BASE ISOLATED STRUCTURES IN NEW ZEALAND

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SUMMARY

This paper reviews briefly the New Zealand developments during the past decade in the Base Isolation of structures to provide increased earthquake resistance. The reasons for adopting the base isolation approach, and the particular problems to be considered, are reviewed briefly for a number of typical applications. There is a brief discussion of a few modified isolator systems which could reduce the costs or increase the effectiveness of future applications.

INTRODUCTION

Many proposals for earthquake resistant structures have provided for high horizontal flexibility near base level. While analysis confirms that some proposed systems would give somewhat reduced seismic loads throughout the structure, they were often impractical because inadequate damping would have resulted in excessive base displacements, small reductions in seismic loads, high P-delta forces, and excessive wind displacements.

In 1970 the New Zealand Physics and Engineering Laboratory embarked on the development of special components for earthquake-resistant buildings. Efforts were concentrated on the development of practical hysteretic dampers, initially based on plastically deformed solid steel beams and later expanded to include plastically deformed lead plugs (Ref. 1). These hysteretic dampers have been combined with flexible mounts, usually laminated rubber bearings or tall and flexible columns and piers, to provide a range of practical base isolation systems.

These base isolation systems have been used in the design and construction of some 20 New Zealand structures during the past decade. Isolators have been used under 2 buildings, 1 chimney, 1 complete bridge and the superstructures of some 16 further bridges. Analytical studies for the isolation of other structures, and also the further development of isolator components, have continued in New Zealand and elsewhere. This practical and analytical experience has set the scene for the next stage in the development of base isolation technology.

NEW TECHNOLOGIES IN EARTHQUAKE ENGINEERING

The introduction of a dramatically different technology, such as base isolation, to the field of earthquake engineering is made difficult by the extent to which this field is still empirical. It is difficult to use a more analytical approach because there is limited data on the earthquake

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motions and deformations to be expected at particular sites, and because of continuing uncertainties about the character of structures under the exceptional loads and deformations due to major earthquakes.

The aseismic design of novel structures highlights the general need for extensive seismological and strong-motion programs, including microzone studies of local ground motions and deformations. Extensive field studies of structural performance during earthquakes are also required, supported by continued laboratory testing of components, to assist in modelling structures for earthquake performance analysis.

Base isolated structures are more readily modelled for design analysis than most of their non-isolated counterparts since the only severely loaded and deformed components can usually be tested readily in laboratories.

CHARACTERISTICS OF BASE-ISOLATED STRUCTURES

The main features of base isolated structures are the subject of many publications including several by the author (Ref. 1, 2, 3, 4).

Structures resist horizontal earthquake forces by a combination of strength, deformability and damping. Structural components are detailed for increased deformability and hysteretic damping, i.e. ductility, to avoid the higher cost of resisting earthquakes by strength alone. High ductilities may be difficult to achieve in design and are sometimes impractical to verify by tests. Moreover, the large deformations of ductile structures sometimes cause costly non-structural damage and may cause the malfunction of facilities and building services.

Base isolated structures concentrate high lateral deformations and hysteretic damping in special components connected between the base and the supporting foundations.

An outline of the principal features of base isolated structures is made clearer by reference to the normal mode shapes of a flexibly mounted uniform 'shear' building as given in Figure 1. These modes no longer strictly apply when hysteretic base dampers are included but the general features of undamped structures are retained.

(a) The high overall flexibility gives long first mode periods which, together with high damping, usually give a low earthquake response spectrum factor.

(b) The high base flexibility ensures, for the second and higher modes of resonance, a low participation factor, which is reflected in the low base shear of mode 2 in Figure 1.

(c) The addition of hysteretic damping gives a large reduction in base displacements and substantial reductions in seismic loads and structural deformations.

(d) Base isolation leads to a more uniform distribution of shears over the lower part of the structure, Figure 1.

(e) Hysteretic damping ensures low base motions during wind storms. "Stepping" structures have base motions further inhibited by gravity forces.

For flexible structures further increases in mode 1 periods, and high damping for mode 1, give diminishing returns. However increased base flexibility and damping give continuing reductions in the responses of the higher modes. Base isolation is therefore best suited to shorter period structures, since their benefits include substantial reductions in mode 1 responses. Sites with ground of low flexibility, which have earthquake response spectra which are high only for shorter periods, require less flexible base isolators than do more flexible sites.

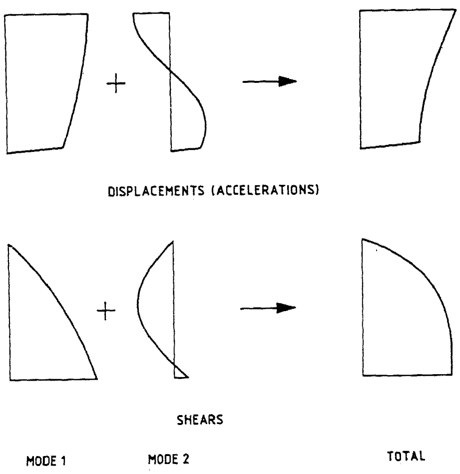

Fig. 1 Form of the modal and overall responses of a uniform shear-type structure with high lateral flexibility at the base.

BASE ISOLATION SYSTEMS USED IN NEW ZEALAND

Of the many forms of base flexibility studied, three have been adopted already in New Zealand Structures.

(a) Side-sway with uplift "stepping", from a narrow base has been used for a chimney structure and a set of slender bridge piers.

(b) Horizontally flexible rubber mounts, with steel laminations to give high vertical load capacity; one building and several bridge superstructures.

(c) Tall flexible piles or piers; also one building and several bridge superstructures.

Hysteretic damping has been provided by one of three types of steel-beam dampers and two types of lead-plug dampers developed at PEL (Ref. 5). The steel beam dampers absorb energy by severe plastic deformation of solid steel beams. They differ in the means of loading and of assuring a "uniform" level of plastic deformation. One has transverse arms which give predominantly torsional deformations, a second has transverse arms which give approximately uniform bending moments along the beam and a third has a uniform thickness beam tapered to match the bending moments from a transverse end load.

One lead plug damper uses cyclic extrusion of the lead and the second a laminated rubber mount. Deformation of the mount, and hence the cavity, causes plastic deformation of the lead plug. Where laminated rubber mounts are appropriate the latter technique combines flexible support and damping in a single, easily installed, package.

South Rangitikei Railway Bridge

This 70 meter high single-track railway bridge has 3 full-height and 2 lesser-height twin-leg piers. The pier legs are hollow boxes with either 2 or 3 interconnecting beams. The bridge superstructure is a continuous narrow hollow box with resilient ground anchors at each end.

The level of plastic deformation available during along-stream swaying of fixed piers was uncertain. Increased along-stream flexibility and reduced pier deformations were achieved by leaving the feet of the slender piers free to lift, within vertical guides. Pairs of torsional beam dampers were connected at each pier foot, a total of 20, each with a damper force of 450 KN. The dampers greatly reduce the extent and the number of the stepping excursions, reducing the deformations of the narrow superstructure to acceptable levels, reducing the effects of foot impact, and reducing side accelerations at the rails to ensure train stability. Local effects of foot impact, and of foot rotation, are provided for by high-capacity laminated-rubber mounts under each foot. Stops at an uplift of 125 mm are provided against the remote possibility of large uplift or overturning failure during a very severe windstorm.

A careful study of ground stability and deformability was made to ensure the effectiveness of the above base isolation system.

Union House, Auckland

Union House is a 12-storey frame building of 3 x 3 bays on a site with about 12 meters of flexible low-strength ground above rock. Severe earthquakes are likely to be centred some 100 to 200 km away, and are likely to cause considerable excitation of the flexible layer and of flexible structures thereon. To meet these problems the steel frame building was made much stiffer by multistorey diagonal braces, and then mounted on an effective base isolation system.

The base of the building was supported from the rock on flexible 12-meter piles which were separated from the flexible surface layer by hollow surrounding cylinders. Hysteretic damping was provided by tapered steel-beam dampers, connected between the base of the building and a basement structure embedded in the upper part of the flexible surface layer. While more effective isolation would be achieved if dampers could be anchored more directly to the bedrock the solution adopted is practical and should be effective.

The design resulted in a substantial reduction in initial costs and should ensure reduced earthquake damage costs.

William Clayton Building, Wellington

This 4-storey reinforced-concrete frame building is 15 x 4 bays and hence contains 80 columns. Base isolation was achieved by placing lead-rubber mounts under each column (Ref. 6).

The lead-rubber mounts were set on ground pads interconnected by an additional set of moderate-strength beams. A horizontal clearance of 150 mm was provided between the base slab and continuous ground-based concrete slabs and walls, to allow 100% strain in the 150 mm high mounts and then provide limiting buffers. All external services were designed to operate under the full available base movements.

The conservative design approach included structural detailing for normal strength and high ductility. However, advantage was taken of lower computed deformations when detailing and separating non-structural features.

Mounts were installed within a crawl space, with provision for convenient inspection or replacement.

The cost of the substantial structural and earthquake modifications required by the above approach, together with the full strength and ductility provisions, have resulted in some increase in net costs. However, the likelihood of severe damage, and the cost of repair after any earthquake, should be substantially reduced.

Bridges

Typical bridge superstructures have horizontal flexibility at most of their support positions to accommodate dimensional changes due largely to temperature cycling. They require very little modification to achieve fully flexible supports, and therefore superstructure isolation normally has low costs.

Isolation of superstructures reduces the imposed earthquake loads and often allows a more favourable distribution of these reduced loads between the support structures. Lead-rubber mounts usually provide convenient low-cost isolation. However, steel dampers have been used to allow additional latitude in distributing damping forces between supports and where support flexibility is not provided by rubber mounts.

ISOLATOR DEVELOPMENTS

Experience with isolator applications and with improved and better understood components suggests modifications for reduced costs or improved performance.

Provision for the convenient replacement of isolator components is often constraining and costly and now appears unnecessary.

Tests indicate that buffers, if used, can be set to allow increased displacements of rubber or of lead rubber mounts; up to twice the net rubber height. For example, the buffer spacing for the William Clayton Building could be increased from ± 150 mm to ± 300 mm. Again, tests demonstrate the effectiveness of mounts which are more slender than those already used; allowing a better match to smaller vertical loads.

Reinforced Concrete Frame Building

As an examaple of possible isolator improvements, consider the consequences of shifting the William Clayton mounts from the column bases to some level in the first storey columns, as suggested by Meggett (Ref. 6).

Consider mid-column mounts as in Figure 2.

(a) This isolator requires very little structural modification. Cynlidrical mounts and spirally reinforced first storey columns would be particularly effective.

(b) With the tapered cavity, the mounts provide tough and resilient buffers.

(c) Fire protection is simple and effective.

(d) The mid-column hinge and the more uniform seismic shear loads, Figure 1, give column end movements which are well balanced over the lower storeys.

Back-up protection against gross mount failures and very large base displacements could be provided by the crossed column and beam arrangement shown on the right of Figure 2.

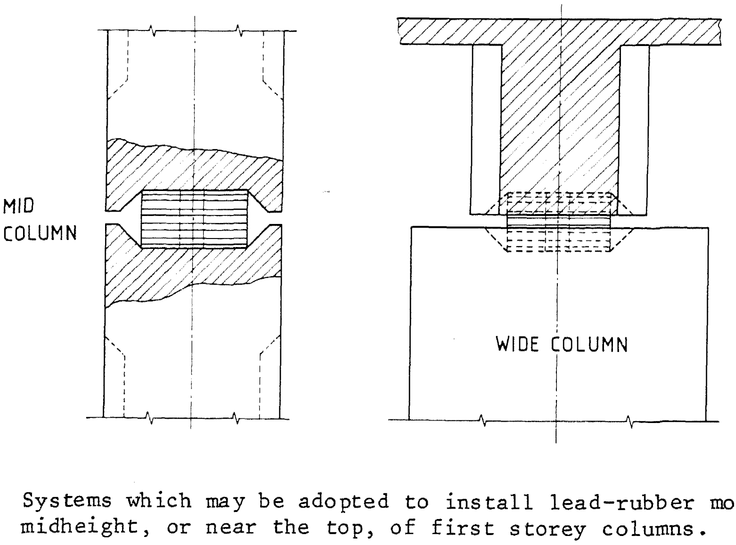

Fig. 2. Systems which may be adopted to install lead-rubber mounts at the midheight, or near the top, of first storey columns.

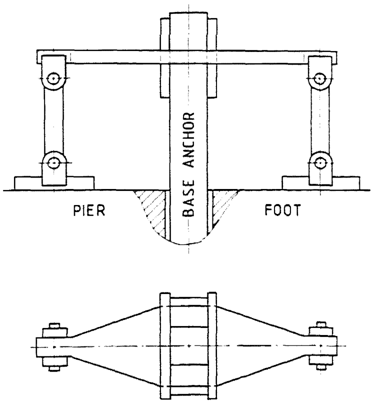

Fig. 3 A simple form of damper which may be used for "stepping" structures; elevation and plan.

Stepping Structures

A further example of isolator improvements is the replacement of the pairs of torsional dampers in the pier feet of the South Rangitikei bridge by balanced tapered steel slab dampers, in future designs, Figure 3. Tapered dampers are particularly simple to design and install when the beam moments are balanced in this way.

Other Isolator Components

There is promise in a range of additional isolator components. Sliding surfaces can provide base flexibility and frictional damping and should have some effective applications particularly in combination with flexible elastic mounts. Developments in engineering materials are doubtless leading towards mounts which can be better matched to the requirements of particular isolator systems.

CONCLUSION

Since base isolation substantially reduces some of the most serious consequences of an earthquake attack on a structure, it should provide an effective approach to earthquake resistance for a range of combinations of site conditions and structural, functional and architectural requirements.

In applying base isolation, care should be taken to consider any unusual problems which may arise. These may be associated with ground deformations, microzone modifications to the response spectra of ground motions, wind storms, or peculiarities in the structure or its functions.

Base isolation does not call for high structural ductility and encourages the use of high-strength moderate-ductility structural forms and materials.

As base isolation systems and their applications are further developed they can be expected to find extensive applications in buildings and in civil engineering structures such as bridges and in industrial plants.

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