TWO DEVELOPMENTS IN SEISMIC ISOLATION-A 'CENTRE DRIVE' AND 'FRICTION BALL'

William H ROBINSON[1]

SUMMARY

Robinson Seismic's latest developments in seismic isolation include two new devices for seismically isolating structures during earthquakes.

The first is an improvement to both the Rubber Isolation Bearing and to the Lead Rubber Bearing consisting of a centre-drive to the top and bottom of the bearings. The 'centre drive' approach has two advantages; first it allows a greater displacement to height ratio and second provides an increased damping capacity at large displacements, thus providing some of the additional damping needed for resisting 'near fault fling' events.

The second advance is a new concept for seismic isolation based on the principle of the inverted pendulum. It consists of 'friction balls' or 'RoBalls' moving between upper and lower spherical like cavities. The Roballs are filled with a material which is able to provide the friction forces required for numerous earthquakes. The RoBall technique is expected to enable light and in the future possibly heavy structures to be more economically seismically isolated.

A series of full-scale tests have been carried out to investigate the feasibility of both of these approaches. In this paper we present preliminary experimental results.

INTRODUCTION

The acceptance by the engineering community of the technique of seismic isolation was given a major boost in the 1970s by the introduction of the lead rubber bearing, commonly known as the LRB. The first structure in the world to be seismically isolated with lead rubber bearings was the Toetoe Bridge, completed in 1978, on the main highway linking Wellington and Auckland, New Zealand (Robinson, 1982). In 1981 the William Clayton building in Wellington, New Zealand was completed (Megget, 1978). This four storey building mounted on 80 LRBs was designed in the late 1970's. The seismic gap of 150mm around the building basement was adequate, according to the state-of-art knowledge for earthquake ground motions at that time. Buffers were provided to restrain the building should the base-isolator displacement exceed 150mm (Skinner et al. 1993).

In the last 10 years or so, many near source records have been obtained from large earthquakes, for example, the Lucene and Joshua Tree records from the 1992 Landers earthquake (M_w=7.2) and the Sylmar record from the 1994 Northridge earthquake (M_w=6.7). A common feature of several of the records is a long period velocity pulse of very large amplitude. Such a pulse can impose very large displacement demands on intermediate and long period structures, including base isolated buildings (Hall et al.1995). These results have encouraged design engineers to increase seismic gaps to 300 to 500mm. This increase in displacement is illustrated by the example of three seismic isolation projects completed in New Zealand during the 1990's, vis: the new Wellington Central Police Station with a gap of 400mm (Charleson, et al 1987), the old NZ Parliament Buildings with a gap of 300mm (Poole & Clendon, 1992) and the new Museum of NZ (Te Papa) with a gap of 450mm(Boardman & Kelly, 1993).

[1] *Robinson Seismic Limited, PO Box 33093, Petone, New Zealand www.robinson-seismic.co.nz*

The lead rubber bearing has been a very useful isolator but like all rubber bearings it is limited by the behaviour of rubber at high strains. To satisfy the requirements of customers, isolation designers are now requiring strains in the rubber as high as 300 to 400%. In addition designers are asking for non-linear restoring forces together with very large displacements (~ 1 metre). We believe that by driving the bearing via the centre of the top and bottom plates (Robinson, 1998a) the maximum displacement can be increased and also provide an increase in the damping of the bearing at large displacements.

Another method to satisfy the demanding requirements of a very large displacement is to use 'friction' operating within an 'inverted pendulum' (Zayas, 1995). We have followed this approach with the invention and development of a 'friction ball' or 'RoBall' rolling between two spherical like cavities (Robinson, 1998b). The RoBall rolling between two spherical like surfaces has no inherent displacement limit, provides a constant coefficient of friction and allows greater freedom in the choice of restoring force.

CENTRE DRIVE FOR LRB AND RUBBER BEARING

The rubber bearings used for seismically isolating structures can be improved by changing the method of attaching the bearing to the structure and to the foundation. A schematic diagram of a rubber or lead rubber with the drive via the centre of the top and bottom plates undergoing shear is shown in Figure 1 (Robinson 1998a). By allowing a rolling action the centre drive approach can reduce the maximum strain in the rubber by >10%.

This approach has the advantage of enabling the bearing to roll and shear. The addition of the rolling action reduces the stresses in the rubber and rubber steel connections. This rolling action also provides via the elastic and plastic bending of the steel plate an additional hysteretic damping. The effect of the rolling action is most marked at large displacements.

We have manufactured in our laboratory a number of rubber bearings covering a range in thickness of the outer steel plates. The thickness of the top plate has been found to determine the point at which the additional hysteretic damping begins.

An illustration of the effect of the plastic deformation of the outer steel plates is shown in Figure 2 where the displacement amplitude in Figure 2a is 200mm, in Figure 2b is 250mm and in Figure 2c is 275mm. The increase in hysteretic damping is clearly shown with the critical damping increasing from 8% to 10% as the displacement amplitude increases from 200 to 275mm.

The increase in damping at large displacements will be useful in reducing near fault fling effects.

PRELIMINARY EXPERIMENTAL BEHAVIOUR OF A NEW ISOLATION DEVICE

Next, we present the preliminary experimental results of a new isolation device, the 'RoBall' (Robinson, 1998b). For commercial reasons, we are not able to present the details of device design at this stage. We have made a number of prototype RoBalls and performed extensive shear tests and compression tests on them. Figure 3a shows the set up of a shear test. This is also likely to be the configuration used in isolation applications. The rolling action of the RoBall means that the device itself has no design displacement limit and so the maximum displacement is limited only by installation requirements. Figure 3b shows a hysteresis loop for the rolling of a prototype RoBall while Figure 3c shows the axial force-displacement relationship in a compression test with loading and unloading. Note that a considerable amount of energy is absorbed in the compression test.

The dynamic behaviour of the device is independent of both frequency and ambient temperature within ranges that are applicable to most practical installations. The friction coefficient, i.e., the ratio of the nominal yield shear force to the compression force, of the prototype, is between 0.23 and 0.3. With further development, the friction coefficient of the device is expected to be variable between 0.05-0.3 depending on application requirements.

The range of possible applications for this device is likely to be very wide. At the present stage of the development, the device is ready for protecting light equipment and light structures from mechanically generated or earthquake induced vibrations. We expect that the device will become an economic alternative to rubber or lead rubber bearings for isolating structures and to provide damping needed for structures to resist near-source ground motions.

For an isolated structure located close to an active fault, it is desirable for the building to be buffered so that the isolator displacement can be limited to the maximum design displacements of the bearings. In a recent paper (Zhao & Robinson, 1999) we showed that buffer-structure impact could have a detrimental effect on the building performance if the buffer is not designed properly. For resisting near-source ground motions with forward directivity effect, it is desirable to have an isolation device that behaves like a conventional isolation device but which also has a gently increasing stiffness at large displacements. This can be easily achieved by using RoBalls, with a compression force-displacement relationship as shown in Figure 3(c), as buffers. Such buffers can also absorb seismic energy to assist in providing the required amount of damping at large displacements.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The performance of rubber and lead rubber bearing isolation systems can be improved by driving the bearings via the centre of the top and bottom plates. These improvements result in a reduction to the maximum strain in the rubber, an increase in the maximum working displacement for the bearing and an additional hysteretic damping provided by the plastic bending of the plates.

2. A new device, the RoBall, promises to be an economical alternative to existing seismic isolation devices. It has no inherent displacement limit, provides a constant coefficient of friction, allows greater freedom in the choice of the restoring force and may also be used as a buffer. As a buffer the RoBall has two very desirable characteristics: it absorbs energy, and has gently increasing stiffness at large displacement amplitudes. The buffer action may also be useful for reducing the transmission of vertical earthquakes forces to the isolated structure.

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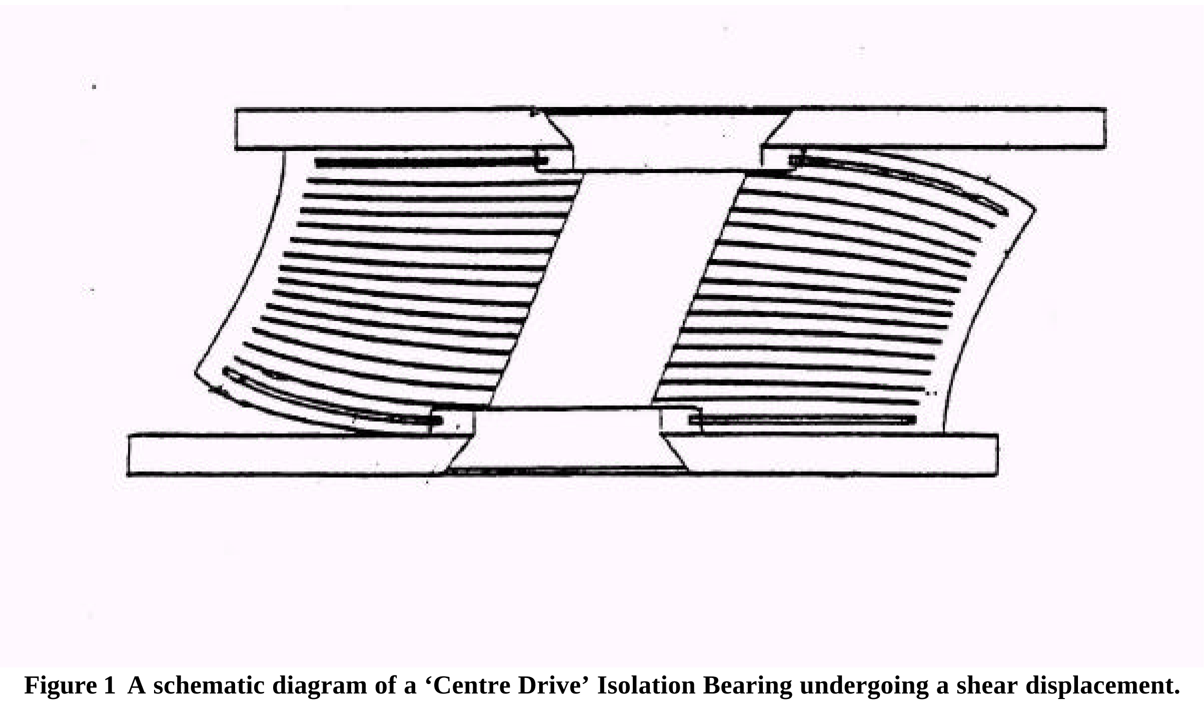

Figure 1 A schematic diagram of a 'Centre Drive' Isolation Bearing undergoing a shear displacement.

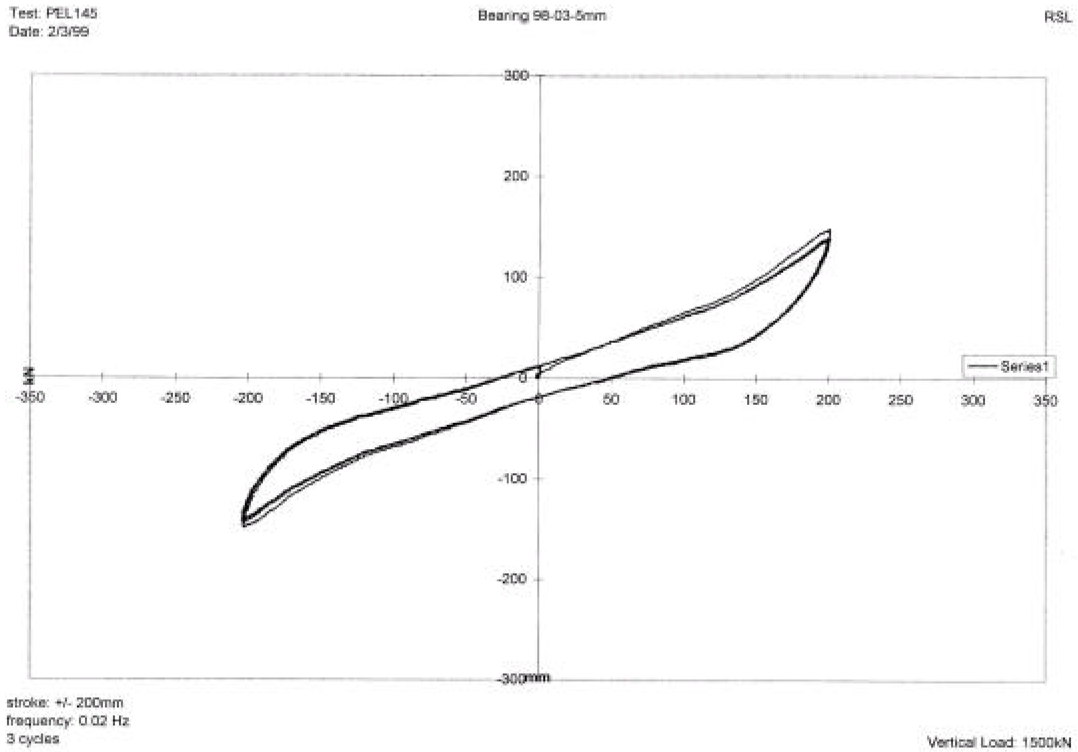

Figure 2 a The force-displacement Hysteresis Loop for a Natural Rubber Bearing, displacement amplitude=200mm, total rubber thickness=100mm, damping=7.9% of critical.

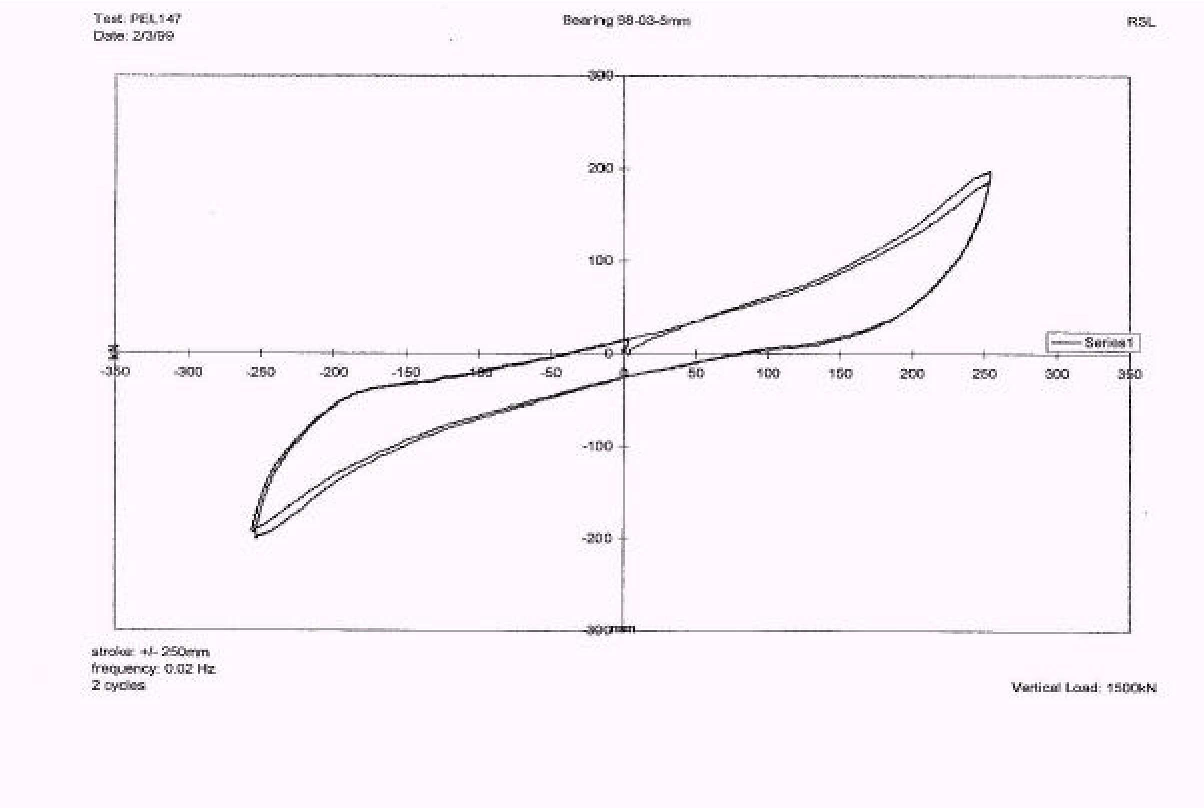

Figure 2b The force-displacement Hysteresis Loop for a Natural Rubber Bearing, displacement amplitude=250mm, total rubber thickness=100mm, damping=9.2% of critical.

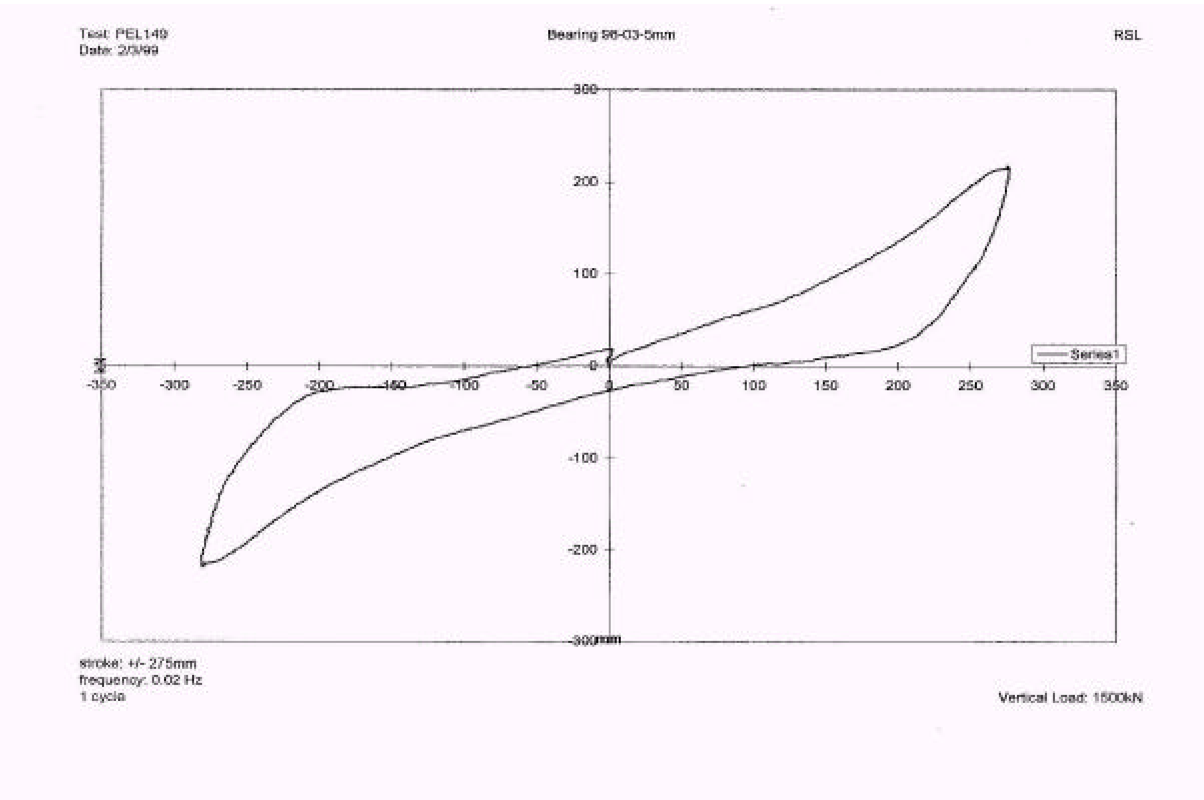

Figure 2c The force-displacement Hysteresis Loop for a Natural Rubber Bearing, displacement amplitude=275mm, total rubber thickness=100mm, damping=10.6% of critical.

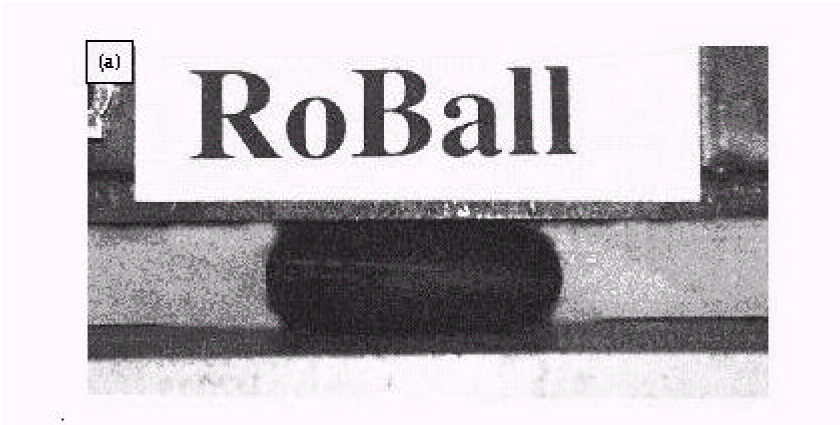

Figure 3a A ‘RoBall’ under pressure.

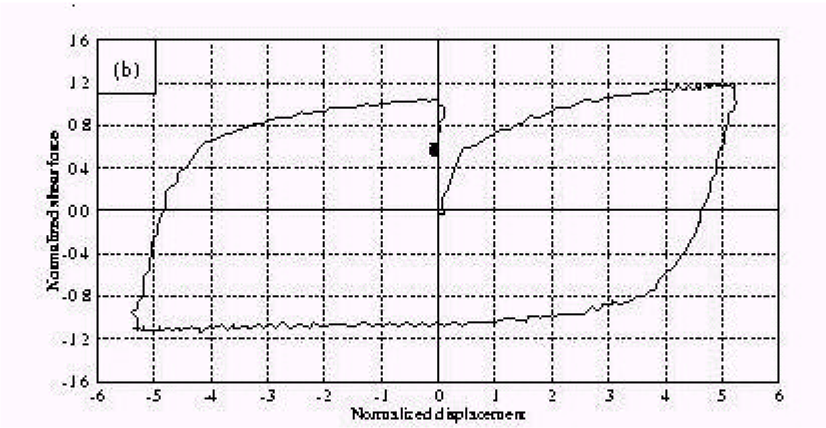

Figure 3b The force-displacement Hysteresis Loop for a ‘RoBall’.

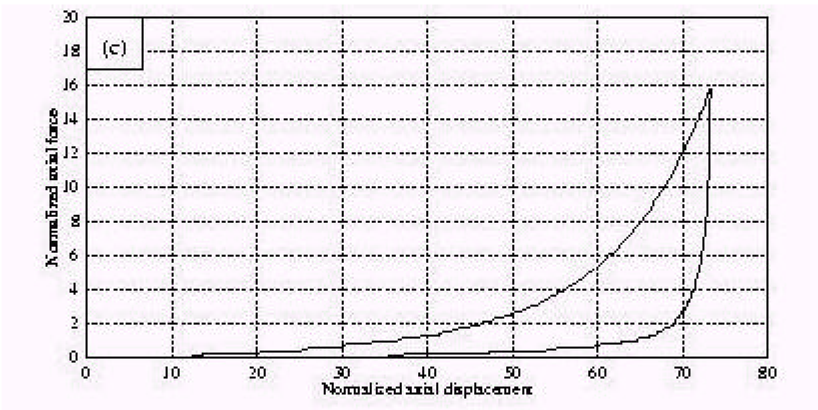

Figure 3c Vertical Force versus Vertical Displacement for a ‘RoBall’.