ADVANCED PASSIVE CONTROL TECHNIQUES FOR RETROFIT OF EXISTING BUILDINGS IN SEISMIC ZONE

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SUMMARY

A great number of existed buildings in China and many countries are lack of capacity for resisting earthquake. In this paper, authors provide a set of advanced passive control technique of retrofit which are more reliable, effective, simple and inexpensive to be used in different kinds of existed buildings. These passive control techniques include Inter-stories Isolation (ISI), Tuned Stories Damper (TSD), Energy Dissipation Art Bracing (EDAB), Energy Dissipation Art Wall (EDAW) and Energy Dissipation Joint (EDJ). Authors introduce the results of dynamic analysis and a series of tests, including full scale tests of isolation and energy dissipation devices, shaking table tests for 1/6 - 1/25 structural models, also suggest a set of evaluation and optimal designing theory and methods for practical engineering application, and describe some construction projects of different kinds of existed buildings.

INTRODUCTION

There are two kinds of techniques of retrofit for existed buildings and facilities at present. One is the traditional technique, another is the new technique suggested in this paper. The traditional technique uses the methods of strengthening the structure then rises the structural stiffness, which will induce to increase the structural response then to loss the safety of structure during earthquake. The construction of traditional technique may be complex in some cases, which may disturb the daily performance of existed building or facilities because that it need to strengthen the columns, beams, walls, joints or whole structure. So the traditional technique may be unsafe, expensive and difficult to be implemented in some cases. The new technique uses the methods only changing the structural dynamic characters (damping, frequency or tuned mass) to reduce the structural response in earthquake also wind, instead of strengthening the structure. The new technique is very effective to control the structural response in earthquake or wind, also is able to ensure the structure to be safe during unexpected higher intensity earthquake. (Zhou, 1997). Authors provide a set of new technique-the advanced passive control technique of retrofit which are more reliable, effective, simple and inexpensive to be used in different kinds of existed buildings. These passive control techniques include Inter-stories Isolation (ISI), Tuned Stories Damper (TSD), Energy Dissipation Art Bracing (EDAB), Energy Dissipation Art Wall (EDAW) and Energy Dissipation Joint (EDJ).

The Inter-stories Isolation (ISI) is formed by that the isolators are located on the suitable story of building instead
of on the base, such as on the first story or middle height stories of existed building which response may be reduced about 50-70% in earthquake. Tuned Stories Damper (TSD) is formed by that one or several stories are added and supported with elastic-damping devices on the top of the existed building which becomes a tuned mass damper system to reduce 40-50% response of existed building in earthquake. Energy Dissipation Art Bracing (EDAB) and Energy Dissipation Art Wall (EDAW) are formed by some high effective energy

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dissipaters which are also designed as architectural-art parts of building instead of pure structural elements. EDAB or EDAW may be put on some weak stories of existed building and are very effective to improve the seismic safety of existed building. Energy Dissipation Joint (EDJ) is always used as connection joint between two buildings, or between the over-bridges and buildings, which are very effective to avoid damage of existed buildings in earthquake.

The results of analysis and tests show that the techniques are very reliable, effective to reduce the seismic response and to improve the seismic capacity of existed buildings. The experiences of application also show that, using these techniques are more simple, inexpensive and practical comparing the traditional techniques of retrofit by strengthening ways, and does not induce any disturbance to normal employment of existed building during construction. These techniques are suitable to be used by selecting for low-rise buildings, multi-stories or high-rise buildings, regular or irregular buildings, general or important buildings in moderate or strong seismic zones.

In order to support the application of this new technique, a very large factory, “Vibro Tech” Company (Canada-China), produces different kinds of energy dissipaters, isolators (laminate rubber bearings) and devices of passive and semi-active control which are with high quality also low price, to satisfy the great demand in China and other countries in the world.

INTER-STORIES ISOLATION (ISI) SYSTEM

Principle and Testing of Seismic Isolation

Isolation system is formed by putting isolators on the bottom of existed building or facilities, or some partial floor with important facilities in the existed building. The isolation system may reduce 60-90% of the structural response in earthquake by isolating the vibration transferred from the motion source. This technique is able to ensure the buildings or facilities no any damage in strong earthquake. The isolation system is suitable to be used for some existed important buildings, lifeline structures or important facilities in the city.

In most cases, the laminated rubber bearings are chosen as the best isolators now. The isolation system includes isolators, upper structure above the isolators and under structure below the isolators. This system possess three characters:

● Soft sliding: The upper structure can softly slide on the isolator’s layer in severe earthquake. This character can isolate the horizontal vibration from ground motion to the upper structure. The principle is to make the natural period of structure very long, then reduce effectively the acceleration response and shear force of upper structure also under structure (Figure 1).

● Certain amount of damping provided by isolators: It will dissipate the energy input to the system then attenuate the displacement response of isolators in earthquake.

● Suitable horizontal stiffness of isolators: Isolators will provide the primary larger stiffness to resist wind load or minor earthquake, provide lower stiffness in moderate or strong earthquake to isolate the vibration, and provide larger stiffness again in extreme strong earthquake to limit the displacement of isolators.

Many tests have been finished and some sets of computation programs of seismic isolation system have been established by authors (Zhou, 1991, 1997). The tests include two kinds of work: Tests for full scale isolators and shaking table tests for large scale structural model.

The tests for full scale rubber bearings produced by Vibro-Tech company in China show that, the rubber bearings possess very high compression capacity, suitable horizontal stiffness and damping, very large capacity of horizontal displacement, perfect permanence (at least 70 years of working life), high capacity of resist low cycle fatigue failure and creeping (Zhou, 1997).

Shaking table tests for large scale structural model (steel and concrete structures) with rubber bearings show that, the acceleration responses on each stories of structure with isolation are nearly the same which means that the elements and joints of structure with isolation nearly work within elastic range during earthquake, the acceleration response on structure with isolation is only (1/4 - 1/12) response on structure without isolation, which means the isolation system is more effective to attenuate the structural response and shear force during earthquake, then to ensure the buildings and inside facilities to be safe (Zhou,1992,1994,1997).

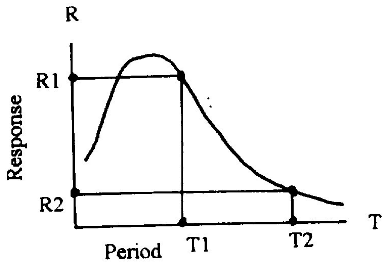


Figure 1: Relation of structural response and natural period

Design and Application of Isolation

The retrofit using isolation can be realized by adding rubber bearings on certain stories from cutting the columns (or walls) in existed building. There are three locations of rubber bearings being used:

● On top of the columns (or walls) in basement, to reduce the seismic response of upper structures, shown in Figure 2.

● On certain stories between different kinds of parts in structures, to reduce the seismic response of upper structures and under-structures. This is the typical Inter-Stories Isolation (ISI) system, shown in Figure 3.

● On top of piers or columns of bridges or other structures, to reduce the seismic response of upper structures and under-structures.

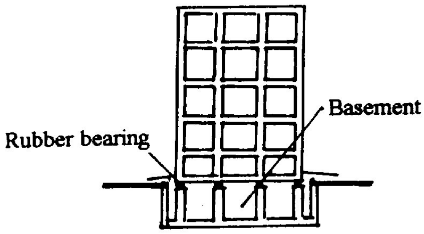


Figure 2: Isolators on top of column in basement

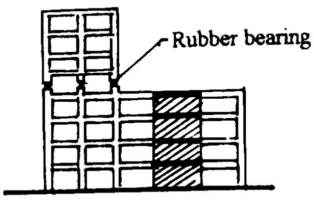


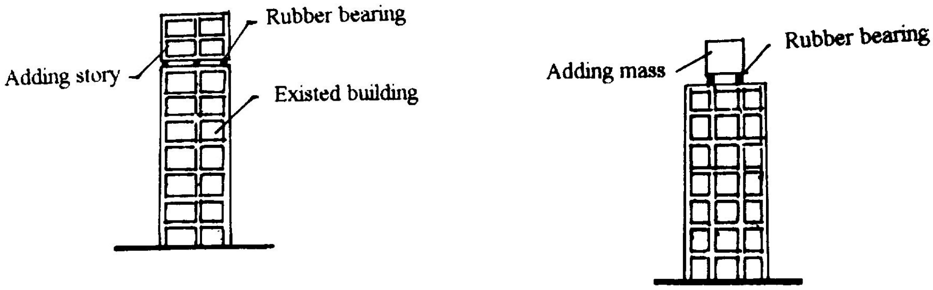
Figure 3: Isolators in Inter-Stories Isolation (ISI) structures

TURNED STORIES DAMPING (TSD) SYSTEM

The system is, on certain position (such as on roof) in existed building or structure, places an additional Filial Structure (possesses mass, stiffness and damping) which natural period is nearly equal to the natural period of existed structure. The dynamic characteristics of existed structure are changed. During the earthquake, the Filial Structure will move against the direction of existed structural vibration then reduce the response of existed structure.

This Filial Structure may be formed by adding one or more stories supported by rubber bearings on the roof of existed building (Figure 4 a), or adding a certain mass supported by rubber bearings on the roof or other floors in existed building (Figure 4 b).

The shaking table tests show that, the response of existed building adding Filial structure is reduced 30-50% of response of existed structure without Filial structure (Zhou, 1996,1997)



(a) Adding stories on top of building **(b) Adding mass on stories of building**

Figure 4: Tuned Stories Damping (TSD) system

ENERGY DISSIPATION SYSTEM

Principle and Testing of Energy Dissipation System

Energy dissipation system is formed by adding some energy dissipaters into the structure. The energy dissipaters provide the structure with large amounts of damping which will dissipate most vibration energy from vibration sources previous to the structural response reaching the limitation, then ensure the structure to be safe in earthquake or to satisfy the using requirement in wind. The energy dissipaters may be set on the bracing, walls, joints, connection parts, nonstructural elements or any suitable spaces in existed buildings, which may reduce 40-60% of the structural response comparing the traditional structure without energy dissipaters. This technique is very reliable and simple, suitable to be used for general or important existed buildings or facilities in the seismic zone.

For building structure or facilities with energy dissipaters, the energy balance equation in any instant of time during earthquake is:

$$Ein = Ep + Ek + Ep + Eb \qquad (1)$$

Where:

Ein -- energy input to the structure.

Ep -- potential energy in structural vibration.

Ek -- kinetic energy in structural vibration.

Ed -- energy dissipated by viscous damping of structure or facilities.

Eb -- energy dissipated by energy dissipater.

Testing and researches indicate that the energy dissipater can dissipate about 90% of the total energy input at the end of earthquake. The effect of Ed are relatively small which can be neglected in Eq. (1), then the energy dissipating design for earthquake resistance need to be satisfied with:

$$Ein < Eb \qquad (2)$$

For calculating energy input Ein, the system can be considered as multi-degree of freedom system. The energy dissipated by energy dissipaters Eb depends on the area enclosed by Load -Displacement loop curve (Zhou, 1982,1987).

The energy dissipaters provide the structure or facilities with large amounts of damping which will dissipate most vibration energy from earthquake or wind previous to the structural response reaching the limitation (damaging the buildings or loosing the performance function of facilities), then ensure the structure or facilities to be no any damage or to keep the normal performance function during earthquake or strong wind.

The shaking table testing of large models with energy dissipaters shown that, the seismic response of structure with energy dissipaters is decreased 40-60% comparing the structure without energy dissipaters (Zhou, 1989,1997).

Design and Application of energy dissipation system

There are different kinds of energy dissipation system being used now:

● Energy dissipaters put on the bracing which are designed as some beautiful art elements for architectural requirement, called Energy Dissipation Art Bracing (EDAB). These bracing can be set along whole structural height for regular building to rise the capacity of anti-seismic, or only be set on some spaces (or stories) of structure for irregular building to avoid torsion damage during earthquake, shown in Figure 5.

● Energy dissipaters put on the walls which are designed as some beautiful art wall for architectural requirement, called Energy Dissipation Art Wall (EDAW). These wall can be set on weak stories of structure to improve the structural working state, avoiding dangerous damage of weak stories during earthquake, shown in Figure 6.

● Energy dissipaters put on the gaps as connection joints between adjacent buildings to avoid impact damage during earthquake, shown in Figure 7 a, or put on the connection joint between over-bridges and buildings to avoid damage caused by unreasonable connection of different buildings with different response during earthquake, shown in Figure 7 b. These are called Energy Dissipation Joint (EDJ).

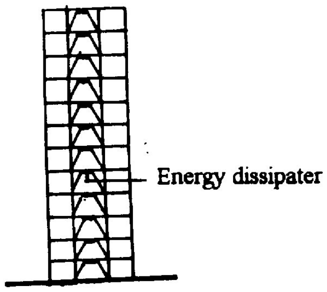


Figure 5: Energy Dissipation Art Bracing

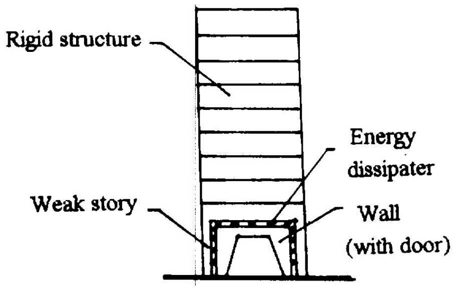
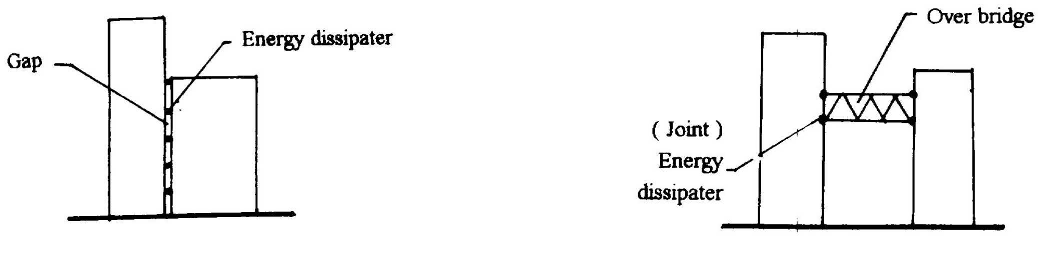


Figure 6: Energy Dissipation Art Wall



(a) Energy dissipaters in the gap **(b) Energy dissipaters in connection joint**

Figure 7: Energy Dissipation Joint

SEVERE PROBLEMS AND SOLUTION WAYS FOR EXISTED BUILDINGS IN SEISMIC ZONE

There are three severe problems of existed buildings and facilities in the seismic zone in China or many countries in the world. These problems described below may cause severe directly or indirectly hazards in earthquakes:

● A large number of existed buildings are lack of capacity for resisting earthquake in original design, which buildings includes general civil buildings or important buildings, low rise buildings or high rise buildings, masonry and concrete structural buildings or steel structural buildings.

● Many building's structures are very unreasonable which will be very dangerous in earthquakes. Such as, some building structures exist weak stories on some middle height-floors or on the ground floor of building which only have columns and few shear wall ; some adjacent buildings are connected by over bridges structures ; some buildings shape are severe irregular□some buildings are severely eccentric of stiffness center and mass (gravity) center which will induce torsion damage in earthquake□some buildings are separated to be different parts by gaps which may induce impact damage during earthquake.

● Most important facilities inside or outside of building are not protected in earthquake. These facilities are more sensitive than buildings for vibration. It will be damaged even the structure without damage in moderate or small earthquake. Its damage may induce severe loss of lifeline of the city, such as the facilities in power plant, communication center, hospital, city command and control center, archives and record center, finance and bank center, information center of city.

A great number of existed buildings with the problems described above in China or many countries in the world. The urgent works are to find the reliable, effective, simple and inexpensive ways to solute these problems. The advanced passive control techniques for retrofit of existed buildings suggested in this paper have been used widely in practical projects to mitigate effectively the earthquake hazards in seismic zone because these techniques possess following advantages:

● Effective to ensure the safety in earthquake: rise the anti-seismic capacity of structures, decrease the seismic response of structure and facilities, avoid impact or other damage caused by unreasonable original design.

● Simple implementation or construction: do not disturb the daily performance of existed buildings or facilities during construction.

● Multi-functions and wide range application: possess both functions, rise capacity of resistant-earthquake and resistant-wind. It will protect both of structure and facilities inside structure. It can be used in low-rise buildings, high rise buildings and irregular buildings, and many kinds of facilities.

● Economical: the cost of retrofit using new techniques is much lower than using traditional techniques, because it only change the dynamic characteristics instead of strengthen the elements or whole structure.

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