Fundamental Studies on a New Type of Base Isolator for Earthquake Protection

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ABSTRACT

Presented in this paper is studies performed on Advanced Lead Rubber Bearings (ALRB), a new type of baes isolation devices. It is expected that installing "multifunctional corrugated rods" on the Lead Rubber Bearing (LRB) makes significant improvement on the earthquake protection effects of the LRB system. Using the ALRB isolators, a 7–story base–isolated RC building, the first one in China, will be constructed soon.

1 INTRODUCTION

Base isolation is an attractive means of protecting structures from severe earthquake excitations. In recent years, the base isolation technique and various practical base isolation systems have been developed and used for mainly bridges and multistory buildings in some countries. Some problems and limitations of base isolation devices, however, have been a hindrance to their wide application. The most important two problems are base uplift and quasi–resonace. This is especially true for medium–rise buildings and structures located in the epicentral region.
A new type of base isolation devices for structures, named Advanced Lead Rubber Bearing (ALRB), has been worked out and developed so that it may be successfully used to a 7–story RC building in Xichang City, well known as the launching base of Chinese satllites.

2 ADVANCED LEAD RUBBER BEARING

The type of the base isolation used for structures most widely is the Lead Rubber Bearing (LRB), namely the laminated rubber bearing with lead plug. The first two newly built LRB base–isolated buildings William Clayton in New Zealand and Oiles Technical Center in Japan were completed in 1981 and 1987, respectively. However,they have not suffered strong earthquakes. so far a unique base–isolated structure which has withstood a destructive earthquake is the Te Teko Bridge with the LRB in New Zealand. On the other hand, the bridge suffered some unexpected damage during the earthquake on 2 March 1987. This fact teaches us that the devices need to be improved further.
To overcome the problems mentioned above, a new type of LRB has been developed, shown in Fig.1. It consists of rubber and sheet–steel laminations, and cylindrical lead plug, and multifunctional corrugated rods, named Advanced Lead Rubber Bearing (ALRB).
It is easy to see that the corrugated rods can resist uplift tension forces. This is important for safety of structures located in the epicenter area, where the vertical component of ground motions always is considerably strong.

As is well known, the isolation reduces the overall lateral stiffness of the structure, and its fundamental frequency is shifted below the frequency range, 1~ 6Hz, associated with the high energy content of typical earthquakes. However, the base isolation systems have their own nutural periods generally, which may cause quasi-resonace or resonace to earthquake excitations whose power essentially is concentrated at the low frequecy end of their energy spectra like 1985 Mexico and 1977 Romania, Bucharest.
The corrugated rods, as a displacement restraint device, can also limit the displacement of the LRB and thereby the isolated building for the low frequency earthquakes as well as for extreme events. They behave elasto-plastically and moreover provide added hysteretical damping. Thus, the corrugated rods are a multifunctional device; and the suggested system ALRB is economical, greatly effective and has bright prospects as a practical earthquake control technology.

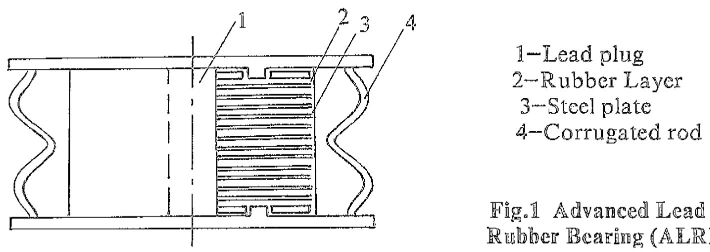

Fig.1 Advanced Lead Rubber Bearing (ALRB)

3 ASEISMIC ANALYSIS OF BUILDING

3.1 Building description

The building designed as a base-isolated one is a seven-story reinforced concrete rigid frame structure with fill walls. It has dimensions of 15.6× 21.9m in plan and 24.9m in height as shown in Fig.2. Total area is 2800 m^2 and the weight 30800kN. When completed, it will be the first LRB base-isolated building in China.
16 ALRBs will be installed between the foundation and the first floor, one under each column. Four of them have no the lead core to cheapen the total cost of manufacture. They were arranged in plan with symmetry, and so did the others with different horizontal stiffness, so that the isolator stiffness center could coincide with the building gravity center. By means of finite element analysis the vertical stiffness of ALRBs with different diameters and details was chosen to ensure the minimization the non-unifom settlement of the columns.

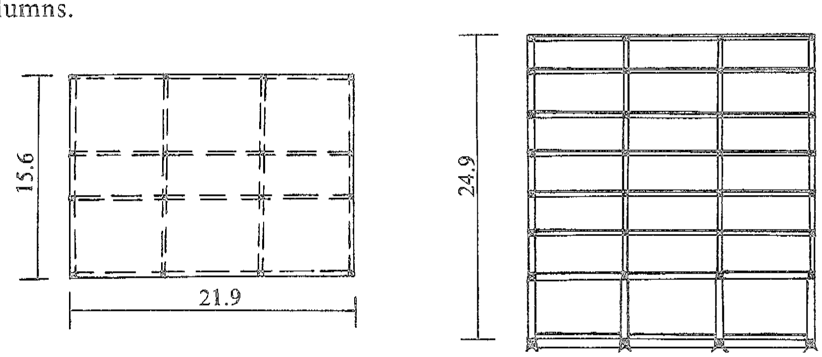

Fig.2 Plan and section of the base-isolated building in Xichang, China (Unit: m)

3.2 Design conditions

In China, the Building Code and the Building standard Law have not included any earthquake aseismic regulations concerning base-isolated structures yet.However, the fundamental philosophy of 2-level earthquake resistant design, adopted in the Building

Code, have to be follewed and satisfied in the design of this base–isolated building, that is to say, the isolated building shall withstand the level–1 design earthquake without structural damage, and not collapse during the level–2 design earthquake.
Concretely, the design criteria adopted for the isolated building are listed as follows.

(1) Shear strain criterion $\gamma \leqslant [\gamma]$
(2) Comprission stress criterion $\sigma \leqslant [\sigma]$
(3) Deflection criterion $\delta < \delta_y$

Where γ is the shear strain of rubber in ALRBs, $[\gamma]$ its allowable values, and 50%and 100% were used for the level–1 and level–2 input respectively. σ is the static vertical compression stress in rubber, and $[\sigma]$ its allowable value, and 10.0MPa was adoped. γ is the interstroy deflection of columns of the superstructure, and $\gamma_y$the yield deflection.
Xichang City is in a highly seismic region with intensity of Ⅸ according to the Earthquake IntensityMaps of China. So 0.4g has been adopted as the Peak Ground Acceleration (PGA) of the earthquake motions for the level–1. Based on a detailed Seismic Risk Analysis and Earthquake Hazard Reduction Program of the Xichang City, conducted in 1989, PGA for the level–2 is 0.54g.
The accelerogram recorded in Qianan County, Hebei Province, on August 9,1976, during the main aftershock of 1976 Tangshan Earthquake, is used as a input seismic wave, as shown in Fig.3. Its peak acceleration of 0.162g, however, has been scaled to be equal to 0.4g and 0.54g for the level–1 and the level–2 aseismic design, respectively.

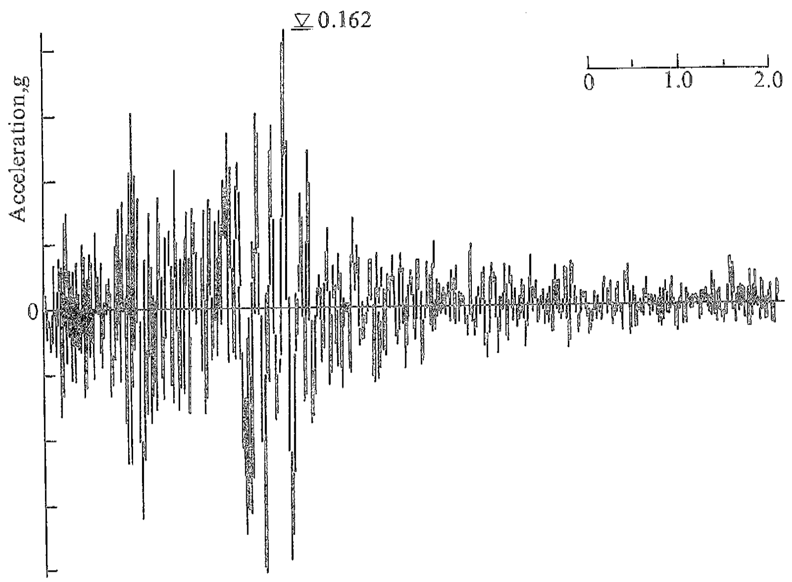

Fig.3 Acceleration History of Ground Motion of Qianan Record, EW,Aug.9, 1976

The building is in the zone of very intense, frequent earthquakes. Two important active faults close to the building site. the distance from a potential eqicenter is only 5km. Therefore the problems of uplift and unexpected events should be received ample attention.

3.3 Computation model and method

The building base–isolated and non–isolated were modelled using truss and beam elements with the well–known ADINA program. For the base–isolated system, the model was considered to be formed by two sybsystems: a base isolation system and a superstructure subsystem, see Fig.4. The later was modelled as multiple lumped–mass and bending–shear elements. Since most likely behaving always within the elastic range, it was treated as a linear system. Based on the hysteresis loop, the total ALRBs as a whole were modelled as a bilinear truss element in the two horizontal directions and as a linear one in the vertical direction. Providing we have the design (idealized) force–displacement curve of the entire isolators, as shown in Fig.5, it is easy to figure out the characteristic parameters of the equivalent truss element. In Fig.5, k_1 is the elastic shear stiffness, k_2 the post yield shear stiffness, Q_y the yield force. In the design, 1360.0kN / cm, 213.0kN / cm and 1460.0kN were adopted for k_1, k_2 and Q_y respectively.

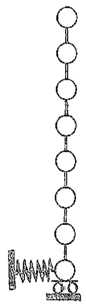

Fig.4 Computation model of the base–isolated building

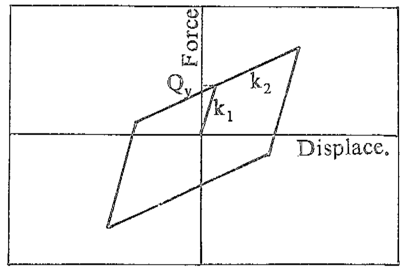

Fig.5 Bilinear force–displacement curve of the entire ALRBs

3.4 Dynamic analysis and results

A step–by–step Wilson–θ integration procedure was used with the time–step of 0.01s.Three cases were analyzed, namely:

(a) the non–isolated building subjected to Qianan record with PGA of 0.4g;
(b) the base–isolated building subjected to Qianan record with PGA of 0.4g;
(c) the base–isolated building subjected to Qianan record with PGA of 0.54g.

Main results of the analysis are illustrated through Fig.6 to Fig.10.Fig.6 shows comparison between responsive acceleration wave patterns in the first 4.0 s, at the roof, of the base–isolated and non–isolated building. The responsive acceleration wave at the roof of the base–isolated building subjected to the level–2 input motion is given in Fig.7. The maximum story–to–story response accelerations of the base–isolated and non–isolated building are illustrated in Fig.8.

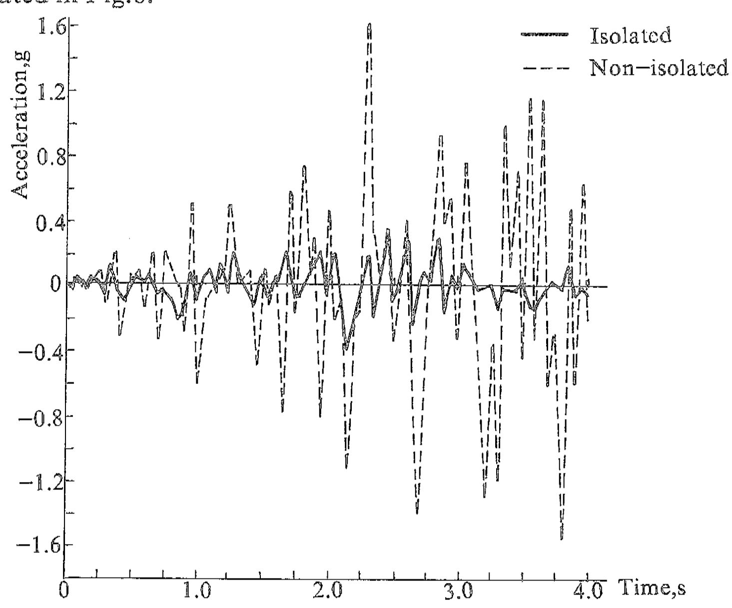

Fig.6 Responsive acceleration waves at the roof of the isolated and non–isolated building, for level–1 input

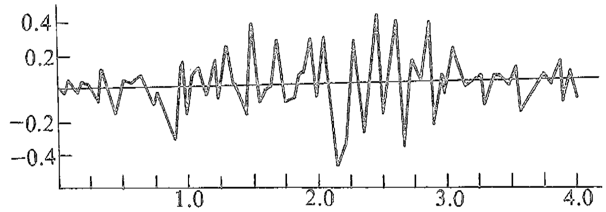

Fig.7 Resposive acceleration wave at roof of the isolated building for Qianan Record with PGA of 0.54g

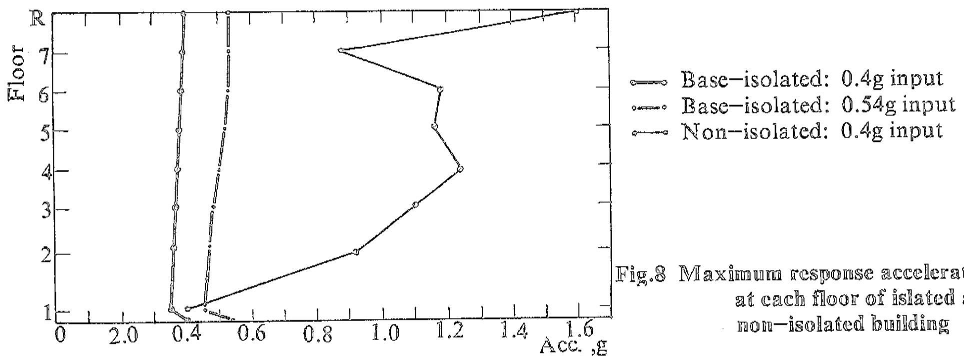

Fig.8 Maximum response accelerations at each floor of islated and non-isolated building

As shown in these figures, the peak acceleration is reduced, to 1 / 4 of that of the conventional building by the isolating effect of ALRBs, from 1.639g at 2.31s to 0.411g at 2.16s for the level-1 input case. It is equel to or even below that in the ground, with no amplification. As is known, Due to the amplification in the case of the non-isolated structure,the higher the floor is ,the stronger the shaking. With the isolated one, however, not only is the acceleration reduced by a large margin, but also all floors swing slowly and uniformly.

The displacement response time-histories in the first 5.5s of the floor level, i.e. the horizontal displacment of isolators, are provided in Fig.9. The peak values are 4.73cm and 6.88cm, occured at 2.16s for the input intensity level-1 and level-2 respectively. These values cause maximum shear strain of 30% ~ 43% to the rubber. The occurance of the maximum displacement is of a isolated peak type as shown in the figure, the second maximum is much more smaller.

Fig.10 shows the distribution of interstory deflections of columns at the time of 2.21s, just

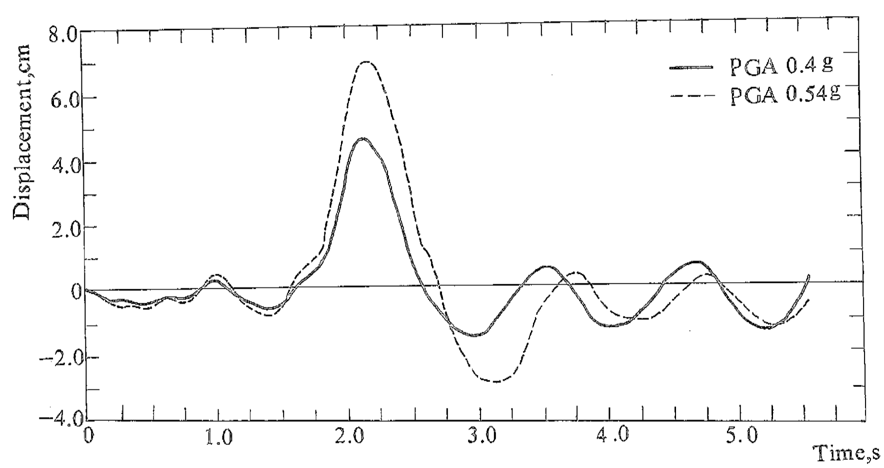

Fig.9 ALRB Horizontal displacement histories induced by Qianan Record with PGA of 0.4g and 0.54g

as occured their peak values. Actually, the column deflection at the 7th floor reached its maximum value of 0.277 cm, i.e., 0.09% of the height of the column. Obviously, all columns behave elastically during the level−2 earthquake, as well as the level−1.
To sum, it was confirmed by the results above that dynamic responses was greatly reduced by adopting the ALRB base isolation.Of course, from the point of view of aseismic analysis futher work is needed. More input motions with different frequency characterestics, especially with low dominant frequency should be used. It should be also considered to simultaneously input three components, including vertical one of ground motions. Due to the long nutural period of isolated structures, the standazation of input motions in terms of PGV(Peak Ground Velosity), rather than PGA, is more reasonable.

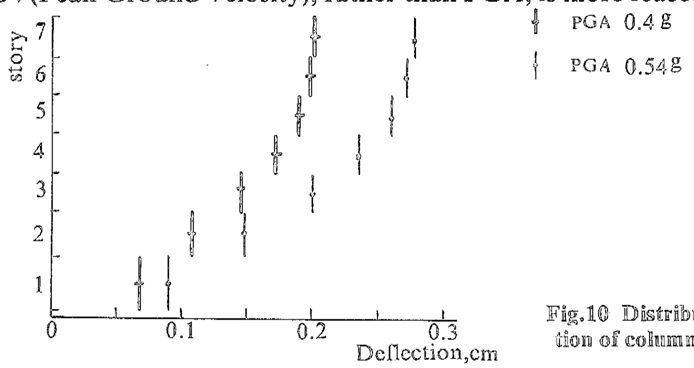

Fig.10 Distribution of interstory deflection of columns at the moment of 2.21s

4 CONCLUSIONS

From the research we have performed some conclusions may by drawn.
The advanced lead rudder bearing (ALRB) is a new type isolator which most likely has bright prospects as a widely applicable, economic structure control device. The corruguated rods can provided to a ALRB with valuable, multiple functions. Among them the uplift resistance function is neccessary for structures in the epicentral region, and displacement restraint function is important during extreme events as well as predominantly long−period motions to cancel system quasi−resonance.
For the 7−story RC building in Xichang City, the dynamic response can be reduced significantly by the ALRB base isolation, and the aseismic safety criteria be satisfied.
Futher investigations on both the new type isolator itself and the base−isolated building are imperatively necessary.

ACKNOWLEDGEMENTS

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