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AN EVALUATION OF ISOLATED STRUCTURES WITH SEISMIC ISOLATORS

BY

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Abstract. The registered records in recent years show that near field earthquake has different characteristics compared to that of a far field earthquake. The most important characteristics are the forward directivity effect with a long period pulse in velocity Accelerogram. To compensate the destructive effect of earthquakes, engineers should use a suitable seismic isolator system. The concept of the seismic isolation system is separating the structure from the strong damaging ground motions, avoiding energy absorption by the superstructure. The present study evaluates the characteristics of near and far field and their effect on the isolated structures with seismic isolator.

Keywords: far and near field earthquake; seismic isolator; supplementary dampening; seismic response.

1. Introduction

After destructive earthquakes such as Northridge (1994), Kope, Japan (1995), Parkfield, California (1966), Chichi, Taiwan (1993), San Fernando,

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California (1971) and Bam earthquake (2003) in recent years, the safety increase and performance of buildings are of great importance. These recorded accelerograms are all in near fault and near fault motions have important characteristics compared to that of far faults. The most important characteristics are the effect of directivity and permanent displacement and mostly it is as a pulse with long period in the time history of velocity. The ordinary structural systems apply strong ground motions, acceleration, force and load directly on the structure during the earthquake and this can damage the structural system. Over the time, the earthquake engineers achieved seismic isolator system and this system are between foundation and structure and it separates structure from the ground to reduce seismic response. Various studies have been conducted on the effect of near field earthquake on different types of structures and by evaluation of the behaviour of these structures and comparison with the results of far field earthquake can be of great importance. Building means, a more or less enclosed and permanent structure for housing, commerce, industry, etc., distinguished from mobile structures and those not intended for occupancy.

2. The Characteristics of Near –Field Earthquake

For the first time, (Hudson & Housner, 1958) pointed out the near-field ground motion contained critical energy pulses. Although the ground motion may have small Richter magnitude and amplitude, it has high damage potential. Then, (Bolt, 1971) recorded velocity pulses that were identified as arising from the rapidly slipping fault based on ground motions recorded in the 1971 San Fernando earthquake. This result led into the division of far and near earthquake.

2.1. Directivity Effect

If the fault propagation velocity is equal to the shear wave velocity (Vr = 0.8Vc), it means that the majority of energy of the fault reaches the site in a great impact. In other words, if the fault is ruptured, waves are propagated from all its components; if the site is in the direction to the fault rupture, the period at which the waves reach the site is low and it acts as impact applied on the site (forward directivity).

If the site is reverse to the fault rupture, the waves can be far away from each other or they reach the site longer (backward directivity). Neutral directivity are occurred when the far or near fault into the site is not defined and it has no specific effect on duration of the time history of earthquake (Baghchesaraei & Baghchesaraei, 2016; Niknam *et al*., 2008). For example, Fig. 1 shows Landers earthquake and the location of two stations in which

Liosern station is in front of rupture face and Cheshvatery station is on the back of the face in which directivity pulse and short duration in the recorded Accelerogram of Liosern station can be observed (Davoudi *et al*., 2010). The most important characteristic of directivity is as follows:

1º Energy as energy accumulated in a short interval affects as impact on the structure (Bray & Rodriguez-Marek, 2004).

2º Directivity phenomenon causes that in near field earthquakes (vPG/aPG) ratio is bigger and (dPG/vPG) is smaller than the fear field earthquake. The above ratios can make velocity-sensitive region much narrower, and the acceleration-sensitive and displacement-sensitive regions as much wider, compared to far-fault motions; the narrower velocity-sensitive region is shifted to longer periods (Chopra, & Chintanapakdee, 2001). Fig. 2 illustrates the response spectra of some recordings near field with the recordings of far field of Taft are plotted as the validity of the above items is observed.

3º The directivity effect perpendicular on fault due to the radial dispersion of shear displacement of fault is higher than directivity in parallel direction and maximum velocity, maximum displacement and response spectra in vertical directivity is higher than the parallel directivity (Somerville, & Graves, 1993). as shown in Fig. 3.

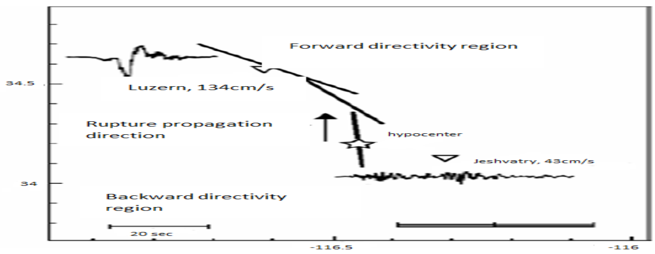

Fig. 1 – Shows Luzern region and earthquake recording stations in 1962 (Chopra & Chintanapakdee, 2001).

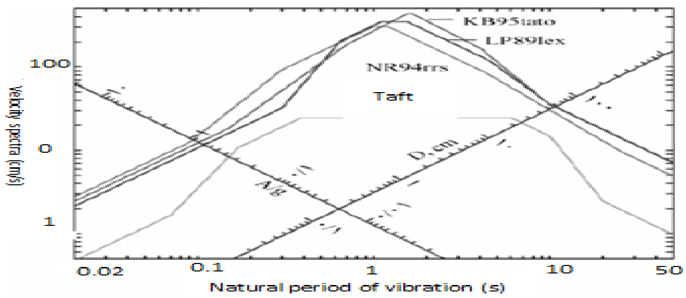

Fig. 2 – The response spectra perpendicular to fault of three recordings of near field with the recordings of far field of Taft (Chopra & Chintanapakdee, 2001).

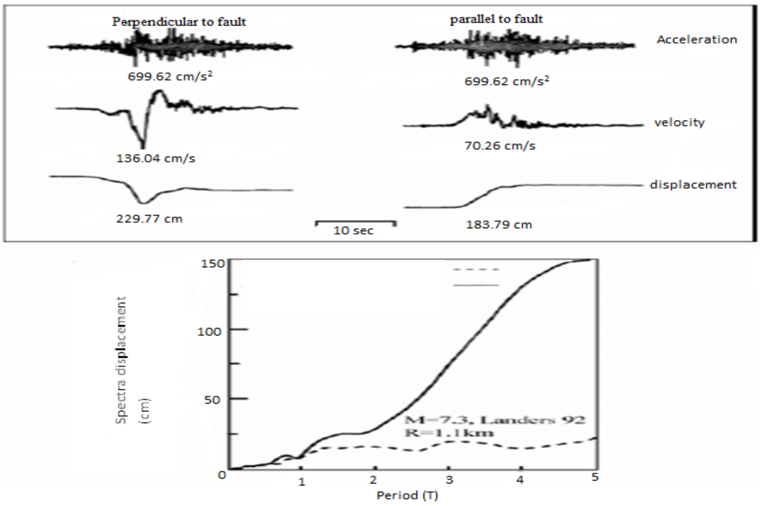

Fig. 3 – The time history of acceleration, velocity and displacement perpendicular to fault and parallel to fault and response spectra of displacement of Luzern station (Somerville & Graves, 1993).

2.2 The Effect of Vertical Component

Many researchers believe that the effect of vertical acceleration of earthquake is one of the differences of far and near field as:

1º Vertical acceleration to horizontal acceleration ratio (aPV/aPH) in near field earthquake is high in near field earthquake compared to that of far field earthquake (The far field earthquake has low vertical acceleration and it cannot be considered) and the difference is higher than 2/3 as considered by the regulations and it is worth to mention that this ratio is higher in soft soil compared to that of other sites (Wang *et al*., 2002; Ni & Zhu, 2004).

2º The ratio of vertical to horizontal response spectra (SV/SH) is dependent on the period of the structure and distance of the structure as for the low period and near fault, vertical to horizontal spectra is higher than 2/3 but for a long period, this value is low (Bozorgnia *et al*., 1995).

The average creep curve of three series of 5 toothed-plate joints is shown in Fig. 3 on a logarithmic time scale for 30%, 40% and 50% load level. The creep curve is steeper for 30% than for 40% and 50%. Partial failures have occurred at load levels of 40% and 50% and these have been excluded from the average creep curves after the failure had initiated. Generally, a shear plug failure under the bolt initiates an increase in creep rate. Sometimes, a single split in the centre of the middle member can be observed.

2.3. The Effect of Permanent Displacement

Other characteristics of the recordings of near field in new earthquakes, including the 1999 earthquakes in Turkey and Taiwan, the permanent displacement of ground fault is in the near fault regions as occurred in a small interval of sliding along with the fault sliding and is independent of the dynamic displacement of the directivity pulse of ground rupture. Thus, this affects the components along with the fault sliding (in parallel to fault sliding in strike slip fault and along the slope in dip-slip fault). For dip-slip fault, the effect of permanent displacement and the effect of directivity are in the same direction and the ground permanent displacement is occurring at the same time with the maximum dynamic displacement and should be considered as coinciding loads. The crossing of loads at one period has extensive damage potential (Stewart *et al.*, 2001) For example, permanent displacement about 2m is created in Yarimca station in Kocaeli earthquake (Fig. 4).

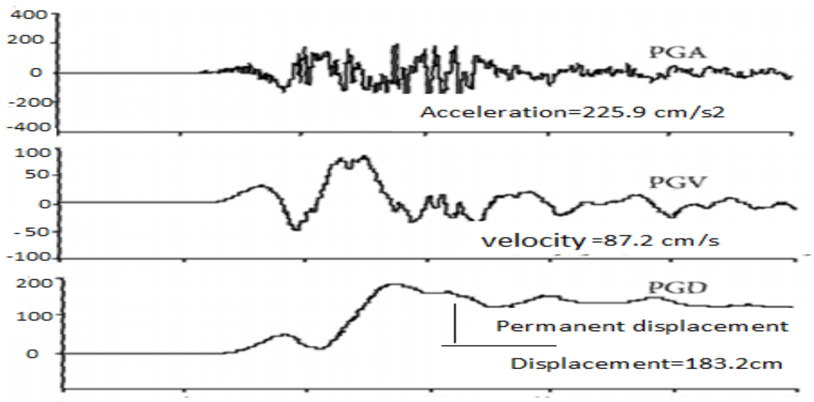

Fig. 4 – NS direction Yarimca station recordings during the Kocaeli earthquake (Kalkan *et al.*, 2004).

2.4. The Hanging Wall Effect

The effect of hanging wall can be created on dip-slip earthquake. As shown in Fig. 5, one of the primary reasons of this effect is high proximity of the sites located in the hanging wall to the fault surface of the sites located in foot wall in a similar distance from the fault (Li & Xie, 2007) R2 ≤ R1.

The hanging wall effect can have the following characteristics in near field earthquakes.

1º More amplitude & less damping in strong ground movement parameters in hanging wall compared to foot wall in a similar distance can be observed (Abrahamson & Somerville, 1996) .

2º This effect has the highest effect in acceleration response spectra in short periods (Somerville, 2000)

3º Not considering the hanging wall effect in empirical models of ground motion parameters applied in the models, it is possible that in many states, great errors are created in the prediction of near field earthquakes and evaluation of the seismic probability risk (Yu & Gao, 2001).

3. Seismic Isolator

Smart buildings are not just about introducing and working innovation or innovation progressions. The isolator changes the acceleration based on the change in period (increasing period) as shown in Fig. 5 and in acceleration spectra, the entrance acceleration to the structure is reduced and the structural system enters the safe zone (Ni & Zhu, 2004). The increase of period has some problems in which as shown in Fig. 6, displacement is increased and some mechanisms are used in the system for energy dissipation (damping) and displacement is reduced. This damping reduces the resonance phenomenon arising from the components with high period in ground motion (The guidance of design and implementation of seismic isolator systems in buildings, 2011).

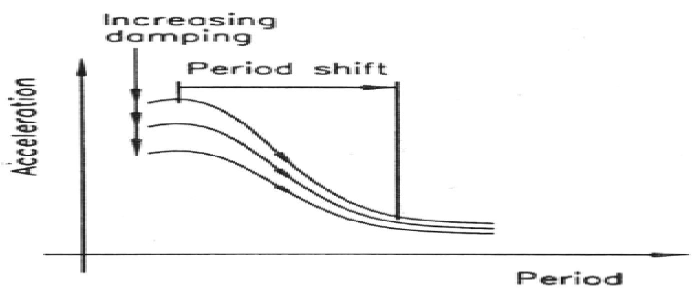

Fig. 5 – Period increase and damping of isolator system and reduction of response acceleration (Skinner *et al.*, 1999).

Thus, it is required that the seismic isolator system has the following capabilities:

a. it should tolerate the vertical forces of the weight of structure and earthquake response during the earthquake;

b. in horizontal direction, it should have the required flexibility;

c. it should absorb energy .

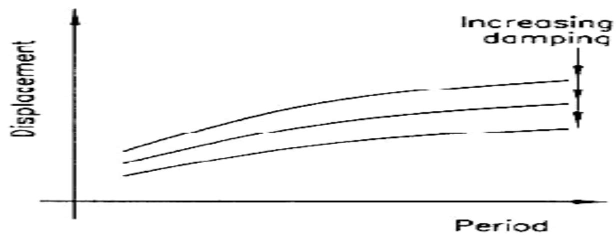

Fig. 6 – The increase of period and dampening of isolator system and increase of displacement of isolator system (Skinner *et al*., 1999).

The seismic isolator systems and their energy absorption capability are identified as effective tool to protect against earthquake. The seismic isolator is installed mostly above the foundation of the building structure reducing the structure response against the earthquake. In addition, the performance of seismic isolator systems is weakened over the time (Lee et al 2014). The building isolated from the bias is generally composed of three main parts:

1º Isolation system including isolation devices such as dampers and ball bearings.

2º Rigid base floor as connected to isolation systems.

3º Superstructure including the beams, column and diaphragms (Melih Nigdeli *et al*., 2013).

Generally, seismic isolators are divided into rubber and friction isolators.

3.1. Elastomers or Rubbers

1º Low damping rubber bearing (LDRB).
2º High damping rubber bearing (HDRB).
3º Natural damping rubber bearing (NDRB) (Alhamaydeh *et al*., 2013).
4º Lead rubber bearing (LRB), (Fig. 7).

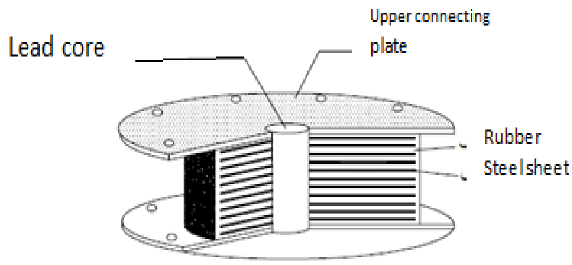

Fig. 7 – An illustration of a rubber isolator (The guidance of design and implementation of seismic isolator systems in buildings, 2011).

3.1. Friction or Sliding (Fig. 8)

1º Sliding isolator with mass energy regulator springs (SSIM) (Lee *et al*., 2014).

2º Friction pendulum system (FPS).

3º Variable friction pendulum system (VFPS) (Panchal, *et al*., 2009).

4º Variable frequency pendulum isolator (VFPI).

5º Variable curvature friction pendulum system (VCFPS) (Sharma & Jangid, 2010).

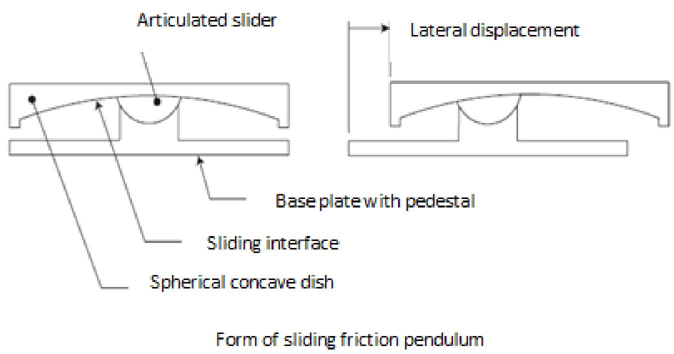

Fig. 8 – An illustration of a rubber isolator (Warn & Ryan, 2012).

4. Supplementary Damping

Isolation from base is one of the extensive and acceptable systems of seismic protection. The near field earthquake effects can increase the displacement of Isolators. The effect of earthquakes with moment magnitude 7 on the isolated buildings from base can lead to high displacement in the Isolators. Great displacement in the Isolators under near field earthquake can result into buckling and the rupture of the isolation system. Thus, using supplementary dampers (Fig. 9) beside LRB or FPS systems is required to reduce displacement in Isolators in near field earthquakes. Using supplementary viscous damping in LRB, FPS Isolators can increase inter-story drift in reinforced concrete structures under far field earthquake. Using supplementary damping is effective in reduction of pure acceleration of stories for LRB, FPS Isolators in near field, but it is increased in the far field (Providakis, 2009).

The application of seismic isolation with supplementary damping or without this type of damping to absorb energy and structure control during the earthquake is proved. Using viscoelastic dampers as connectors between the isolated buildings and neighboring buildings showed that the function of isolated building was increased and the probability of collision phenomenon of the neighboring buildings was reduced. If we are faced with the challenge of restriction of the highest total displacement namely in near field sites, normally the designers trust in the dampers with viscous fluid. Using damping system with viscous fluid results into the high consistency in the forces of superstructure levels and the reason is the reduction of the phase difference of the highest response of velocity and displacement (Alhamaydeh *et al*., 2013).

For a two degree of system under pulsing artificial motions similar to the near field earthquake features, the increase of period of the pulses increases the displacement of Isolators. Using supplementary damping in the base can control the displacement of Isolators. Although using supplementary damping in isolation surface cannot guaranty the best performance for the superstructure, in all states (*e.g*. Decrease inter-story drift), namely for the short-period pulses: this is occurring due to the supplementary energy dissipation in the base to reduce the effect of isolation and it causes that the structure behavior is like the ordinary pinned base structure (Mazza & Vulcano, 2009).

Fig. 9 – An example of viscoelastic damper (Morgan & Mahin, 2011).

5. Conclusion

Smart buildings are not just about introducing and working innovation or innovation progressions . The isolator changes the acceleration based on the change in period (increasing period) as shown in Fig. 5 and in acceleration spectra, the entrance acceleration to the structure is reduced and the structural system enters the safe zone . The increase of period has some problems in which as shown in Fig. 6, displacement is increased and some mechanisms are used in the system for energy dissipation (damping) and displacement is reduced. This damping reduces the resonance phenomenon arising from the components with high period in ground motion.

As it was mentioned, the following results are achieved:

• Friction isolator can decrease the passage acceleration to structure with the friction coefficient lessening as it can build period. Despite the fact that this diminishes the structure speeding up, the displacement value is expanded.

• Using FPS framework in near field earthquake can build the quickening of the superstructure and base shear is likewise expanded.

• By introducing VFPS, the base shear and displacement of Isolator amid the near field earthquake is controlled in a decent range and this framework has high impact on the structure adaptability and the application conditions are more appropriate in near field earthquake.

• Seismic Isolator has reasonable execution in far field earthquake yet in near field earthquake, in view of the high seismic need, there is a demand for utilizing an isolator with huge scale and it is expensive.

• LRB, HDRB Isolator has high damping in comparison to other ones.

• Combination of LRB, HDRB isolators with thick damping functions admirably in near field locales, however utilizing this framework in far field earthquake isn't prescribed because of the making of creating auxiliary powers in the damper and their perplexing impacts.

• HDRB isolator can ingest much vitality as the sliding ball bearing with elastic covering and high damping can channel the disaster with the diminishment of frequency in the essential modes and lessening of quasi-acceleration speed range in majority of earthquakes.

• In some cases, particularly when the structure is on hard soil and the structure is of short buildings (it has low basic period), the isolator frameworks can be compelling yet in the event that the structure is on delicate soil, the building is high rising (it has long basic period), seclusion frameworks have low impact.

• Using supplementary viscous damping in LRB, FPS Isolators can improve inter-story drift in reinforced concrete structures under the far field earthquake.

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EVALUAREA STRUCTURILOR IZOLATE FOLOSIND IZOLATORI SEISMICI

(Rezumat)

Înregistrările cutremurelor de pământ din ultimii ani au reliefat faptul că mişcările seismice prezintă caracteristici diferite în funcţie de distanţa epicentrală. Unul din cele mai importante efecte este legat de prezenţa unor vârfuri semnificative ale vitezei înregistrate la nivelul terenului cu preponderenţa în direcţia de propagare a faliei. Pentru a limita efectele dezastruoase produse de mişcările seismice, inginerii trebuie să utilizeze sisteme de izolare adecvate. Izolare seismică presupune decuplarea structurii de teren pentru a evita disiparea energiei seismice la nivelul suprastructurii. Lucrarea de faţă analizează caracteristicile mişcărilor seismice în funcţie de distanţa epicentrală şi efectul acestora asupra structurilor isolate seismic.