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Reduction of Structural Response of the Fixed Building using Base Isolation System

A.Vinod Kumar, J. Joel Shelton

Abstract*: Earthquakes does not take lives of the people in particular, but the building takes the lives of the people. So we have to look over how to mitigate the damage to buildings,so that no harm should be experienced by the inhabitants. At present scenario Structural Dynamics is one of the most important subjects in civil engineering discipline because of rapid advancement in science and technology. Many of the structural Engineersare researching how to predict the earthquakes and how to mitigate the damage caused by earthquakes for engineering structures. But we are unable to mitigate it completely. However we can control the severity of earthquakes to limited by using energy dissipating systems. Some of the earthquake energy dissipating systems widely implemented and accepted seismic protection systems are base isolation system and tuned mass damper systems. The aim of base isolation is to decrease the response of the structures in earthquake prone areas. The theme of this project is toreduce the structural response of building by base isolator which are subjected to earthquake groundmotion by using array programming languages (MATLAB and SCILAB) in Graphical User Interface (GUI). At present many disciplines of engineering using these languages for computing complex problems within limited time for aaccurate results.

Keywords: Energy dissipating devices,Base isolation system,array programming languages, Graphical User Interface (GUI), MATLAB, and SCILAB.

I. INTRODUCTION

An earthquake is a natural phenomenon with violent shaking of the ground. Sudden movements of earth crust mostly due to tectonic movements caused vibrations of the earth's surface. Yearly there are many earthquakes occurs around the world. But only some of them are very dangerous. Mere earthquakes are the not the factor in taking the lives of the people. Main cause is buildings which takes lives of the people. In urban areas the construction of high rise buildings are increasing rapidly due to urbanization and decrease of land area with respect to population. These high rise buildings are to be designed seismic resistant in seismic prone zones.In conventional design sufficient strength, stiffness and ductility are provided to sustain moderate earthquakes. But the disadvantages of conventional design Inelastic deformation require large storey drift, localized damage to structural elements and secondary systems (nonstructural elements) and strengthening attracts more earthquake loads.

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So in order to counteract these disadvantages energy dissipating systems comeinto play. One of such important energy dissipating systems is passive control systems. Best example for passive control system is base isolation system. The main idea behind this system is to minimize theearthquake induced forces transferred to the superstructure. The earthquake energy is prevented from entering the structure from Earthquake ground motiondecoupling the structure from its base. Therefore reducing ductility demand, inter-storey drifts and base shear. The decoupling of the structure is done by interposing a lower horizontal stiffness between superstructure and the base of the structure. Therefore decreasing the fundamental frequency of the structural vibration and it also helps in energy dissipation, which reduces the transmitted acceleration to the superstructure. In this manner base isolation provides seismic protection to structural and non-structural elements. Generally the material with lower horizontal stiffness and higher vertical stiffness are used in base isolation systems. Typical example is laminated rubber bearing system. In recent years this type of system became practical and economic alternative to conventional seismic design.This technique is being used in new and existing (as retrofit) structures, both important and trivial structures in different types of structures in different countries. It is worth mention that during the major earthquake in Tohoku, Japan some base-isolated structure had performed well within the limits (Takewaki 2011). This will make confidence in the base isolation technology and its widespread use in routine constructions. In past researchers is conducted experimental studyto find the effectiveness of base isolation with respect to fixed structures. In the year 1997 A.H. Barbat and L.M. Bozzo [1] conducted various numerical analyses on base isolated systems. Theyhad found base isolated buildings are very effective at the time of earthquakes.In the year (2014)Syed Ahmed Kabeer K I and Sanjeev Kumar K.S [2] had analysied the building with and without base isolation in ETABS software.They used rubber bearings as base isolators.In the year 2001 P.Bhaskar Rao and R.S.Jangid [3] conducted shake table test to find the response of base isolated system and fixed base system. They found that base isolation structure is more effective than fixed base structure. In the year (2014) Dr. R. S. Talikoti and Mr. Vinod R. Thorat [4]had conducted a study on base isolated buildings by using SAP 2000 software. In the year (2016),Supradip Saha and Dr. Rama Debbarma [5] had analysed the SDOF system with base isolation.They found that the structural responses are reduced to 44.925% and 41.70% for displacement and acceleration respectively. By the advancement of science and technology many researchers are being adopting numerical methods by using programming languages to study the behavior of base isolation systems.

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So that we can reduce the time and cost to analyze the base isolated structures. Among programming languages, array programming languages (such as MATLAB, SCILAB, FREEMAT, GNU OCTAVE etc.,) are very easy to use because of many predefined functions.
The objectives of this study is to decrease the building responses namely base shear, storeydrifts, and lateral earthquake forces with the aid of base isolation systemby adopting response spectrum analysis and compare the results by using array programming languagesMATLAB (R2014a) and SCILAB with Graphical User Interface (GUI)

II. STRUCTURAL MODELING

A.Basic Properties of the Building

The plan of the building considered for numerical investigation in show in the figure 1. It is six storey RCC building which is regular in plan and elevation. Plan dimensions are 1200 mmx1200 mm with two equal spans in both directions and storey heights are equal up to fifth storey (3000 mm) and sixth storey height is 2500 mm, Beam sizes are 250mm x 250 mm,Column sizes are 450mm x450mm, Slab thickness is 0.15m up to fifth storey and sixth storey slab thickness is120 mm, Grade of concrete is M30.

B. Structural Modal of Lumped Mass System of a Building

The structure is idealized as a six storey shear type of building as shown in figure 2 and 3. The building is modeled as 6-DOF System forfixed base system 7-DOF system for base isolation system. In this modal we approached lumped mass system. Here damping of the super structure with damping ratio as 5% for all modes. For base isolation building the isolationsystem is assumed as rubber bearing with particular lateral stiffness.

Assumptions

- The effects of soil structure interaction are not involved in analysis.
- Total mass of the super-structure is concentrated at the floor levels.
- The columns are non-extensible and weightless providing lateral stiffness.
- The slabs and beams are infinitely rigid as compared to columns.
- The structure is subjected to single horizontal component of earthquake ground motion.

Besides this, for base isolated building we assume that the superstructure is considered to remain within the elastic limit during earthquake excitation. This is reasonable because the base isolation reduces the structural response due to earthquake in such a way that the structure remains within elastic limits.

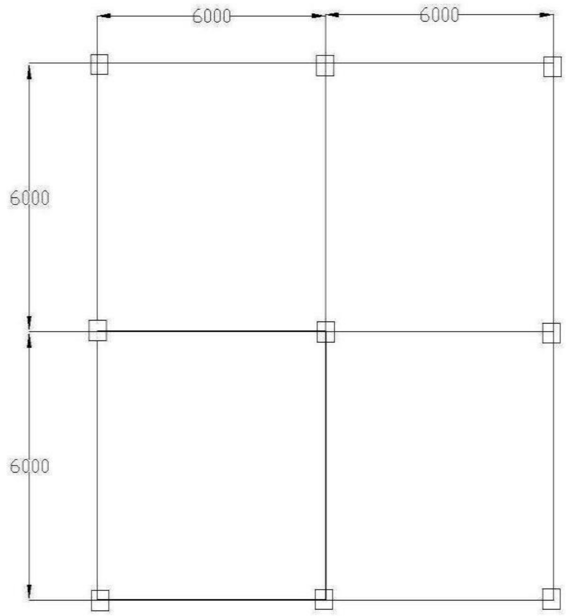
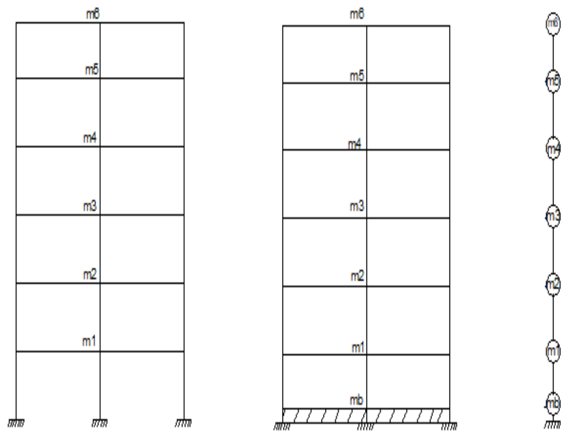


Fig 1. Plan of the building model



(a) (b) (c)

Fig.2 The model of a: (a) Fixed building (b) Base -Isolated building and (c) lumped mass system of a base -isolated building

III. METHODOLOGY

In this paper Response Spectrum analysis for the fixed building and fixed with base-isolation building has performed by using array programming language (MATLAB R2014a) and SCILAB 6.0.1 version with Graphical User Interface (GUI). In order to draw the response spectrum graphs Wilson's Recurrence formula or interpolation formula is used.

A.Response Spectra Analysis for MDOF System:

To perform earthquake analysis require the earthquake ground motion data at each and every place because it is very difficult to setup the earthquake measuring instruments. So in order to overcome this difficulty the best option is response spectrum analysis.

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This method calculates the maximum response values of lateral forces and lateral displacements of the building in each mode of the particular structure. In this analysis damping matrix [C] is not required. But required only the damping ratios of the particular mode.

Response Spectrum is the loci of the maximum Response of the Single Degree of Freedom (SDOF) system due to particular ground motion for a given damping ratio and time period(T) or frequency.

Multi degree of freedom (MDOF) systems are usually analyzed using Modal Analysis or modal Super Position Method. A typical MDOF system with 'm' degree of freedom is shown in Figure (3). When the system subjected to earthquake it vibrates in many different ways. The many different ways are referred as mode shapes of the building

The equations of motion for multi degree freedom(MDOF) of system is given by

$[M]\{\ddot{u}(t)\} + [C]\{\dot{u}(t)\} + [K]\{u(t)\} = -[M]\{r\}(\ddot{u}_g)$(1)

Where,

[M] = Mass matrix (m × m); [K] = Stiffness matrix (m× m); [C] = Damping matrix (n × n); {r} = Influence coefficient vector (n×1); [M], [C], [K] are the superstructure mass, damping and stiffness matrices respectively

$\{\ddot{u}\}$ is the storey acceleration

$\{\dot{u}\}$ is the storey velocity

{u} is the storey displacement

Where, m=degree of freedom of structure

$\ddot{u}_g$ is the earthquake ground motion acceleration

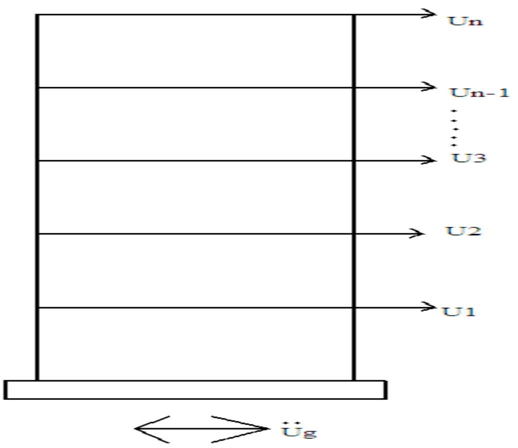

Fig: 3 MDOF system with 'n' degrees of freedom

Φi = Eigen vector or mode shape of the i^th mode

ω_i = natural frequency in the i^th mode.

Let the displacement response of the multi degree freedom system is expressed as

$\{u(t)\} = [\Phi][\{q(t)\}$

Where,{q(t)} represents the modal displacement vector and [Φ] is the mode shape matrix given by:

$[\Phi]=[\Phi_1, \Phi_2, \Phi_3, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, \Phi_n]$(4)

Substituting,{u (t)} = [Φ]{q} in equation (1) and pre multiply by $[\Phi]^T$

$[\Phi]^T[M]\{\ddot{q}(t)\}[\Phi] + [\Phi^T][C]\{\dot{q}(t)\}[\Phi] + [\Phi]^T[K]\{q(t)\}[\Phi] = -[\Phi]^T[M]\{R\}(\ddot{u}_g)(t)$(2)

The above equation gives rise to

$[Mstar]\{\ddot{q}(t)\}+[Cstar]\{\dot{q}(t)\}+[Kstar]\{q(t)\}= -[\Phi]^T[M]\{r\}(\ddot{u}_g)(t)$(3)

Where,

$[\Phi]^T[M][\Phi]$ =[Mstar] =modal mass matrix

$[\Phi]^T[C][\Phi]$ = [Cstar] = modal damping matrix

$[\Phi]^T[K][\Phi]$ = [Kstar] = modal stiffness matrix

By properties of the [Φ], the matrices [Mstar] and [Kstar] are the diagonal matrices. However, for the classically damped system (i.e. if the [Cstar] is also a diagonal matrix), the equation (3) reduces to the below equation

$\{\ddot{q}(t)\}+2*\xi_i\omega_i\{\dot{q}(t)\}+\omega_i^2\{q(t)\}=-\varepsilon i(\ddot{u}_g)(t)$(4)

Where,

q(t) = modal displacement response in the i^th mode,

ξ_i = modal damping ratio of the i^th mode

Γi = modal participation factor for i^th mode given by

$\Gamma_i=\frac{\{\Phi i\}^T*[M]\{R\}}{\{\Phi i\}^T[M]\{\Phi i\}}$

Equation (4) is the form of equation (1),representing the vibration of SDOF system, the maximum modal displacement response is found from the response spectrum i.e.

$q_{i,max}=(abs(q_i(t))_{max}=\Gamma_i S_d(\xi_i,\omega_i)$

The displacement response of the structure in the i^th mode is

$U_i = \Phi_i q_i$

$=\Phi_i\Gamma_i S_{di}$

The acceleration response of the structure in the i^th mode is

$\ddot{U}_i = \Phi_i\Gamma_i S_a(\xi_i,\omega_i)$

The maximum lateral force produced by the i^th mode

$\{F_i\}=\{\ddot{U}_i\}[M]$

The base shear of the building is calculated by using the following formula

Q=ΣF

There are some modal combinations rules in order to find the total response of the all the modes of the structure. In this paper Square root of the sum of squares (SRSS) and Complete Quadratic Combination (CQC) methods has mentioned in IS 1893 part-1 (2016) are used

B.Base-Isolation Parameters:

The base isolation of the building which is as shown in figure (2) is introducedby thelower lateralstiffness material in between superstructure and foundation. The stiffness of the base isolation is designed such that the time period of the first mode of base isolation system is 1.5 sec In this paper we assumed the Mass of slab resting on base isolation system is same as that of mass of the first storey and time period (T) of base isolation as 1.5 sec.

$T_b=\frac{2*\Pi}{\omega b}$, where $\omega_b = \sqrt{\frac{Kb}{(M+mb)}}$

Where, $M=\Sigma m_i$ is total mass of the building

m_b=mass of the base slab rested on base isolation system with lateral stiffness (K_b)

The DOF of fixedbuilding is N and DOF of base isolation structure is N+1. In this paper we have taken 6 DOF fixed structure and 7 DOF base isolation system which are shown in figures (2.a) and (2.b) respectively.

The both structures are subjected to earthquake ground motions i.e,Bhuj, Chamba, Chamoli, El-Centro (N-S) component and Uttarkashi.

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The time period of fixed base structure for the first mode is 0.3714 sec. The stiffness of the base isolation is designed such that the time period of the first mode of base isolation system is 1.5 sec.

The base -isolation damping is considered as 5% as that of the structure. The mass of the base slab located on base - isolation system is 8.0447 x 10^4 kg. The lateral stiffness of the base-isolated rubber is 9.6468 x 10^6 N/m.

C. Graphical User Interface (GUI)

Now a days programming languages usage is very rampant in engineering sciences, especially in earthquake related subjects. Many programming languages like MATLAB,SCILAB,GNU OCTAVE,PYTHON etc., not only just to perform calculations but also to visualize the results in the form of graphs. The platform by name Graphical User Interface(GUI) is very powerful tool to visualize our results in a sophisticated way. Therefore users can feel comfort and can also create applications. The MATLAB and SCILAB GUI's are created in this project is as shown in below figures

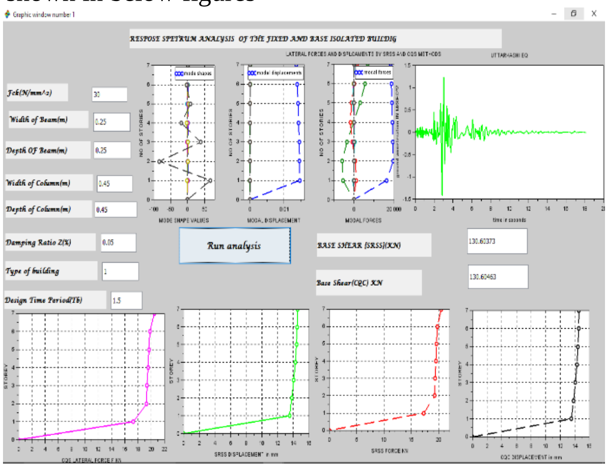

Fig 4: Graphical User Interface in SCILAB

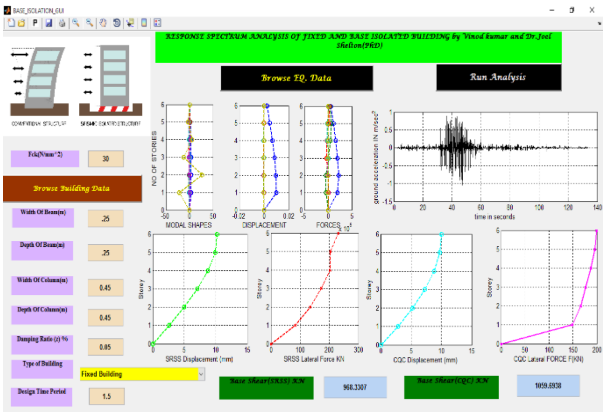

Fig 5:Graphical User Interface in MATLAB

IV. RESULTS AND CONCLUSIONS

By increasing the time period of the first mode (T1=0.3714 sec) of the structure by using base isolation from time period of T1=1.5 sec reduces the lateral earthquake forces on the structure.The structure which is subjected to Utterkashi earthquake ground motion of Peak Ground Motion(PGA)2.48 m/sec^2 gives base shear of 1425.029 KN and 1603.778 KN in SRSS and Coefficient Quadratic Combination(CQC) methods respectively and after lower stiffness base isolator is arranged between superstructure and foundation the base shear reduces drastically 505.248 KN in SRSS and 505.557 KN in CQC respectively.Not only base shear decreases but also the interstorey drifts of the building is also decreases from 0.449 to 0.098 and 0.358 to 0.0863 in SRSS and CQC methods respectively .They are within in the limits of 0.4% of total height of the building which is mentioned in IS 1893 PART-1. The base isolator displaced 52.37 mm after hitting the Utterkashiearthquake so that the superstructure doesn't experiences more interstorey drifts.The base isolator displacements of base isolation building due to five earthquakes are as shown in below table (1)

Table1: Base isolator displacement in SRSS and CQC methods

Name of Earthquake	Chamoli	Bhuj	Chamba	El-Centro	Uttarkashi
SRSS (Base displacement in mm)	104.990	44.067	13.514	106.00	52.37
CQC (Base-isolator displacement in mm)	105.017	44.087	13.53	106.07	52.42

The % decrease of base shears after installation base isolator for the building is as show in table (2)

Table2:% decrease of base shears after introducing base isolator to the building

S.no	Name of Earthquake	% decrease of Base shears after introduction of base isolator system	
		SRSS	SRSS
1	Chamba	89.66	90.66
2	Chamoli	9.28	19.13
3	Bhuj	51.26	59.83
4	Utterkashi	64.54	68.47
5	El-Centro(NS)	65.47	68.79

From the table (2) for different earthquake ground motions,% decrease of base shears are not equal because the response spectrum acceleration graphs are different for different earthquake ground motions. So that while analyzing in response spectrum analysis we have to select the time period or base isolated stiffness such that spectral acceleration is small.

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