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SEISMIC BEHAVIOUR OF BASE ISOLATED STRUCTURES WITH VARIOUS DISTRIBUTIONS OF ISOLATORS

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ABSTRACT

This study concerns with the seismic response comparison of a fixed base building with a base isolated building and parametric study of a base isolated building. The structural system considered for analysis is a three storey reinforced concrete building, which is idealized as a shear type building with one lateral degree of freedom at each floor level. The isolation systems considered for this study are Laminated Rubber bearing (LRB), Lead Rubber Bearing (N-Z bearing) and Friction Pendulum System (FPS). The response of fixed base building and of base isolated building is compared in terms of maximum top floor acceleration, inter-storey drift, maximum floor displacements and base shear. For parametric study important isolation system parameters considered are: (i) isolation time period, isolator damping for LRB; (ii) isolator yield strength, isolation time period, isolator damping for N-Z bearing and (iii) isolation time period, friction coefficient for FPS. It is found that base isolation technique is very effective in reducing seismic response of structure and isolation system parameters significantly influence the earthquake response of a base isolated structure.

I. INTRODUCTION

This Report tries to contribute to a better understanding of the behaviour of base isolated asymmetric structures. Numerous variants of originally symmetric four storey RC frame building isolated by a simple lead rubber bearing base isolation system with various distributions of isolators were considered as test examples. The symmetrical structural variant and appropriate LRB bearing properties were designed according to Eurocode 2 and 8. The asymmetric variants were produced by shifting the center of mass CM toward one side of the building. Additional ``torsionally unrestrained" and ``torsionally restrained" sub-variants of each building variant were obtained by changing the mass distribution, while total mass sum remained unchanged. For the base isolation system we have considered six different distributions of bearings characterized by the position of the center of isolators CI in respect to the center of mass CM of the superstructure. Two symmetric (Uniform and Peripheral distribution) and four asymmetric distributions of isolator this were included in the analyses. The Report analyses the positive and negative effects of different bearing distributions to the displacements and rotations of the superstructure as well as to the base isolation system and tries to determine the most favorable distribution of isolators that is able to balance the effects of introduced eccentricities. The results obtained by 3D nonlinear dynamic analyses are presented as an average of maximums for ten selected ground motions and three different scaling. They indicate that all six considered distributions of bearings, however differently, substantially reduce the unfavorable torsional effects, which are with different extent transferred from the superstructure to the base isolation system. It was further observed that CI D CM distribution, favored by common building codes, is best only for accommodating the torsional effects in the base isolation system. A significantly different conclusion was found observing the nonlinear behaviour of the superstructure, where CI D CM distribution might cause more damage in the flexible side frames.

The research and numerous applications in the field of seismic base isolation have undoubtedly proved that this system of alternative seismic protection is extremely effective in minimizing the damage of certain type of buildings during seismic action. The technical development of rubber bearings and dampers in recent years has reduced their price and such systems have become an important alternative for construction of building structures in seismic areas, even for ordinary multi-storey buildings such as offices, residential housing, industrial buildings and others [3].

It is also a fact that the architectural design is based on completely different values compared with those favored by earthquake engineering and that the recognizable complex irregular buildingsusually win the first prizes in competitions led by the architects and the investors. Such structures are very often asymmetric in plan or/and in elevation and thus completely irregular from a structural point of view. We do believe that the correct usage of base isolation systems with respect to certain structural rules, limitations and rational technological limits, can substantially reduce the negative torsional effects produced by structural asymmetry and thus contribute to general structural safety in seismic areas.

Our research, summarized in the Report, is focused on the study of the seismic behaviour of the in plan asymmetric multi-storey base isolated structures. The literature survey showed that the response of base isolated asymmetric buildings is still an ongoing research topic with relatively few works available. Some of the first reported research studies on rigid superstructure models could be found in [4,5] and on multi-storey models in [6]. They have concluded that a base isolation system with zero or a small amount of eccentricity (e.g. CI CM) significantly reduces torsion in base isolation systems caused by superstructure asymmetry.

1.1 Problem Statement

In existing approach the same building structure with various reinforcement distributions had already been used in several previous research reports by the first author and his co-authors, which addressed the problems of non-linear torsional response of fixed base buildings. More detailed descriptions of the selected structure can also be found in [2] as well with some modifications in [5].

1.2 Objectives

Our aim is focused on the study of the seismic behaviour of the plan asymmetric multi-storey base isolated structures. The literature survey showed that the response of base isolated asymmetric buildings is still an ongoing research topic with relatively few works available. Some of the first reported research studies on rigid superstructure models could be found in [4,5] and on multi-storey models in [6]. They have concluded that a base isolation system with zero or a small amount of eccentricity (e.g. CI CM) significantly reduces torsion in base isolation systems caused by superstructure asymmetry,

1.3 Scope of the Project Work

The nonlinear response of FB and BI asymmetric variants with various positions of the center of isolators CI is obtained for ten ground motion records scaled to building design acceleration. The torsional coupling was introduced by the variation of the mass eccentricity and torsional-to-lateral frequency ratio s of the superstructure. From the results obtained from the present study, the following conclusions may be drawn which are only applicable to frame type building structures within the selected range of structural and base isolation eccentricities. The conclusions are based on the analyses made for buildings in which eccentricity was created only in one direction. In the case of a large two directional eccentricities the observed amplifications might be even bigger. The FB structure was designed according to Eurocodes and therefore the obtained conclusions might be extended to similar code designed FB and BI buildings.

II. LITERATURE REVIEW

2.1. SEISMIC RESPONSE OF SIMPLY SUPPORTED BASE-ISOLATED BRIDGE WITH DIFFERENT ISOLATORS:

The seismic response of simply supported base-isolated bridge with different isolators is presented. The isolated bridge deck is idealized using simplified model of a simply supported
rigid deck with three degrees-of-freedom, two lateral translational, mutually orthogonal and one rotational. The rotational degree-of-freedom of the bridge deck may arise because of the dissimilarity in properties of different seismic isolation devices such as elastomeric and sliding systems supporting the bridge deck. The sources of dissimilarity in the isolators considered here are the isolation stiffness and the yield force. The flexibility of abutments and bridge deck is ignored and two horizontal components of earthquake ground motion are applied, considering

Bi-directional interaction of the seismic response. The governing equations of motion for the uncoupled and torsionally coupled bridge are derived and solved using Newmark's method of integration to obtain the seismic response. The parametric studies are conducted for different system configurations, isolation systems and frequency ratios during torsionally coupled and uncoupled conditions. The seismic response of base-isolated bridge is seen to be considerably altered due to the dissimilarity in the isolator properties. The eccentricity arose due to the isolation stiffness affects more than that due to the isolator yield forces. The effectiveness of isolation reduces at higher eccentricities and the torsionally coupled response diminishes with the increase of uncoupled torsional to lateral frequency ratio.

2.2. BEHAVIOR OF BASE-ISOLATED STRUCTURES WITH HIGH INITIAL ISOLATOR STIFFNESS

Analytical seismic response of multi-story building supported on base isolation system is investigated under real earthquake motion. The superstructure is idealized as a shear type flexible building with lateral degree-of-freedom at each floor. The force-deformation behaviour of the isolation system is modelled by the bi-linear behaviour which can be effectively used to model all isolation systems in practice. The governing equations of motion of the isolated structural system are derived. The response of the system is obtained numerically by step-by-method under three real recorded earthquake motions and pulse motions associated in the near-fault earthquake motion. The variation of the top floor acceleration, understory drift, base shear and bearing displacement of the isolated building is studied under different initial stiffness of the bi-linear isolation system. It was observed that the high initial stiffness of the isolation system excites higher modes in base-isolated structure and generate floor accelerations and story drift. Such behaviour of the base-isolated building especially supported on sliding type of isolation systems can be detrimental to sensitive equipment installed in the building. On the other hand, the bearing displacement and base shear found to reduce marginally with the increase of the initial stiffness of the initial stiffness of the isolation system. Further, the above behaviour of the base-isolated building was observed for different parameters of the bearing (i.e. post-yield stiffness and characteristic strength) and earthquake motions (i.e. real time history as well as pulse type motion).

2.3. SEISMIC ISOLATION AND ENERGY DISSIPATING SYSTEMS IN EARTHQUAKE RESISTANT DESIGN

Seismic isolation and energy dissipating systems present an effective way to common seismic design for improving the seismic performance of structures. These techniques reduce the seismic forces by changing the stiffness and/or damping in the structures, whereas conventional seismic design is required for an additional strength and ductility to resist seismic forces. The research and development works of passive, active and hybrid devices are ongoing intensively. This paper presents a brief history of isolation techniques and introduces these systems from passive devices to sophisticated ones and completely active systems. By focusing on the passive systems especially base isolation systems, development and progress involved in those are reviewed. A note is also made about applications and the conclusion of the recommended provisions from codes for new buildings and other structures is reviewed. On the other hand, this paper reviews the situation of earthquake protective systems used in Turkey. This technique is not yet very common, but a number of research activities is going on in order to investigate the behaviour

of the isolated buildings. Civil engineers, architects, constructors and owners have great responsibilities concerning applications of these systems, but especially the users have sanction, therefore widely use of the earthquake protective systems will be provided by the users' awareness.

2.4. ISOLATED BUILDINGS ON SLOPING GROUND

Building frames on sloping ground (hilly areas) one of the factors which reduces the capacity of the structure due to the fact that the column in the ground storey are of different heights which leads to combination of short column and long column. Along with this if building has an open ground storey, it is often induced in structures either due to client requirement or improper planning. If this structure is subjected to earthquake which becomes more vulnerable in severe zones. The present comparative study made an attempt to understand the effect of earthquake load on building frames on sloping ground with fixed base and isolated base under severe zone. The computation models of ordinary moment resisting frame was developed in SAP2000 as 3D space frame to carry the dynamic linear seismic analysis as per IS 1893 Part (I) -2002 respectively. The vertical and horizontal stiffness of lead rubber isolator is designed for maximum gravity load and design displacement of the structure and values were assigned for isolated models. This study may help to understand the effect of base isolation under seismic forces, the efficient level and stability of the lead rubber isolator for different storey buildings with base isolation on different sloping ground. Analysis results shows reduction in base shear and story acceleration values for base isolated building. The displacement, story drift and time period of base isolated structure is increased as compared to fixed base structure on different slope. Comparative results shows that the efficient level of base isolation is at the foundation.

2.5. NATURAL BASE ISOLATION SYSTEM FOR EARTHQUAKE PROTECTION

The performance of a well-designed layer of sand, geo-grid, geo-textiles and composites like layer of sand mixed with shredded tyre (rubber) as low-cost base isolators is studied in shake table tests in the laboratory. The selected base isolator is placed between the block and the sand foundation. Accelerometers are placed on top of the footing and foundation sand layer. The displacement of the footing is also measured by transducers. The whole set-up is mounted on the shake table and subjected to sinusoidal motion with varying amplitude and frequency. Sand is found to be effective only at very high amplitude (>0.65 g) of motion. Among all the different materials tested, the performance of a composite consisting of sand and 50% shredded rubber tyre placed under the footing is found to be the most promising as a low-cost, effective base isolator.

2.6. COMPARATIVE STUDY FOR SEISMIC PERFORMANCE OF BASE ISOLATED & FIXED BASED RC FRAME STRUCTURE

A large proportion of world's population lives in regions of seismic hazards, at risk from earthquakes of varying severity and frequency of occurrence. Earthquake causes significant loss of life and damage of property every year. So, to mitigate the effect of earthquake on building the base isolation technique one of the best solutions. Seismic isolation consists of essentially the installation of mechanisms which decouple the structure from base by providing seismic isolators. The seismic isolation system is mounted beneath the superstructure and is referred as 'Base Isolation'. The main purpose of the base isolation device is to minimize the horizontal acceleration transmitted to the superstructure. Base isolation is very promising technology to protect different structures like building, bridges, airport terminals and nuclear power plants etc. from seismic excitation. In this report, the G+14 storied frame structure is taken to compare the seismic effect of fixed base structure with respect to isolated structure. The (G+14) storied frame structure is design with base isolation by using the ETAB software. High Damping Rubber Bearing (HDRB) is used as an isolator having efficient results for frame structure over the fixed base structure than any other isolation system. The report concluded that the very less values come for lateral loads by using High Damping Rubber Bearing. It has high flexibility and energy absorbing capacity, so that during an earthquake, when the ground vibrates strongly only moderate motions are induced within the structure itself.

2.7. ANALYSIS OF SEISMIC PERFORMANCE OF FPS BASE ISOLATED STRUCTURES SUBJECTED TO NEARFAULT EVENTS

The paper examines the seismic behaviour of base isolated structures with friction pendulum slide bearing devices subjected to near fault events characterized by significant vertical ground motion components. In particular, in order to evaluate the effects of the mass eccentricity, of the ratio between the superstructure mass and the overall mass system, of the bearing radius of curvature and of the friction on the seismic response, non-linear dynamic analysis, carried out by using MDOF numerical model, have been performed by considering two near-fault seismic events, L'Aquila 2009 and Emilia Romagna 2012. The results obtained show that mass eccentricity do not influence significantly the main seismic response parameters, while the massratio, the friction coefficient and the radius stronglyaffect the seismic behaviour of the base isolated structures.

III. METHODOLOGY

Original fixed base (FB) structure:

Many parametric studies have used the idealized one storey or multi-storey building models to ease the formation and the range of numerous parameters to be observed in their studies. In such cases it is possible however, to neglect or misinterpret the characteristics of realistic buildings and the obtained conclusions might be inaccurate or irrelevant for common building practice. For this reason we have decided to use in our study a fairly simple, but completely realistic 3D building structure designed according to Eurocode 2 and 8. This double symmetric ``original building variant" was then changed to numerous different mass eccentric sub-variants and isolated with different base isolation systems in a physically possible and realistic manner.

The original fixed base (FB) four-storey reinforced concrete 3D frame building is presented in Fig. 1. The cross sections of the structural members are equal in all frames and in all storeys. The Eurocode 8 design spectrum for soil class B scaled to the peak ground acceleration 0:35g was used for the building design. The behaviour (reduction) factor q was equal to 3.75 (medium ductility class). Storey masses amounted to 295 (237) tons and mass moments of inertia to 16,900 (13,600) tm2 in the bottom storeys and at the roof, respectively. The design base shear was equal to 23% of the total weight.

IV. CONCLUSION

The nonlinear response of FB and BI asymmetric variants with various positions of the center of isolators CI is obtained for ten ground motion records scaled to building design acceleration. The torsional coupling was introduced by the variation of the mass eccentricity and torsional-to-lateral frequency ratio s of the superstructure. From the results obtained from the present study, the following conclusions may be drawn which are only applicable to frame type building structures within the selected range of structural and base isolation eccentricities. The conclusions are based on the analyses made for buildings in which eccentricity was created only in one direction. In the case of a large two directional eccentricities the observed amplifications might be even bigger. The FB structure was designed according to Eurocodes and therefore the obtained conclusions might be extended to similar code designed FB and BI buildings. The top displacements and rotations of all asymmetric BI buildings are substantially smaller (up to 8 times) than those of FB buildings in absolute measure. However, the torsional amplifications of the superstructure with respect to the symmetric structure of BI buildings are not necessarily smaller than for FB buildings. Depending on the position of the center of the isolators CI, the torsional amplification ratio of the BI structure can be increased (maximal up to 1.3/ 2 at the stiff/flexible side) or decreased even below the response of the symmetric structure

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