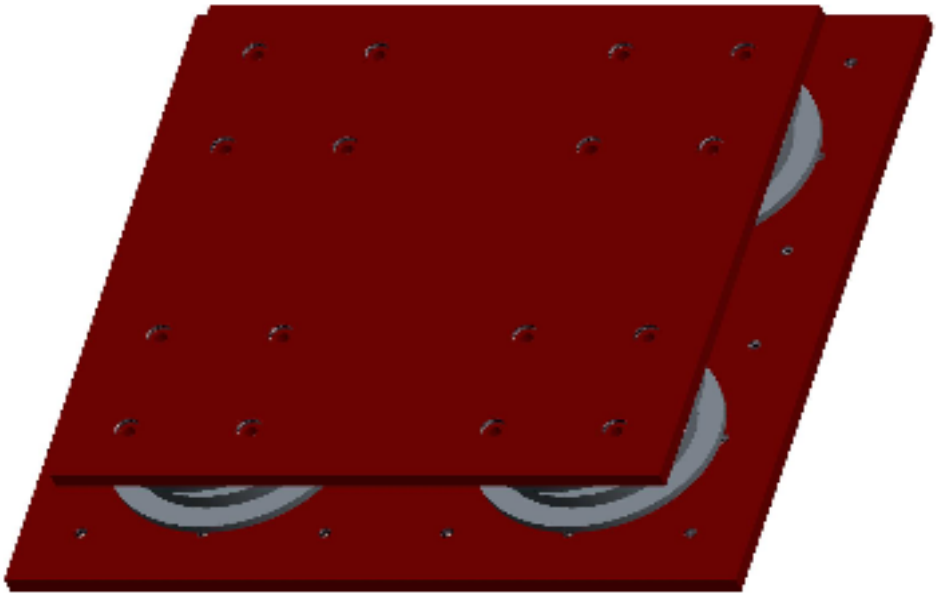
Part C: (For model 2)



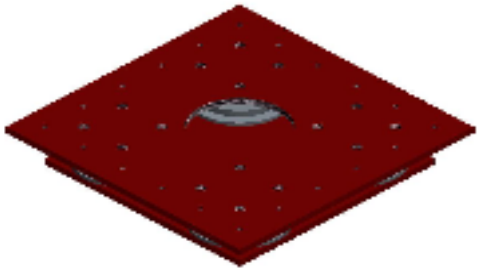


Assembly of bearings with Earthquake Shake table

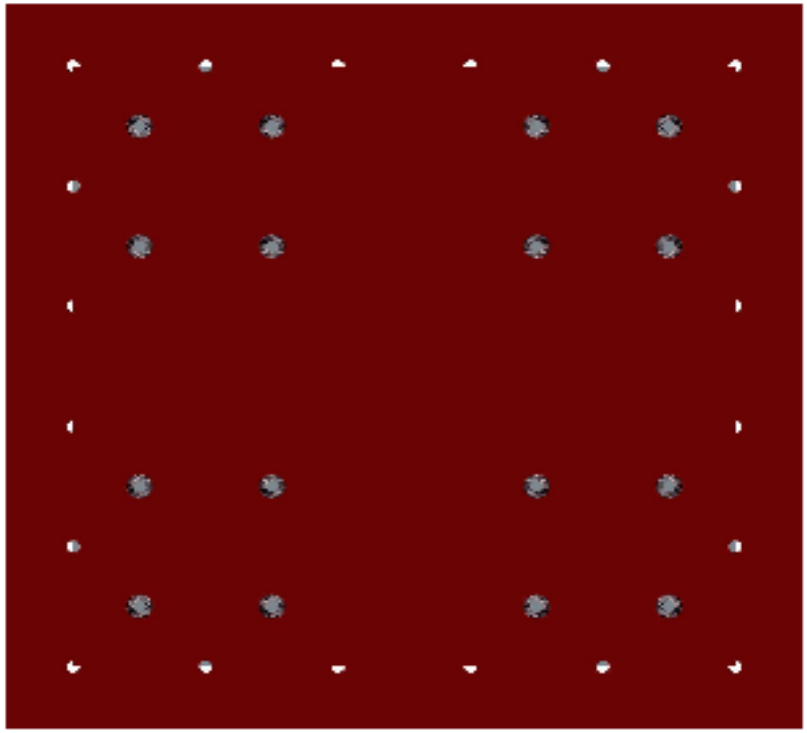




SCALE 0.200



Main Assembly



SCALE 0.200

Models of Building Structure

- ***Dimensions:***
  - Length = 300 mm
  - Width = 150 mm
  - Height = 400 mm

ANALYSIS OF ISOLATION SYSTEM:

1) Linear Static Analysis
2) Linear Response Spectrum Analysis
3) Non-Linear Static Analysis
4) Linear Time History Analysis
5) Nonlinear Time History Analysis

- ***Linear Static Analysis:*** Linear analysis methods give a good indication of elastic capacity of the structures and indicate where first yielding will occur. The linear static method of analysis is limited to small, regular buildings.

- ***Linear Response Spectrum Analysis:*** Linear response-spectrum analysis is the most common types of analysis used. This is sufficient for almost all isolation system based on LRB and / or HDR bearings.

- ***Non-Linear Static Analysis:*** In a nonlinear static analysis procedure the building model incorporates directly the nonlinear force-deformation characteristics of individual's components and elements due to inelastic material response.

- ***Linear Time History Analysis:*** Linear Time History Analysis provides little more information than the response spectrum analysis for a much greater degree of effort and so is rarely used.

- ***Nonlinear Time History Analysis:*** Nonlinear Time History Analysis can be used for all isolation systems regardless of height, size, geometry, location, and Non-linearity of the isolation system.

Analytical Simulations

- *Geometry of single storey model:*

Single storey:

Weight total: 3.670 kg

Steel plate: (nos. of plates=2)

L=300 mm, width=150 mm, thickness= 12mm

Columns: (total nos.= 4)

Height=400 mm, width= 25 mm, thickness= 7mm

(1) Mass calculation:

Weight of M.S.Plate on 4 FPS Bearings = 31 kg

Weight of Single Storey Building Model= 3.670 kg

Total weight = 34.670 kg

$$\text{So, mass assigned on one bearing} = \frac{Total\ weight\ on\ bearing}{4}$$

$$= \frac{34.670}{4}$$

$$= 8.667\ kg$$

(2) Moment of Inertia:

$$I = \frac{bd^3}{12} \times 2$$

$$= \frac{\left(25 \times 10^{-3} \times \left(7 \times 10^{-3}\right)^3\right)}{12} \times 2$$

$$= 1.4291 \times 10^{-9}\ m^4$$

(3) Time Period of Bearing:

- The natural time period (T) of the friction pendulum bearing is selected simply by choosing the radius of curvature of the concave surface (R) as

$$T_b = 2\pi\sqrt{\frac{R}{g}}$$

$$= 2\pi\sqrt{\frac{0.475}{9.81}}$$

$$= 1.38\,\text{sec}$$

Where,

R = radius of concave surface of bearing

g = gravitational acceleration

(4) Effective Stiffness:

$$K_b = M\left(\frac{2\pi}{T_b}\right)^2$$

$$= 8.667\left(\frac{2\pi}{1.38}\right)^2$$

$$= 179.340\ kg/s^2$$

Where,

M = mass assigned on 1 bearing

T_b = time period

Experimental Setup:

- A series of experiments was designed and conducted to examine the behavior of actual friction pendulum bearing under a variety of conditions. This chapter outlines the purpose of the experiments, describes the facilities and test apparatus, and details the specimen, its instrumentation, and each class of excitation, and the nature of the data collected.

- The purposes of this experimental program are the following:

  Record structural response quantities of interest (floor accelerations) and compare the time period computed from nonlinear analysis in SAP2000.

- There are different examples of computer based softwares given here for analysis of Base Isolated Strucures.

✓ SAP2000 – General purpose linear and nonlinear analysis
✓ ETABS – for linear and nonlinear analysis of buildings
✓ DRAIN-2D – for two dimensional nonlinear analysis
✓ 3D-BASIS – for analysis of base isolated building

Model with FPS

Other Equipments for setup:

Earthquake Shaketable

Shake tables may be able to reproduce motion in only one horizontal direction (uniaxial), in one horizontal and the vertical direction (biaxial), or in both horizontal and the vertical direction (triaxial). Triaxial tables are the most realistic but also more expensive. Many tests and much research are consequently done on uniaxial or biaxial tables.

Accelerometer

An instrument, almost always electrical, that provides a signal (typically a Voltage) proportional to the acceleration occurring at the location of the instrument. Instruments can be based on the piezo-electric or piezo-resistive principle, strain gages, or servo accelerometers based on capacitance measurements.

- *Accelerometer & sensors*

- *Bearings*

Acceleration of B.I model connected with shaketable

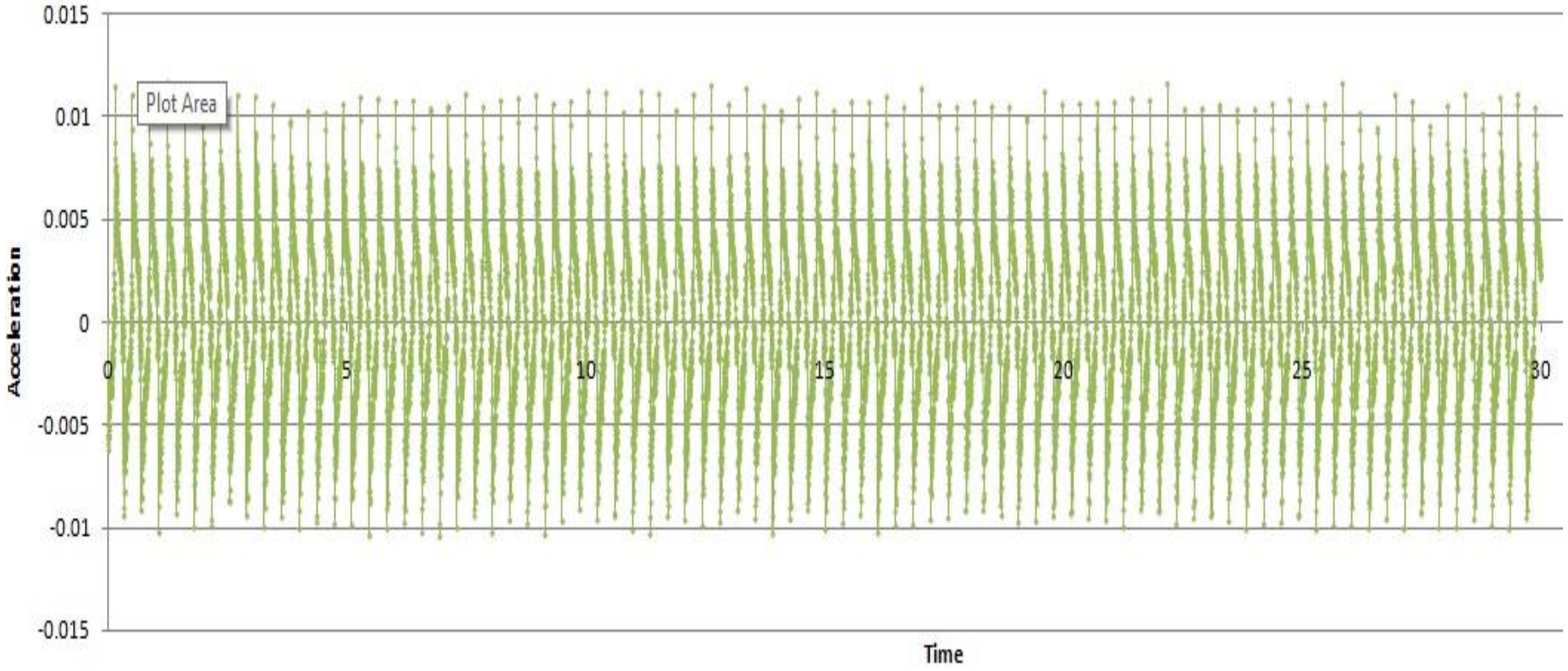
(1) Input Data for Single Storey Building model structure-

Present Frequency: 10 Hz

No. of Data: 8

Present Travel (Amplitude): 10 mm

Cycle Repeat: 20



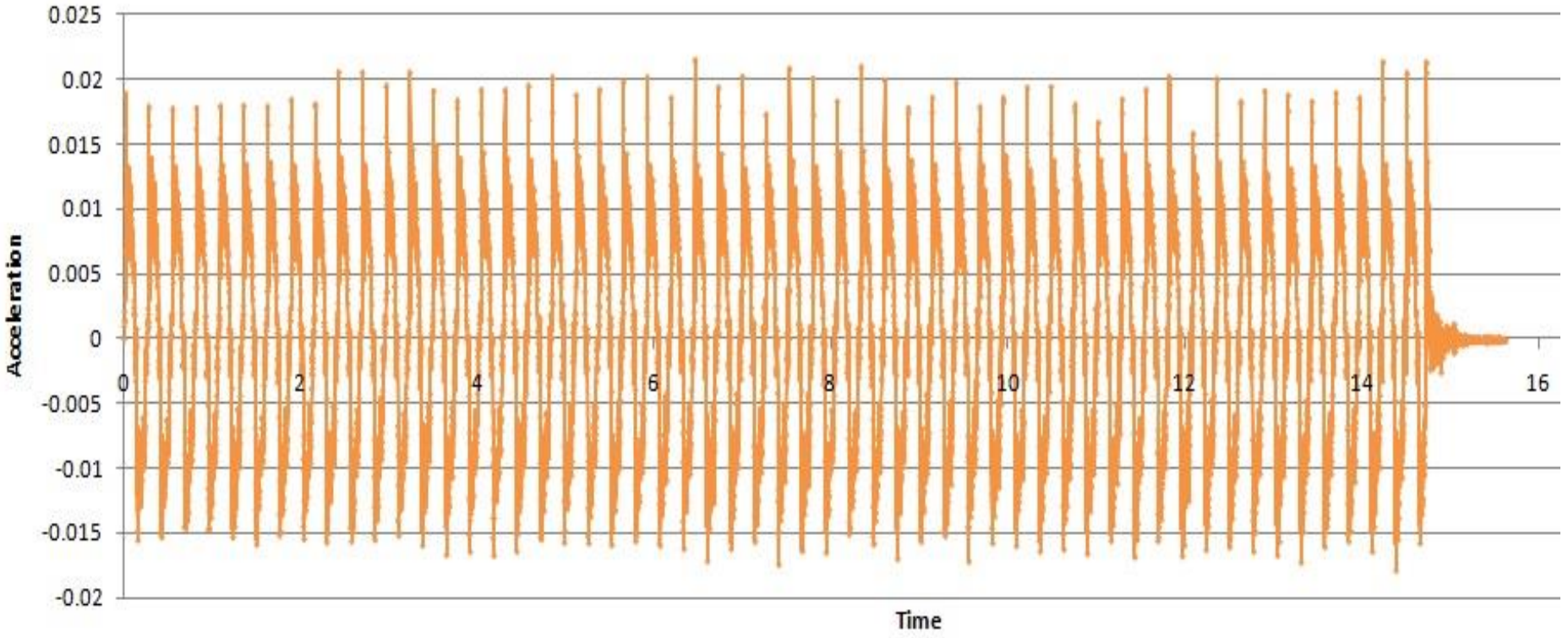
(2) Input Data for Single Storey Building model structure-

Present Frequency: 20 Hz

No. of Data: 8

Present Travel (Amplitude): 10 mm

Cycle Repeat: 20



Modelling of B.I structure using SAP2000

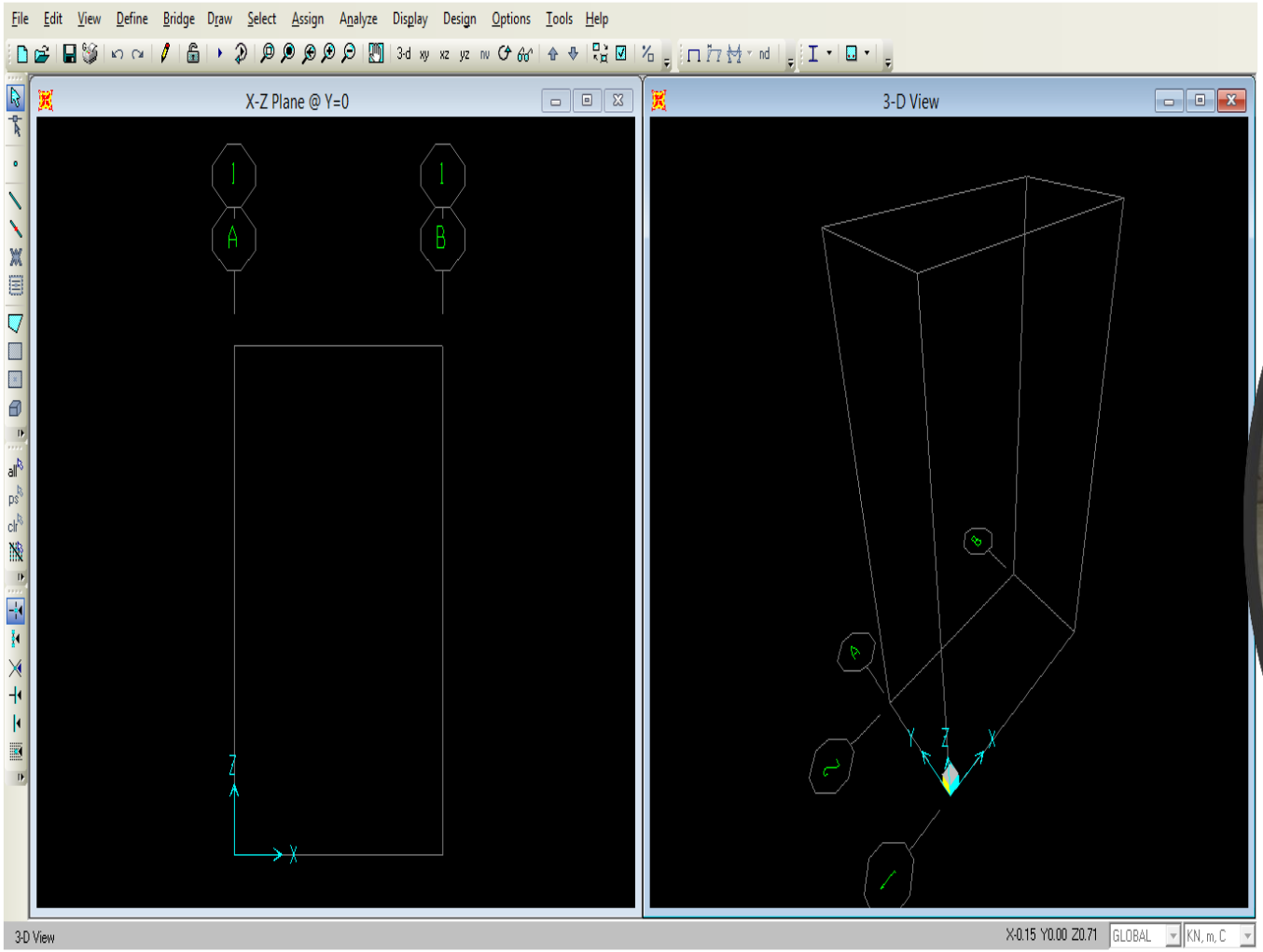
- SAP2000 is a stand-alone finite-element-based structural program for the analysis and design of civil structures.

- It offers a powerful user interface with many tools to aid in the quick and accurate construction of models, along with the analytical techniques needed to do the most complex projects.

- SAP2000 is an extremely versatile and powerful program, with many features and functions.

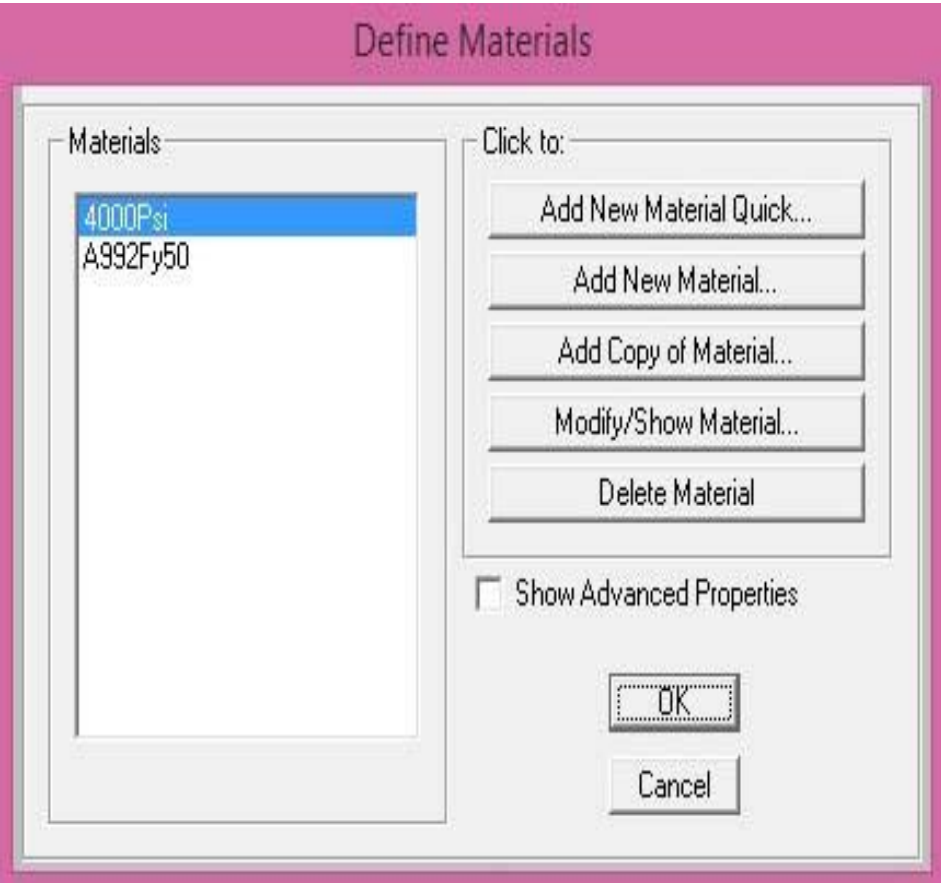
Steps for modelling

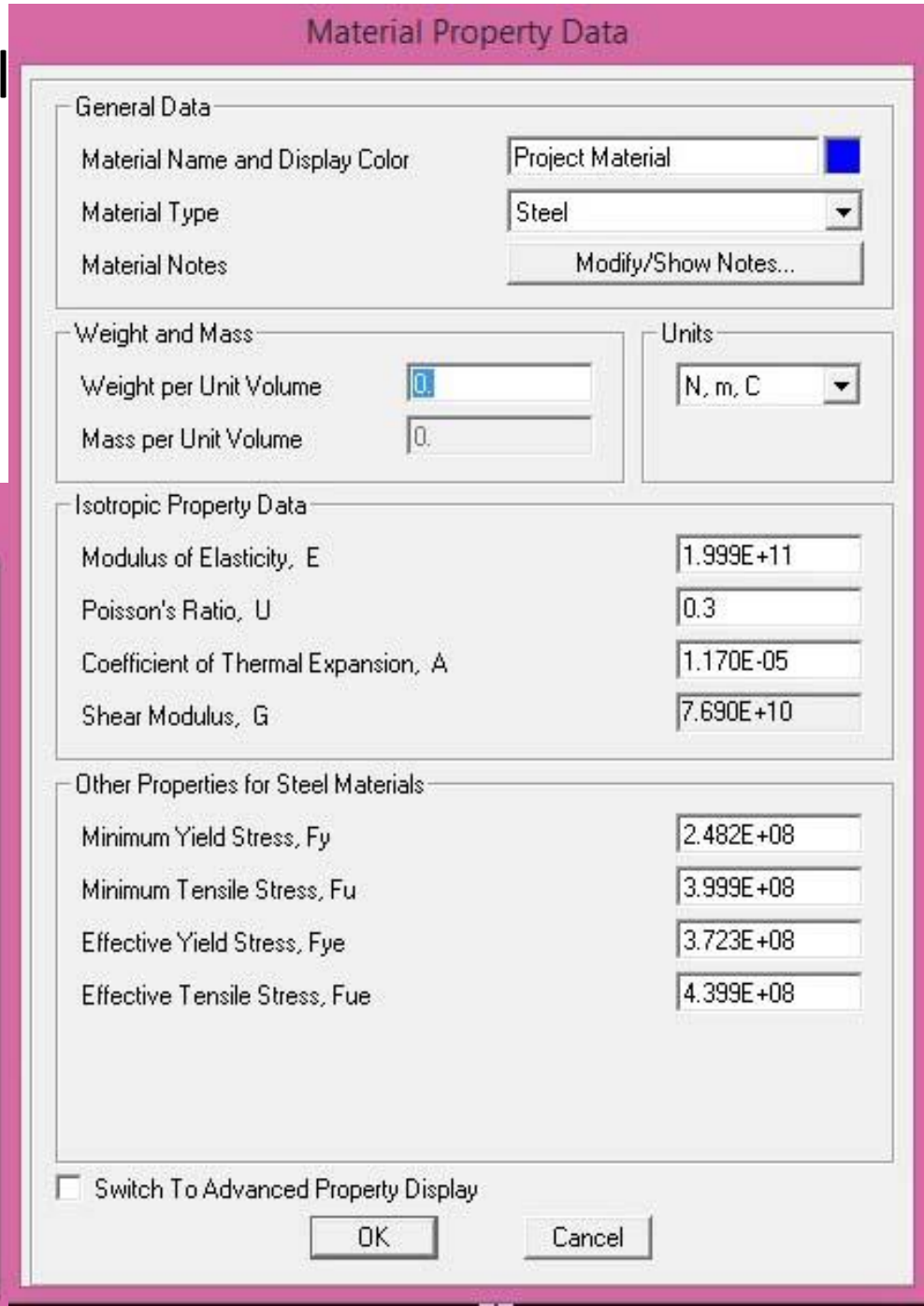
Step (1): Input the data of model including length, width, and height.



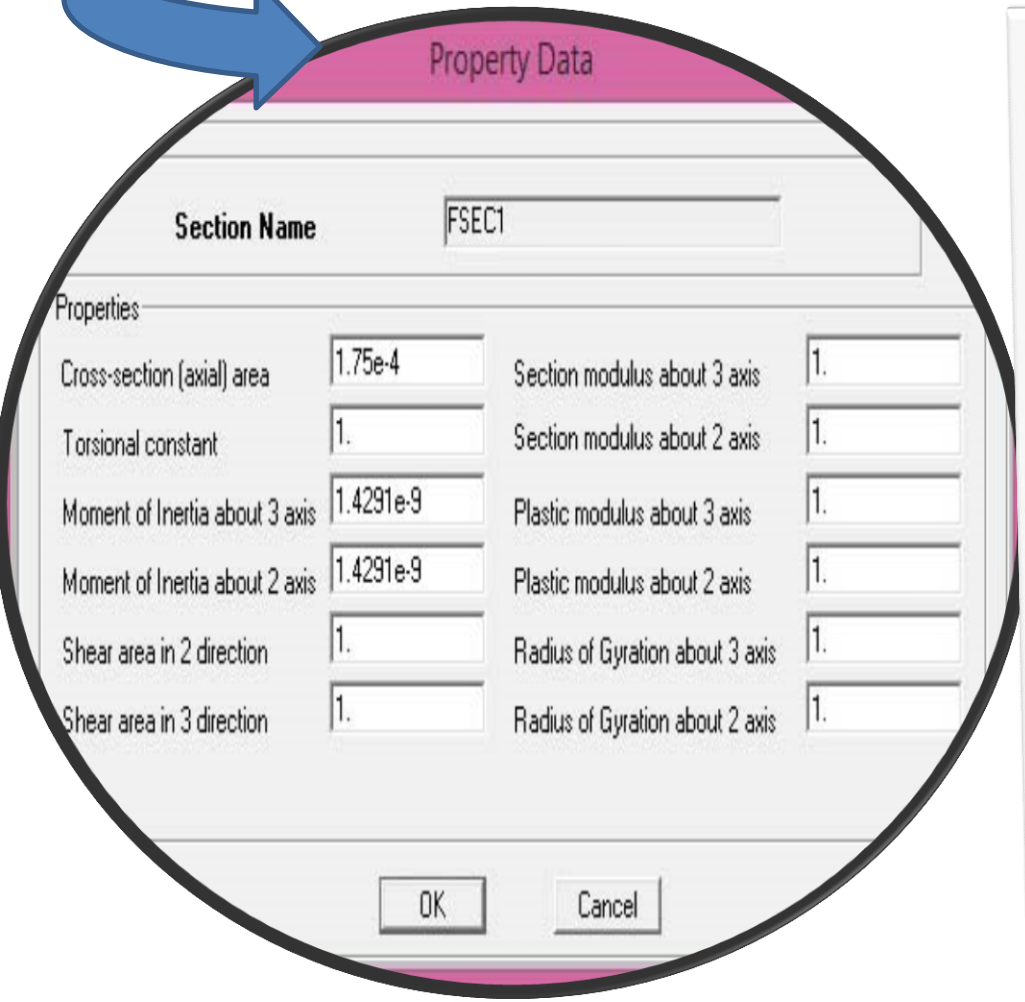
Step (2): Defining the material data

- Two default material properties are predefined, ***one for concrete and one for steel.***

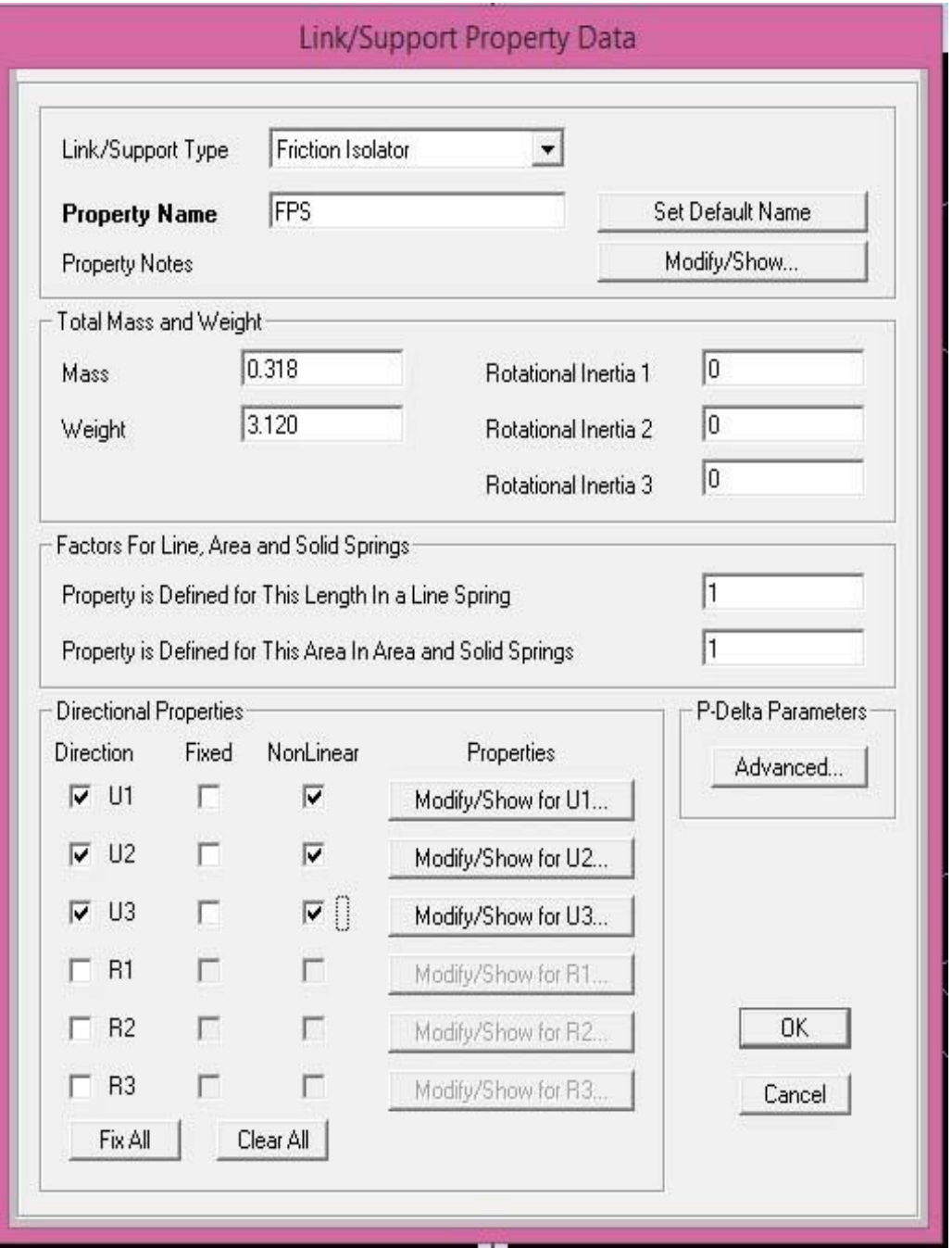




Input the **section property** data.



After giving the data, it shows the different frames which are using in the experiment.



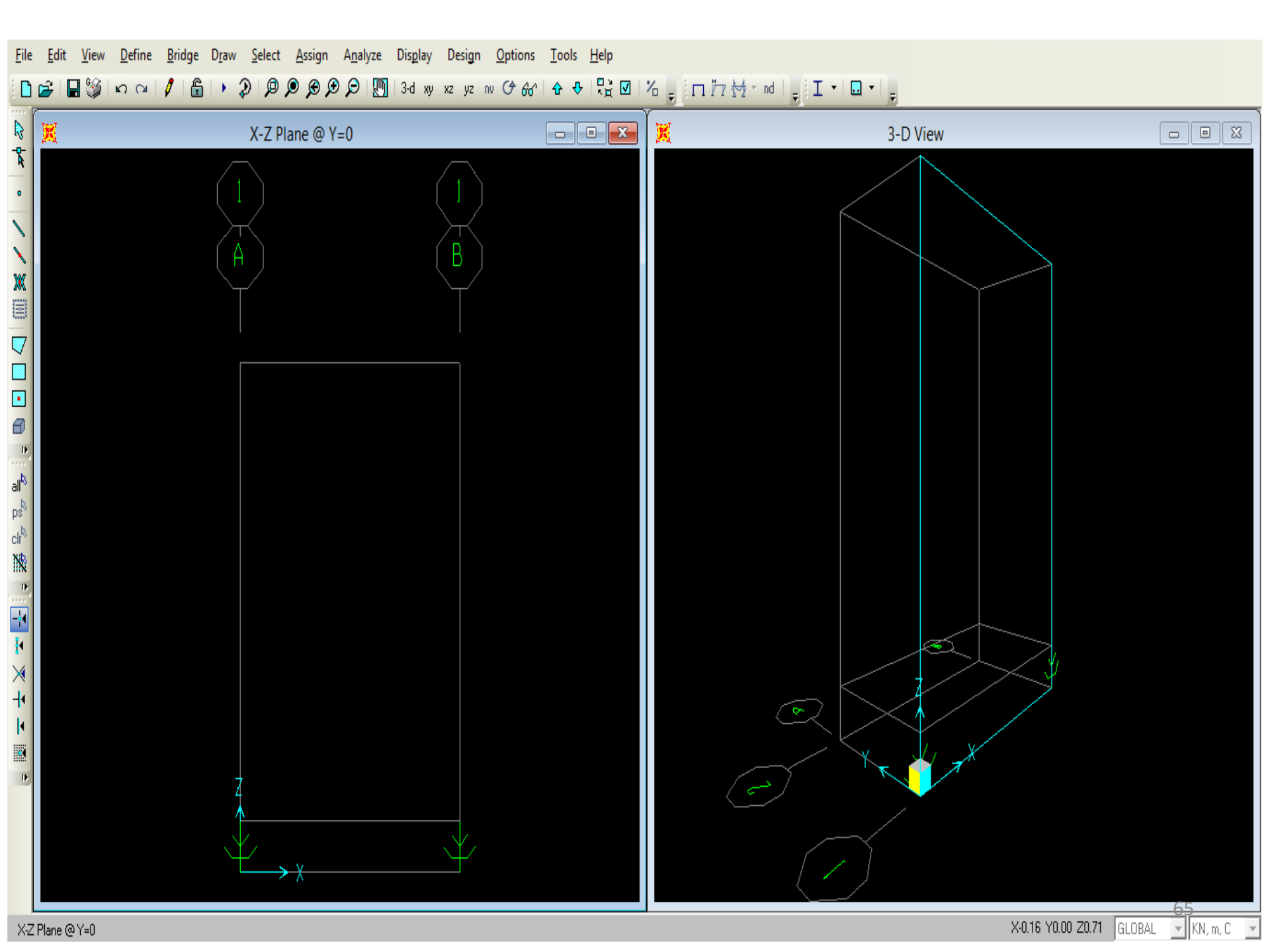
Step (3): Adding the FPS at model foundation

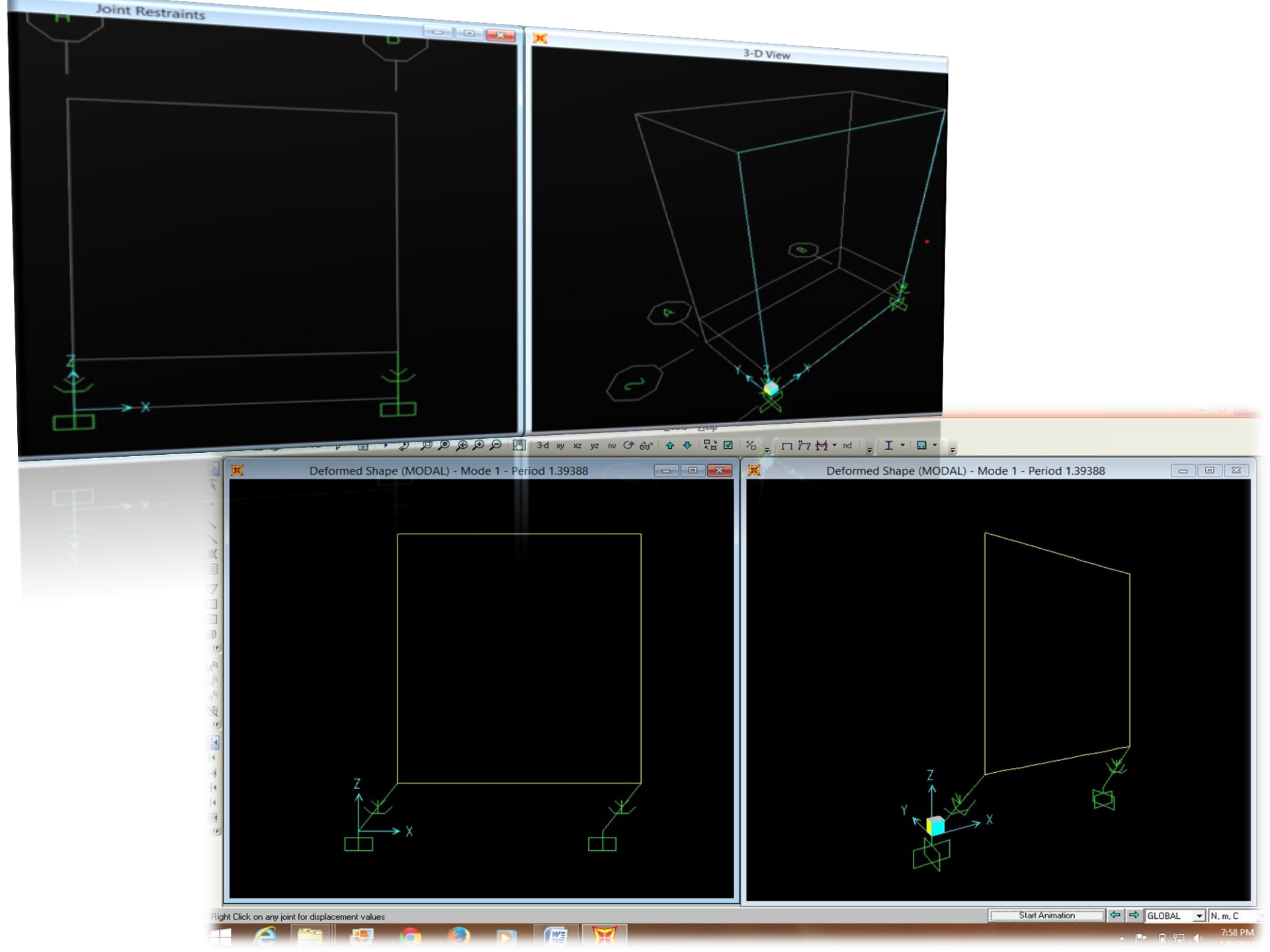
Linear Properties of FPS:

Direction	U1	U2	U3
Effective Stiffness	1.000E+10	179.34	179.34
Effective Damping	0	0	0

Non-Linear Properties of FPS:

Direction	U1	U2	U3
Stiffness	1.000E+10	1.000E+08	1.000E+08
Friction Co-efficient, slow	---	0.08	0.08
Friction Co-efficient, fast	---	0.08	0.08
Rate Parameter	---	100	100
Radius of Sliding Surface	---	0.475	0.475


File Edit View Define Bridge Draw Select Assign Analyze Display Design Options Tools Help
X-Z Plane @ Y=0
1
A
1
B
Z
X
3-D View
Z
Y
X
X-Z Plane @ Y=0
X-0.16 Y0.00 Z0.71
GLOBAL
KN, m, C


Joint Restraints
3-D View
Deformed Shape (MODAL) - Mode 1 - Period 1.39388
Deformed Shape (MODAL) - Mode 1 - Period 1.39388
Right Click on any joint for displacement values
Start Animation
GLOBAL
N, m, C
7:58 PM

Results from SAP2000

- In SAP2000, the mass is applying at top of the model but on bearings, the distribution of mass is half at one side and half distributed another side.
- After that, software is given the deformed shapes governed by FPS bearing.
- The time period on software also gives the approx same as analytical calculation is 1.38 sec.

Behavior of DCFP

- When friction is the same on both concave surfaces, the hysteretic behavior is rigid-linear like that of the traditional Friction Pendulum bearing.

- When friction is different, the behavior changes to rigid- bilinear. The analytical force-displacement relationship is shown to accurately capture the experimentally observed behavior except for the effect of the velocity dependence of the coefficient of friction.

- Histories of displacement and velocity confirm that simultaneous sliding occurs over the entire range of motion when friction is equal on both surfaces.

- When friction is different, upon initiation or reversal of motion the slider temporarily sticks on the surface with higher friction. This is demonstrated by the periods of zero velocity on the upper surface.

Conclusion:

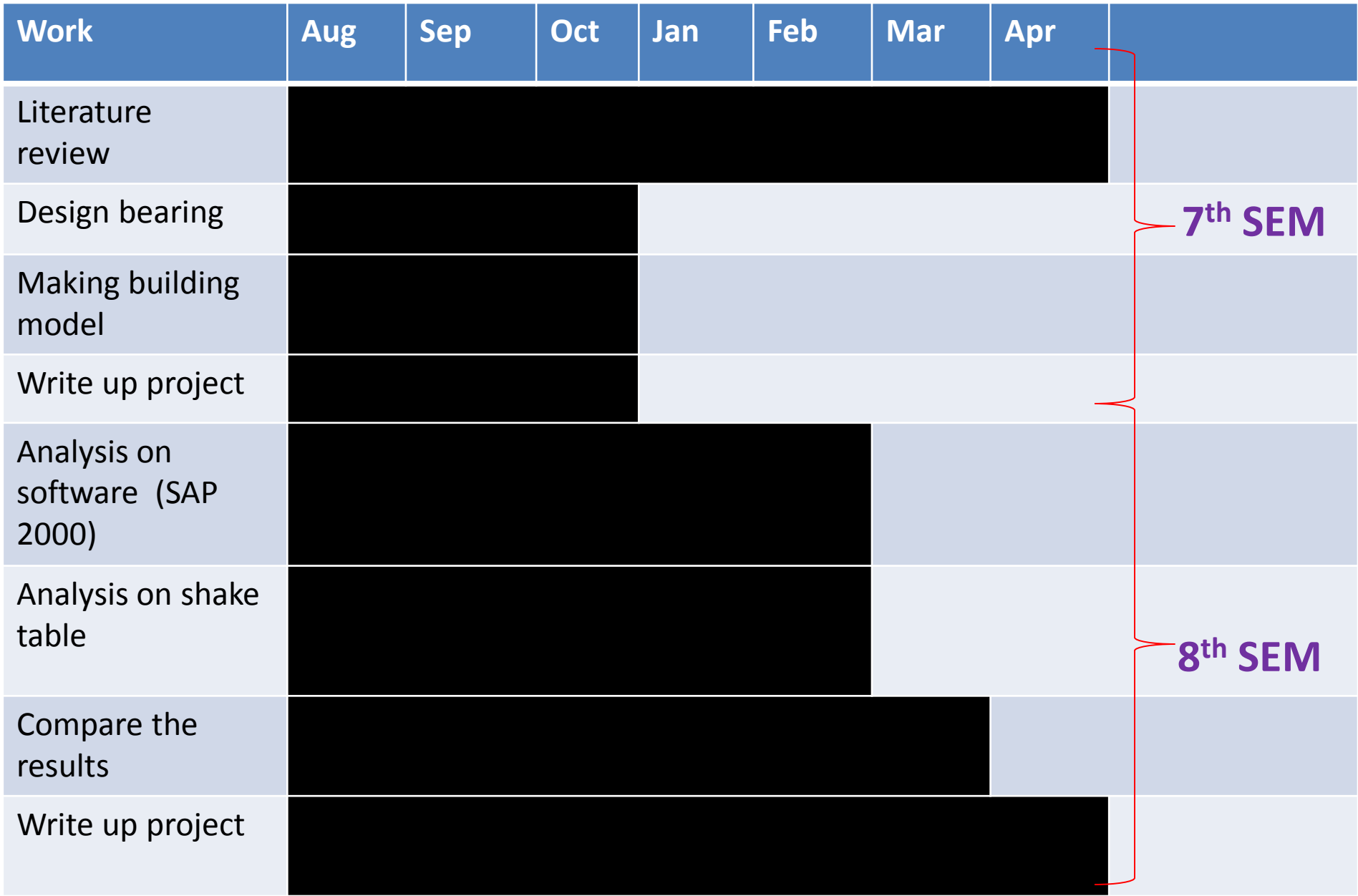
- The bearing behaves much like a traditional FP bearing with effective radius of curvature equal to the sum of the radii of curvature of the two concave surfaces (but modified for the height of the slider) and friction equal to the average of the coefficient of friction at each sliding interface.
- The displacements on each surface are equal in magnitude and equal to half of the total displacement. The time period of FP bearing is matched with the software modeling.
- The difference in responses was simulated by comparing two identical model structures, one with a FPB base isolation system and one without any base isolation. After simulations, the structure with the FPB base isolation showed a significant decrease in lateral acceleration due to varying lateral forces, as expected.
- Future research will be made considering different types of bearing, in order to compare the effectiveness of each type. It will be also performed research in order to establish rules in using FPBs for asymmetrical structures.

Patent Report (PSAR)

Patent-1	Friction pendulum bearing
Patent-2	Seismic isolation bearing
Patent-3	Sliding pendulum seismic isolation system
Patent-4	Bearing for protection for structures, formed as sliding pendulum bearing, has sliding material which comprises a plastic with elasto-plastic compensating quality, especially plastic with low friction
Patent-5	Sliding concave foundation system
Patent-6	Accelerometer
Patent-7	Sliding pendulum seismic isolation
Patent-8	Multifunction vibration isolation strut
Patent-9	Friction pendulum bearing system
Patent-10	Base isolation pad

Patent-11	Multi-step base isolator
Patent-12	Building structure shock isolation system
Patent-13	Steel rubber seismic isolation bearing
Patent-14	Device for base isolating structures from lateral and rotational support motion
Patent-15	Base isolated building of wind resisting type
Patent-16	Seismic isolation device and seismic isolation structure
Patent-17	Seismic isolation system
Patent-18	Sliding pendulum bearing
Patent-19	Sliding pendulum seismic isolator
Patent-20	Directional rolling friction pendulum seismic isolation system

WORK PLAN


Work
Aug
Sep
Oct
Jan
Feb
Mar
Apr
Literature review
Design bearing
Making building model
Write up project
Analysis on software (SAP 2000)
Analysis on shake table
Compare the results
Write up project
7th SEM
8th SEM

References & Literature

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  Seismic Protective System: Seismic Isolation, FEMA
- Assist. Eng. Fanel Scheaua,

  Seismic Base Isolation of Structures Using Friction Pendulum Bearings, University of Galati
- Ahmed Elgamal, Michael Fraser

  Earthquake Engineering, *Prepared from Dr. Benzoni's SE207 Base Isolation Course Notes*
- Nikolay Kravchuk, Ryan Colquhoun, and Ali Porbaha,

  Development of a Friction PendulumBearing Base Isolation System for Earthquake Engineering Education, California State University, Sacramento, CA
- Earthquake Quiz, Courtesy by IIT Kanpur
- 1) Camelia Ştefania JURCĂU (2) Gilbert-Rainer GILLICH

  The Use of the Friction Pendulum Bearings for Isolation of the Built Environment, "Eftimie Murgu" University of Resita

THANK YOU…

Morning means more inning given by god.

Play and win it…☺