ON selection and scaling of ground motion by optimization for analysis of seismically isolated structure

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Abstract-Seismic-isolation laminated rubber is used as a means of suppressing damage to structures caused by earthquakes. Placed between the ground and a building structure, it absorbs seismic energy by flexibly deforming in the horizontal direction. Seismic isolation laminated rubber has a characteristic called a "non-linear restoring force" (which depends on displacement amplitude), and comprehending the dynamic response reflected in that characteristic is a vital factor in the design of the rubber.A method for reducing the damage to a structure caused by an earthquake namely, using laminated rubber for seismic isolation is proposed, and the vibration characteristics of the rubber (which minimizes the seismic response of the structure during an earthquake) is optimized. A method called "Equivalent Linear System using Restoring Force Model of Power Function Type" (PFT-ELS) is applied to nonlinear vibration analysis of the rubber. In that analysis, a building with 15 layers of the laminated rubber is modeled. The seismic response of the building is analyzed, and the usefulness of the laminated rubber is demonstrated by comparing the seismic responses in the cases with and without the laminated rubber. In addition, the hysteresis restoring-force characteristic of the laminated rubber, which minimizes the seismic response of the building, was optimized by using a multi objective optimization. Based on these results, the optimum restoring-force characteristic for different earthquakes was determined. As a result, it was clarified that the developed optimization method can determine the vibration characteristics of the laminated rubber for minimizing the damage to the structure in the design phase.

Keywords—Seismic-isolation, Equivalent Linear System, seismic Response, Seism Tectonic.

I. INTRODUCTION

In Emilia region (Northern Italy) a 5.9 moment magnitude MW earthquake occurred on 20th May 2012 at 02:03:52 a.m. UTC, causing 7 casualties, about 50 injured and 5000 homeless people. At Finale Emilia (Modena, Northern Italy) the epicenter of the earthquake was located. In the area on the following days a series of after-shocks occurred until a second main shock of 5.8 moment magnitude struck the same zones on 29th May, 2012, with an epicenter located at Medolla (Modena, Northern Italy), 20 km west from Finale Emilia. At 09:00:03 a.m. (local time) earthquake is occurred, when the daily activities were starting again, and caused further 20 casualties, about raised the number of homeless from 5000 to 15000 and 350 injured. The structures may be subjected the earthquake is surely the most reliable test, in order to evaluate their seismic vulnerability [2, 3].This is the reason why after a strong motion a series of interesting studies are carried out to examine the structural behavior of different building typologies under seismic actions and to test the validity of seismic codes in force [2, 5]. Earthquake is one of most destructive, unpredictable and dangerous natural hazard, which can leave everything up to few hundred kilometers in complete destruction in seconds. In year 2011 more than 300 hundred natural disasters were happened, 206 million peoples were affected, $ 366 Billion were the economic losses and over 30,000 people lost their lives (20,000 alone in Japan's Earthquake and Tsunami in March 2011) [1] . In the developed countries would result higher economic losses and more number of deaths in developing countries indicated by the EM-DAT (2011) reports. Due to economic conditions people have invested so much money for construction and people are forced to live in high vulnerable locations, and post disaster moving to safer location is not an option as they cannot abandon their present houses. With earthquakes India has enough experiences and it is not rare or unusual anymore and the kind of damage that they can leave behind within seconds [7]. In the world (BMTPC, 2006) about 59% of India's land is prone to moderate to severe earthquakes which it one of highest risk prone are areas. During the last 20 years more than 25,000 people died in 8 major earthquakes and the last major earthquake in India was a decade earlier in Bhuj, Gujarat, which occurred on 26th January 2001 and claimed over 14,000 lives and caused severe damage to building and infrastructure high economic losses (Arya,2000; Ghosh,2008; NDM, 2011) [1, 6].

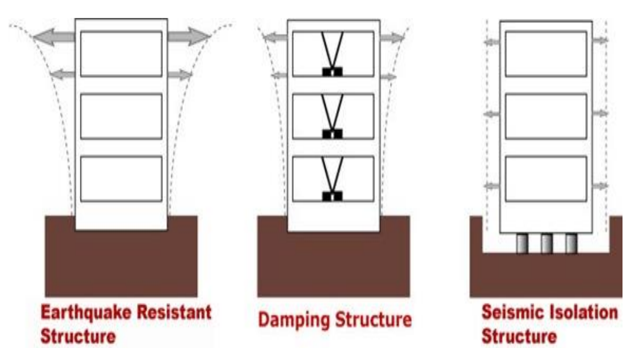


Fig.1 Types of building structures.

On 25 April 2015 (local time 11:56 a.m.) an intense ground shaking struck Central Nepal. With its hypocenter located in the Gorkha region (about 80 km north–west of Kathmandu) the moment magnitude of the earthquake was $M_W 7.8$. The

earthquake occurred at the subduction interface along the Himalayan arc between the Indian plate and the Eurasian plate. From west to east the earthquake is rupture propagated and from deep to shallow parts of the shallowly dipping fault plane [United States Geological Survey (USGS), (2015)], and consequently, strong shaking was experienced in Kathmandu and the surrounding municipalities [12]. Since 1934 this was the largest event, M_w8.1 Bihar–Nepal earthquake (Ambraseys and Douglas, 2004; Bilham, 2004). The 2015 main shock triggered numerous landslides and rock/boulder falls in the mountain areas, blocking roads, and hampering rescue and recovery activities and destroyed a large number of buildings and infrastructure in urban and rural areas. Moreover, aftershock occurrence has been active since the mainshock; several major aftershocks (e.g., M_w6.7 and M_w7.3 earthquakes in the Kodari region, north–east of Kathmandu)
caused additional damage to rural towns and villages in the northern part of Central Nepal [9, 10]. As of 26 May 2015, the earthquake damage statistics for Nepal from the 25 April 2015 main shock stand at the total number of 8,510 deaths and 199 missing. In addition, the major aftershock that occurred on 12 May 2015 caused 163 deaths/missing. Center for Disaster Management and Risk Reduction Technology (CEDIM), (2015) reports that the total economic loss is in the order of 10 billion U.S. dollars, which is about a half of Nepal's gross domestic product. The 2015 earthquakes will have grave long-term socioeconomic impact on people and communities in Nepal [United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA), (2015)] [3, 8]. In Japan Hyogo-ken Nanbu earthquake was the one of most destructive earthquakes on 17 January 1995, even though of a moderate magnitude (M=6.9). In Kobe city and its surrounding area the earthquake caused extreme damage, close to the northern edge of the Osaka basin (Architectural Institute of Japan, 1995). The area of the highest seismic intensity (VII-JMA scale) mainly in a densely populated part of Kobe. The earthquake occurred on a system of predominantly strike-slip faults that form the northern boundary of the Osaka basin [11, 13].

II. RELATED WORK

Dr. P.K. Champati Ray *et al.* [1] – The reason for the failure and damage of structure were discussed and improving future constructions and possible methods for retrofitting have been recommended. With the reported damage these scenarios were matched. In Indian condition the HAZUS methodology can be used as HAZUS building types have some similarity with Indian building types. The results showed that concrete types of buildings were highly vulnerable and there is a high probability of slight damage to such buildings. However, the drawback of using such method is that the capacity curves and vulnerability functions given in HAZUS have been derived for building types in the US, which may differ from the other parts of the world. Therefore, it is concluded that Indian building structural parameters, which are currently unavailable, should be developed and used for generating more realistic damage scenarios using such methodology.GennaroMagliulo*et al.* [2] –with a huge economic loss, damage to industrial precast structure was mainly caused by the 20th and 29th May Emilia earthquakes, because of both the high percentage and the vulnerability of the precast buildings in the area. From the precast structures study, the review of the recorded structural damage and past code design provision, the following conclusion can be drawn.KatssuichiroGoda et al. [3]-This paper summarizes key findings of ground shaking damage in Nepal, and is organized as follows. To link building damage observations with available seismological data, seism tectonic setting of Nepal is reviewed, and earthquake rupture process and aftershock data, which are available from the U.S. Geological Survey (USGS), are analyzed to gain scientific insights into ground motions that were experienced during the mainshock and major aftershocks. It is important to note that strong motion observation networks in Nepal are not well developed and data are not publicly accessible. This means that the estimation of observed ground motions at building damage sites is highly uncertain. Currently, recorded time-history data of strong motion are only available at the KATNP station, which is located in the city center of Kathmandu.ArbenPitarka *et al.* [4]- In this paper, based on a kinematic fault model and a simplified 3D velocity structure of the Kobe area the near-fault ground motion from this earthquake.
Using a 3D finite-difference method (FDM) the kinematic
earthquake rupture and the wave propagation are modeled. In the Kobe area simulation identifies the basin-edge effect as an important factor that influenced the ground-motion amplification pattern. Prasad et al. [5] identified 34 building types that are generally found in India. The classification is based on the structural system of the buildings, which are mainly divided into three types namely adobe and random rubble masonry construction, masonry construction and finally framed construction. These were divided into subclasses based on different parameters like roof material, floors etc. Height of the building is also considered as one of the major factor in classification as the strength and natural period of vibration depend on the height of the building.Bruce R. Ellingwood et al. [6]. This paper reviews some of these special considerations specifically as they pertain to probability-based coded design and reliability-based condition assessment of existing buildings. Difficulties experienced in implementing probability-based limit states design criteria for earthquake are summarized. Comparisons of predicted and observed building damage highlight the limitations of using current deterministic approaches for post-earthquake building condition assessment. The importance of inherent randomness and modeling uncertainty in forecasting building performance is examined through a building fragility assessment of a steel frame with welded connections that was damaged during the Northridge Earthquake of 1994. The prospects for future improvements in earthquake-resistant design procedures based on a more rational probability-based treatment of uncertainty are examined.J. M. Carlson et al. [7]-in this paper examine the dynamic behavior of a simple mechanical model of an earthquake fault. This model, introduced originally by Burridge and Knopoff [Bull. Seismol. Soc. Am. 57, 341 (1967)], consists of an elastically coupled chain of masses in contact with a moving rough surface. This version of the model retains the full Newtonian dynamics with inertial effects and contains no externally imposed stochasticity or spatial inhomogeneity. The only nonlinear feature is a velocity-weakening posed stochasticity or spatial inhomogeneity. Stick-slip friction force between the masses and the moving surface. This system is being driven persistently toward a slipping instability and, therefore, exhibits noisy sequences of earthquake like events. It observe these events in numerical simulations and are able to predict many of their features analytically. Their size distributions are found numerically to be consistent with the Csutenberg-Richter law. Some aspects of the size distributions can be understood by scaling arguments.Moeindarbari et al. [8]

artificial neural network approach is used for surface response to facilitate the prediction of failure. In this paper, the author proposed sensitivity analysis method to identify the critical uncertainty of the parameters. Optimal design variables of the structure are determined by annealing algorithm. This experiment is performed on the 3-story concrete building to reduce the cost of the construction.Soto et al. [9] proposed a neural dynamic optimization model and replicator dynamic system for vibration control of smart base isolated irregular buildings. It uses game theory for resource allocation algorithm to determine the control decisions. The efficiency of the proposed model is evaluated on the 8-story irregular steel building. 3-D base isolated benchmark structure is used for evaluation also.Pandey et al. [10] in this paper, the author analyzed the cost of damage caused by the earthquake. It also presents the stochastic model of seismic risk analysis and analysis of damage cost. It uses poisson process for reformulation of seismic risk analysis.

Bekdaş et al. [11] proposed BAT algorithm which is based on optimum tuning of mass dampers for improving the seismic safety structures. This method optimized the mass, damping ratio and period and different earthquake records are considered during optimization. This experiment is done on the 10-story building and evaluation of result is done by comparing other methods like genetic algorithm, harmony search and particle swarm optimization. The results of the experiment show robustness and feasible approach.Anajafi, et al. [12] introduced the partial mass isolation system for seismic vibration control of buildings. The result of the proposed approach is shown by using identical IC's at different stories. It provides the advantage of facilitating the design and construction of the system which provides an optimal solution. In this method PMI is used with isolated mass ratio and performs better. Performance is also improved by allocating the IC's only at a subset of upper stories.Etedali, et al. [13] Gases Brownian motion optimization (GBMO) algorithm is introduced in the proposed work for the optimal tuning of FOPID (fractional-order proportional–integral–derivative) and PID controllers. It shows the frequency responses of the structure for controlled and uncontrolled cases effectively. In this work four earthquake excitation is also compared and the proposed method performs same in displacement of the structure.

III. THE PROPOSED METHOD

*A. Methodology:*Implications on seismic design 2.4.1 Principles of member design as seen throughout section 2.2.1, as long as adequate reinforcement detailing is assigned, flexural yielding mechanisms have greater potential for developing and maintaining ductile response against cyclic loading. Conversely, mechanisms characterized by exhaustion of shear capacity or anchorage failure tend to present f seismic design is inelastic she Some good rules of practice towards design for ductile response at the plastic hinges may be briefly summarized: inverse rein forcibly the beneficial, ƒ To use low ileent ratios to prevent high rates of strength and stiffness degradation malized compressive is chapter serves also to justify the so-called weak-beaƒ Design philosophy and is of fundamental or which seismic resistance systems are composed of ductile frames. Attending to the strictbehavior of beams and columns, this concept establish mechanism of the structure is composed of flexural plastic hinges is occurring in are intended to remain in the elastic domain. Column design moments are, according to this concept, derived at beam-column joints with respect to the actual resisting moments of the plastic hinges in the beams. Columns are traditionally designed to withstand axial lo structure and from "live loads", whereas beams have the f mainly by flexure. During an earthquake, columns are additionally submitted to lateral loading to which they respond with flexural strength. Beams. However, roughly estimation of the reinforcement is used. Thus, it is expected that most of the dissipation capacity of the structure is allocated in the beams. Rather brittle modes of failure. The obvious implication for the case o that modes of failure in flexural behavior should be pursued and those exploring bond-slip deformations should be avoided. ƒ To limit the compressive strength of concrete, as lower strength concrete classes are more ductile To adopt close spacing of treatment and most special proper hoop configurations to increaseeffect of confinement ƒ To avoid asymmetry of cross-section lay-out as this leads to higher pinching effects in the weak "direction" and consequently, lower energy dissipation capacity tens reinforce ƒ For the case of columns, to design for moderate levels of nor axial force.

*B. Proposed methodology:*RPSD method

Rigid-plastic structures the main idea of the RPSD method is to assume that the dynamic response is in no way influenced by the elastic properties of the structure. Therefore, we deal with rigid-plastic structures. In this type of structure, one has rigid-plastic behavior in the plastic hinges and rigid behavior in the remaining part of the structure. Consequently, if rigid-plastic structures are designed to develop a chosen collapse mechanism, they are treated as assemblages of rigid bodies where the only source of internal displacements is due to deformations at the plastic hinges. 3.1.1.1 Plastic hinges the assumption regarding rigid-plastic behavior at the plastic hinges is worthy of closer examination. The discussion in Section 2 showed that the cyclic behavior of reinforced concrete members in flexure is dominated by the so-called pinching effect, which is mainly due to crack closing and the baushinger effect. Pinching mainly affects the capacity of yield zones to dissipate energy. As this effect increases, energy dissipation capacity decreases, and thus seismic performance becomes poorer. However, provided that some rules are observed, high levels of ductility can be achieved throughout the period of seismic loading, as is the case of fig.3.Based on these types of observations, and for engineering purposes, when considering rigid-plastic relationships, it follows that a great deal of simplicity may be introduced in the treatment of the hysteretic behavior of flexural plastic hinges subjected to large ductility demand. Fig. 3.2 depicts the rigid-plastic hysteretic relationships in terms of strength demand vs. deformation, F vs. δ, assumed herein for the plastic hinges. In Fig. 3.2a), the classic rigid-plastic relationship (Nielsen, 1998) is shown. As may be seen, no change of deformation occurs at all for strength demand within the yield strength limits -fP or fP. The hinge is therefore said to display rigid behavior. When the strength demand in one direction is the yield strength, deformations take place. This corresponds to plastic behavior. In Figure 3.2b), a modified rigid-plastic hysteretic relationship is introduced. It is clear that the same conditions as in the classic case apply. However, we can further assume that when the sign of the strength demand changes, the residual deformation at the end of the previous period of plastic behavior is "lost" without any resistance from the plastic hinge. In the following, this type of behavior will be referred to as slip behavior. Fig.4.1 shows the dynamical responses of the rigid-plastic and elastoplastic models until t= 1.6s subjected to the Kobe ground motion. Symmetric accelerogram. The dynamical response to the Symmetric ground motion of the rigid-plastic model with pinching and of the

Takeda model with short and long period are depicted in terms of time-history curves in Figure 3.16. It may be observed that these models yield much closer results to one another for this ground motion than those discussed in the previous section. This is mainly due to the hysteretic behavior of the present models, which have similar performances in terms of energy dissipation capacity. In fact, observing their hysteretic curves in fig, 3.2 (b) and fig.2.3, it may be concluded that the consideration of pinching effect implies periods of significantly smaller resistance (non-existent for the case of the rigid-slip model) to imposed deformations from the ground motion. Therefore, these models are more prone to accumulate

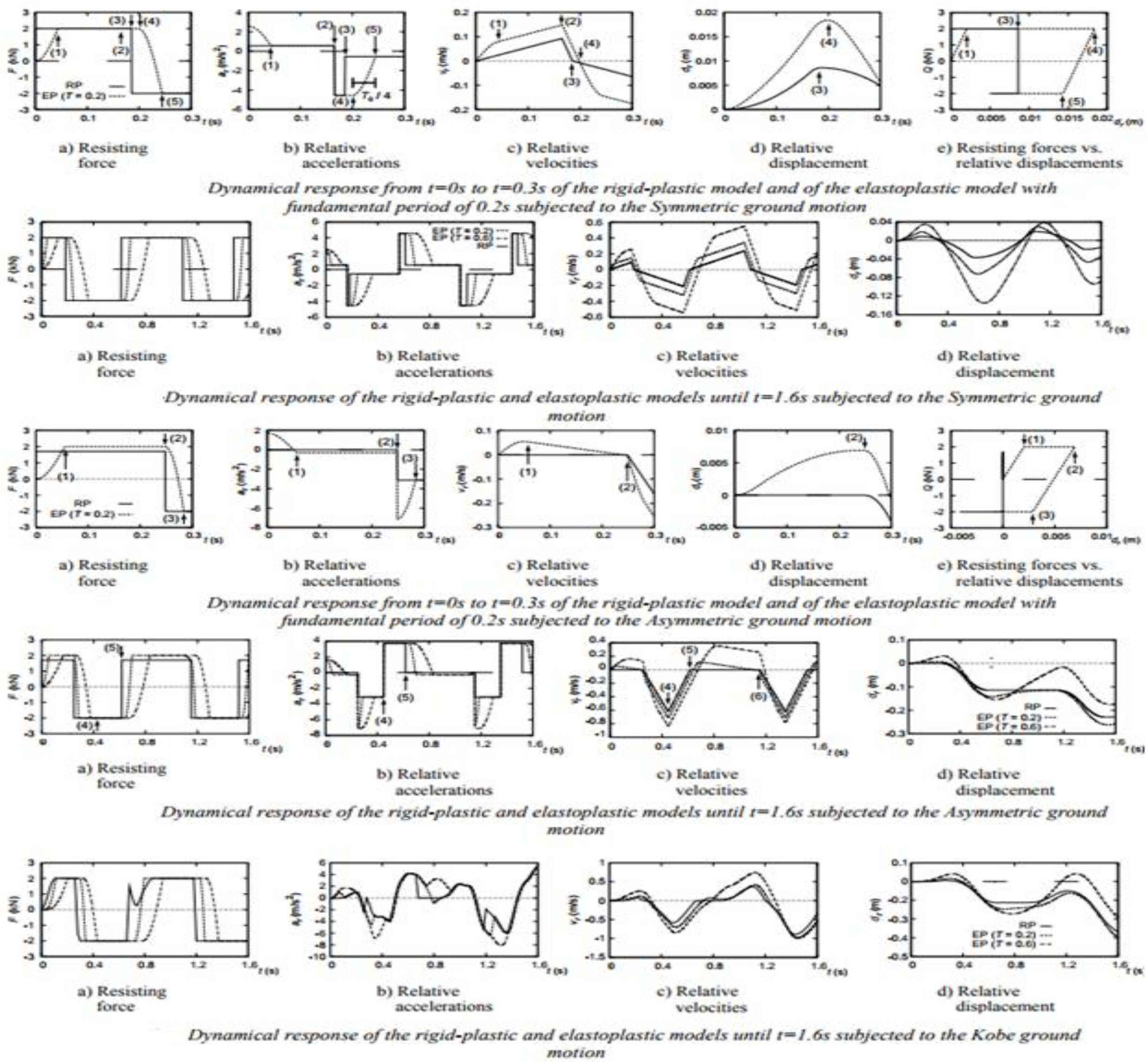


Fig.4.1 Dynamical responses of the rigid-plastic and elastoplastic models until t= 1.6s subjected to the Kobe ground motion

kinetic energy that has to be dissipated mainly by plastic behavior at the hinges. Therefore, they more easily tend to experience a reversal in relative motion of the mass. This leads to larger amplitudes of motion, as observed when comparing Fig.3.11and Fig.3.16. In Fig.3.15 one may see a detail of the response for the first 0.3s of the rigidplastic model with pinching and of the Takeda model with short period, conveniently explaining the deviations between these two models: ƒ From the beginning of the actuation of the ground motion, until shortly after its first reversal, points (2) and (3) in Fig. 3.15, the rigid-plastic model with pinching and the Takeda model develop the same response as the rigid-plastic model and the elastoplastic model respectively (compare with Fig.3.10): The rigid-plastic model immediately undergoes plastic behavior because the magnitude of the ground motion, 2.56 m/s2 , is larger than ay, 2.0m/s2 . When there is a reversal in the ground motion, the models remain in the plastic domain until the kinetic energy is dissipated, point (2) in Fig.3.15c). The Takeda model initially displays elastic behavior, which explains the "smooth" transition from point (0) to (1) in Fig.3.15a) and e). When the capacity of the plastic hinge is exhausted, the model experiences plastic behavior and proceeds until point (3), with the same value for the relative accelerations as in the rigid-slip model. ƒ When the rigid-plastic model with pinching again undergoes rigid-behavior, the ground acceleration is large enough to immediately impose a change of sign in the bending moment at the plastic hinge. This means that there will be a period during which the model is not able to resist the external forces associated with ground motion. The length of this period is directly related with the residual deformation previously imposed, as resistance resumes only when the model is back to its original position. In this particular case, the period corresponds to the time interval between points (2) and (5) in Fig.3.15 (a), during which dynamical equilibrium imposes ar(t)=-ag(t)=–2.56m/s2 (see the equation (3.19) corresponding to slip behavior). On the other hand, the Takeda model performs a smooth transition, as the following in fig.4.2

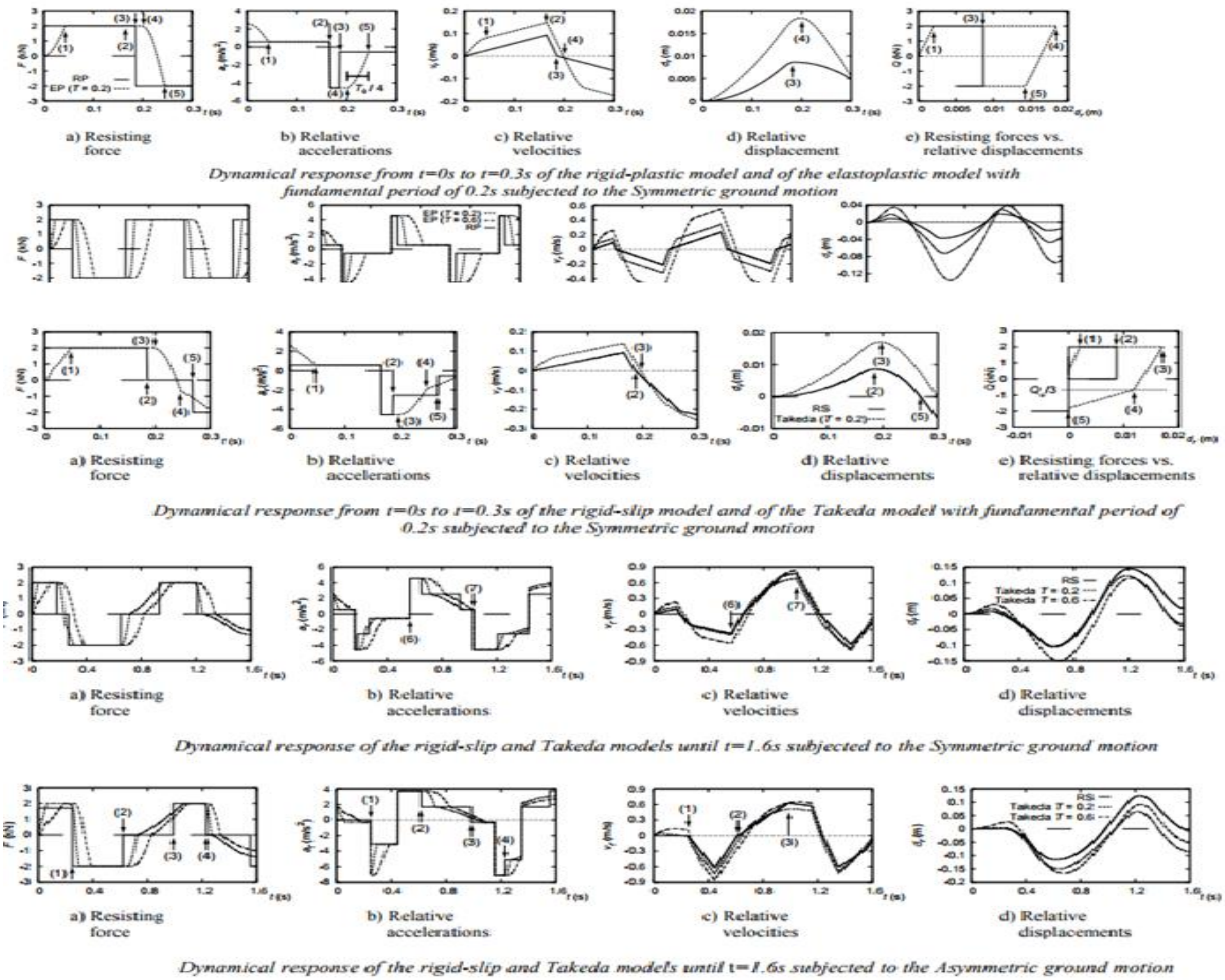


Fig.4.2 Dynamical responses of the rigid-slip and Takeda models until t= 1.6s subjected to the Asymmetric ground motion

IV. RESULTS

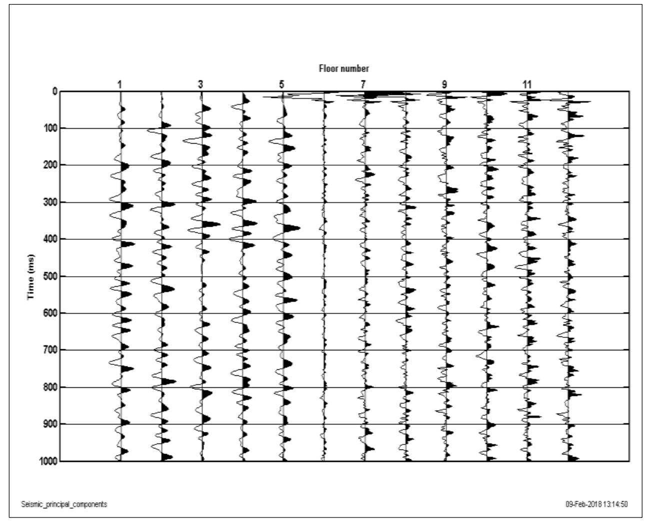
A. MATLAB: Here we use mat-lab as a simulator to simulate the result on seismic resistance buildings. In the survey of 2017 it is concluded that Mat-lab is being used by more than 2 million peoples like engineers, scientist and the person belongs to economic background. Millions of scientist and engineers use Mat lab for analyzing and designing. Mat lab is tool used for simulation and mathematic calculation purpose. Most common Mat lab used to express mathematic calculation is matrix-based Mat lab language. Graphic form of Mat lab makes visualization easy and helps to gain sufficient insight data. Mat lab is a high performance language for technical computation. Mat lab used for several purposes like, Integration of computation, visualization purpose and programing is such manner that problems and solutions can expressed in simple mathematical notations. Mat lab can be used

in math and computation, algorithm development, modeling, simulation, prototyping, data analysis, exploration, visualization; scientific, engineering graphics etc. Basic data element of a MATLAB is an array which doesn't need dimensions. It is an interactive system. In this system we can solve technical problem especially with matrix and vector formulations, in the meantime it would take to write program in a scalar non-interactive language like C or FORTRAN. For easy access to matrix software we write MATLAB developed by the LIPACK and EISPACK projects and together they represent state-of-the-art in software of matric computation. It is a standard instructional tool for introductory and advanced courses in mathematics, engineering and science in universities and in industry it is a tool for productive research, development and analyses. It consists of a set of features of

applicationspecific solutions termed as tool box. Toolboxes are a comprehensive collection of MATLAB functions (M-files) that extend the MATLAB to solve any problem. Area where toolboxes are available includes signal processing, control system, neural networks, fuzzy logics, wavelets, simulation etc.
MATLAB system consists of five main parts:

- Mat lab language: It is a high level array language and contains features like control flow statement, data structure, input/output and oriented programming. It allows both “programming in the small” and “programing in large” to rapidly create quick and dirty throw away programs and to create complete large and complex application program respectively.
- Mat lab working environment: It is a set of tools and facilities that we work as a MATLAB user or programmer. It gives the facility for managing variables and to import and export data. The set of tools includes developing, managing, debugging and profiling M-files.
- Handle graphics: It is a MATLAB graphic system. It includes high-level commands and low level commands for two-dimensional and three-dimensional data for visualization, image processing, animation, and presentation graphics. It also includes low level commands that allow to customize the appearance of graphics fully and to build complete Graphical User Interface (GUI) on our MATLAB applications.
- Mat lab function library: It is collection of computational algorithm ranges from elementary functions to sophisticated function. Some example of elementary function is sum, sine, cosine and complex arithmetic and of sophisticated function like matrix inverse, matrix Eigen value, Bessel function and fast Fourier transform.
- Mat lab application program interface (API): It is a library which allows writing C and FORTRAN programs which interact with MATLAB. It gives facilities for calling routine from MATLAB i.e. dynamic linking, for reading and writing MAT-files. MATLAB is called as computational engine.

B. Simulation Results: The results are stated as follows:



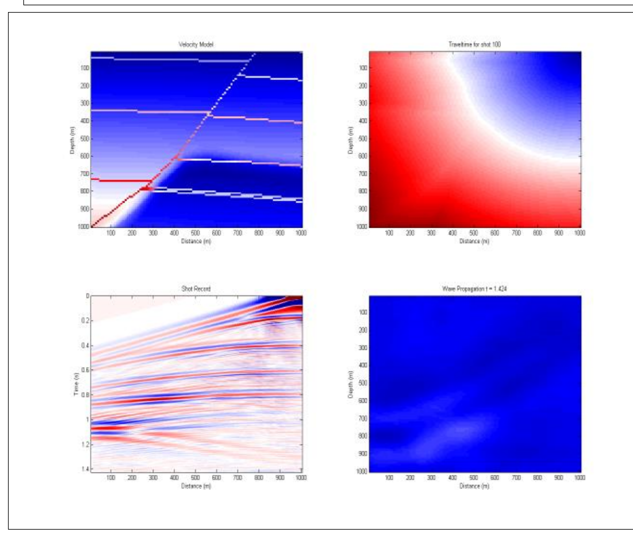


Fig. 5.1 Earthquake effect on seismic building

Fig.5.2 Floor wise affect during earthquake.

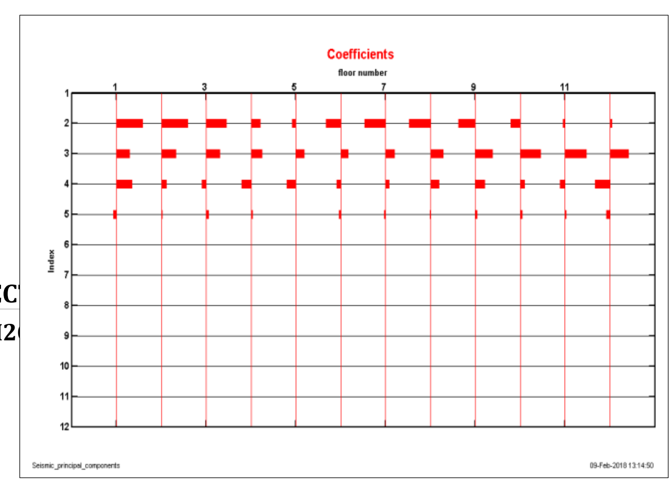
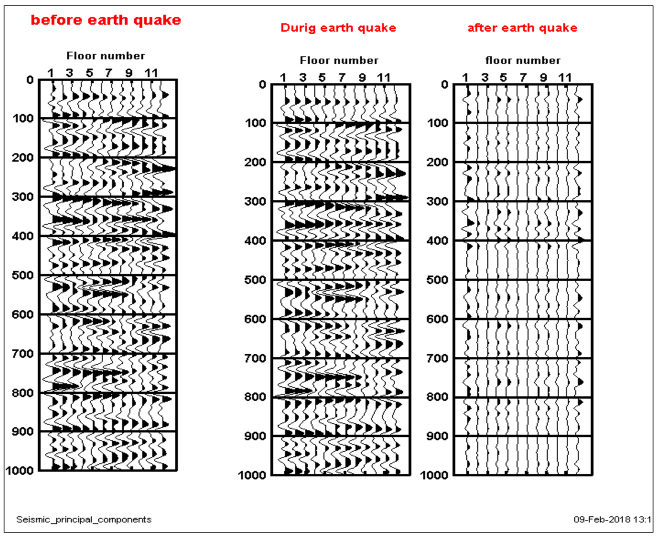


Figure 5.3 Coefficient changes floor wise

Fig. 5.4 Coefficients before earthquake during earthquake and after earthquake.

V. CONCLUSION

Choosing a seismic structural configuration that is expected to give desirable earthquake behavior (a) Overall geometry of the building of required height should be convex. It should be well proportioned, in keeping with elevation slenderness ratios and plan aspect ratios that have been observed in well-designed buildings. For instance, the proportioning of the building should be such that (i) the maximum slenderness ratio (H/B) achieved in different well-designed buildings worldwide is generally found to be around 10, and that of maximum plan aspect ratio (L/B) to be around 4; (ii) the absolute dimensions of buildings should not be unduly long to attract differential ground motion under different parts; for this a seismic wavelength analysis is required to understand the relative dimension of the building with respect to the predominant seismic wave; (iii) the absolute plan area of the building should not be too large to attract large inertia force; and (iv) the obvious irregularities as stated in the design codes and literature of standard should be minimized, if not entirely eliminated. (b) Structural system chosen should be suitable for good earthquake performance, with vertical and horizontal members of lateral load resisting system (LLRS) that can carry earthquake effects safely during strong earthquake shaking. For instance, the structural system should (i) be symmetrical in both directions in plan, (ii) be regular in stiffness along elevation with gradually increasing stiffness towards the lower levels of the building (for instance, open ground storey buildings are unacceptable with sudden drop in lateral storey stiffness and lateral storey strength in the lower storey), (iii) have many direct and short load paths, i.e., the building should have large redundancy, but there should be no unexpected load paths that are not known at the time of design e.g., short-column effects owing to lateral restraint offered by infills are unacceptable, (iv) have no or only limited offsets in plan of the building, and (v) no cut-outs in horizontal LLRS elements, e.g., slabs should not have any cut-outs along their edges. 248 Also, just moment resisting frames may be unsuitable for resisting effects due to strong earthquake shaking in RC buildings; RC walls or braces should be used in buildings meant to be built in moderate to severe seismic zones.



This proportioning of the building geometry and choosing the most suitable seismic structural configuration is best achieved by an objective negotiation effort between the architect and structural engineer involved in the project.

VI. REFERENCES

[1] Malladi, VENKATA PURNA TEJA. "Earthquake, Building Vulnerability and Damage Assessment with reference to Sikkim Earthquake." *University of Twente. Retrieved on October* 20 (2012): 2014.

[2]Magliulo, Gennaro, et al. "The Emilia earthquake: seismic performance of precast reinforced concrete buildings." *Earthquake Spectra* 30.2 (2014): 891-912.

[3]Goda, Katsuichiro, et al. "The 2015 Gorkha Nepal earthquake: insights from earthquake damage survey." *Frontiers in Built Environment* 1 (2015): 8.

[4] Pitarka, Arben, et al. "Three-dimensional simulation of the near-fault ground motion for the 1995 Hyogo-Ken Nanbu (Kobe), Japan, earthquake." *Bulletin of the Seismological Society of America* 88.2 (1998): 428-440.

[5]Haldar, P., and Singh, Y. (2009). Seismic Performance And Vulnerability Of Indian Code- Designed Rc Frame Buildings. ISET journal of Earthquake Technology, 46(1), 29-45.

[6] Ellingwood, Bruce R. "Earthquake risk assessment of building structures." *Reliability Engineering & System Safety* 74.3 (2001): 251-262.

[7] Carlson, J. M., and J. S. Langer. "Mechanical model of an earthquake fault." *Physical Review A* 40.11 (1989): 6470.

[8]Moeindarbari, Hesamaldin, and TourajTaghikhany. "Novel procedure for reliability-based cost optimization of seismically isolated structures for the protection of critical equipment: A case study using single curved surface sliders." *Structural Control and Health Monitoring* 25.1 (2018).

[9] Soto, Mariantonieta Gutierrez, and HojjatAdeli. "Vibration control of smart base-isolated irregular buildings using neural dynamic optimization model and replicator dynamics." *Engineering Structures* 156 (2018): 322-336.

[10] Pandey, Mahesh D., and J. A. M. van der Weide. "Probability distribution of the seismic damage cost over the life cycle of structures." *Structural Safety* 72 (2018): 74-83.

[11] Bekdaş, Gebrail, Sinan MelihNigdeli, and Xin-She Yang. "A novel bat algorithm based optimum tuning of mass dampers for improving the seismic safety of structures." *Engineering Structures* 159 (2018): 89-98.

[12] Anajafi, Hamidreza, and Ricardo A. Medina. "Partial mass isolation system for seismic vibration control of buildings." *Structural Control and Health Monitoring* 25.2 (2018).

[13] Etedali, Sadegh, Abbas-Ali Zamani, and Saeed Tavakoli. "A GBMO-based PI λ D μ controller for vibration mitigation of seismic-excited structures." *Automation in Construction* 87 (2018): 1-12.