



BASE ISOLATION

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Strategies to Reduce Demand

- Conventional structural design increases building strength to resist increased seismic loads.
- An alternative strategy is to reduce the seismic demand so that the forces the building need resist are lower, using:
 - Base Isolation
 - In-Structure Damping
 - Active Control
- This presentation addresses the first of these, base isolation.

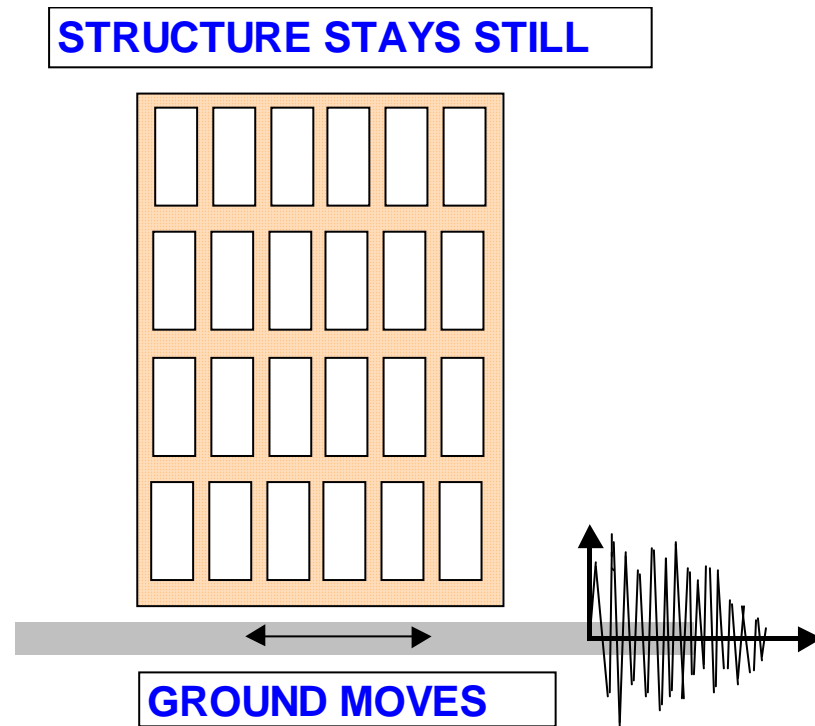


The Base Isolation Concept

- In concept, base isolation is separation of the building from the ground so that the violent earthquake motions will not be transmitted into the structure.
- Analogous to adding a suspension system to the building (springs plus shock absorbers).
- Has been compared to a boxer “rolling with the punch” instead of standing firm to take the full force of it.



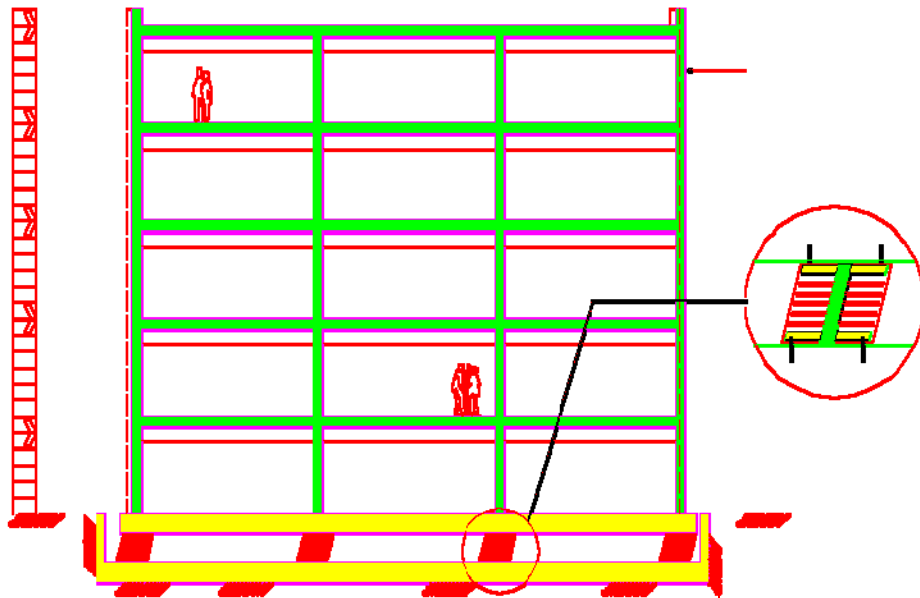
“Perfect” Base Isolation



- Would require total separation (air gap, sky hook, magnetic levitation, a well-oiled sliding surface).
- Apart from practical problems, cannot use perfect isolation because:
 - Building would move under wind loads, traffic vibrations etc.
 - After an earthquake, the building would likely end up several metres or more away from the starting point



Practical Base Isolation



- Separate the building from the ground.
- Add devices between the structure and the foundation.
- Devices allow movement under earthquakes but not wind.
- Devices also control the magnitude of the displacements.



History of Base Isolation

- First patent in 1909; an English physician proposed a layer of talc, sand or mica to allow a building to slide.
- Anecdotal applications in early 20th century. Frank Lloyd Wright designed the 1923 Imperial Hotel in Tokyo to float on the site's alluvial mud “as a battleship floats on water”. It survived the 1923 M8.3 Great Kanto earthquake.
- Practical isolation became feasible after about 1960 with the development of the elastomeric bearing (layers of rubber and steel), which can support heavy loads.
- NZ has been a pioneer in the field. The first practical systems were developed at DSIR in the 1970's, with key inventions made by the late Dr Bill Robinson.
- First NZ applications were bridges in the early 1970's and the William Clayton building in the late 1970's.



Current Status of Base Isolation

- Growth has been relatively slow in NZ and the US, but very rapid in Japan.
- Applications in Europe, Asia and the Middle East are growing faster than NZ /US, although not as rapidly as in Japan.
- NZ has about 50 isolated bridges but only about a dozen isolated buildings. Uptake is higher for bridges as they require bearings anyway.
- This NZ average of one building per 2 years shows that market penetration is low.
- After 40 years, base isolation is now classified as a “mature” technology and academia are focussed on other technologies (e.g. active control).



Performance of Isolated Structures

- Christchurch Women's Hospital the only isolated building in Christchurch. It performed as designed and remained operational.
 - Although this can be interpreted as proof of the effectiveness of the isolation system, it must be tempered by the fact that many 1950's and 1960's era hospital buildings also remained operational.
- USC Hospital in 1994 Northridge earthquake suffered no damage.
 - This is a more conclusive piece of evidence in that other hospitals in the region were severely damaged.
- There are other reports of successful performance from California and Japan (discussed later).
- Earthquakes have identified the need to ensure movement joints are maintained (e.g. some moats blocked in the years after construction).
- Isolation is not activated for smaller events which do not exceed the system trigger point. Trigger points may be high for systems designed to resist very large earthquake.

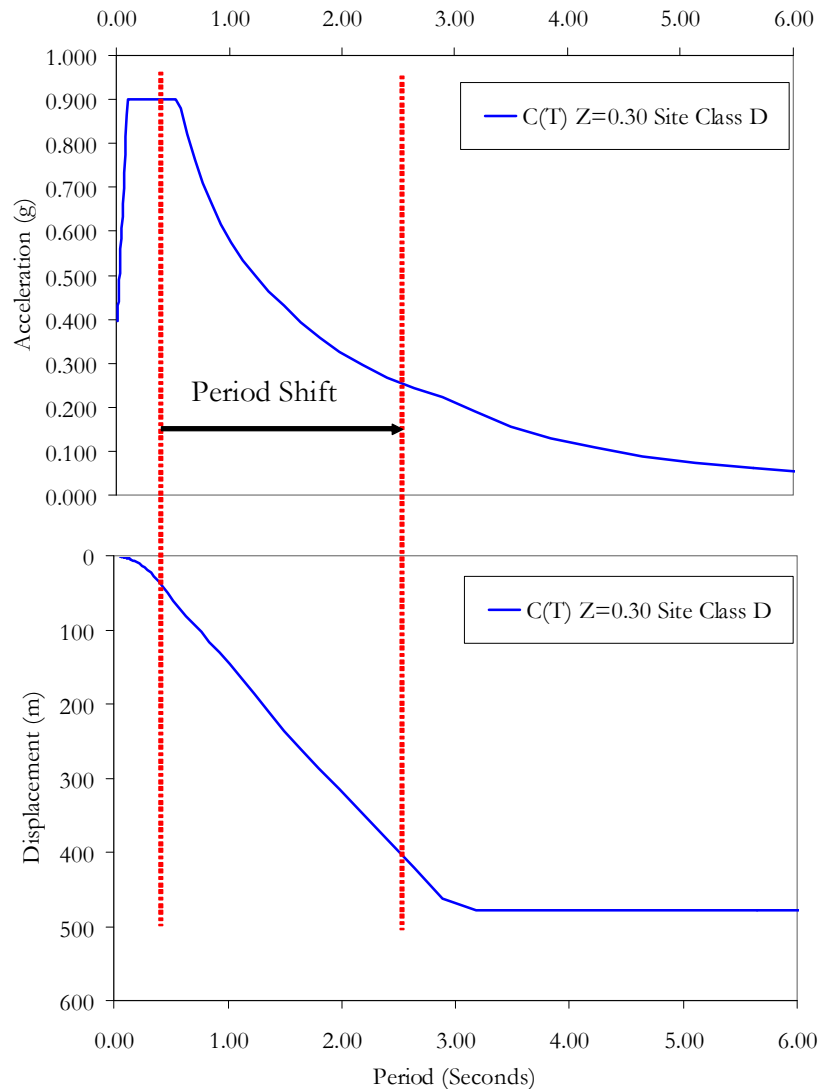


Quote from *Japan Property Central*

- Buildings constructed after 1981 in Japan may be built to three different levels of earthquake resistance:
 - (1) Basic earthquake resistance (*taishin*)
 - (2) Vibration control (*seishin*)
 - (3) Base isolation (*menshin*)
- *Menshin* is the most expensive of all and is almost always used on buildings over 20 stories high. It is both expensive to install and expensive to maintain.
- There are a total of 2600 *menshin* buildings across Japan. A survey was conducted by the Japan Society of Seismic Isolation after the March 11, 2011 Tohoku earthquake.
- The Society surveyed 327 *menshin* buildings. While the majority reported no damage, 28% (90 properties) did report some kind of damage resulting from the dampers or moving parts not functioning properly. The majority of the buildings with damage were in greater Tokyo and Miyagi Prefecture. The failure of the base isolation structure in some buildings is of concern to the Society.



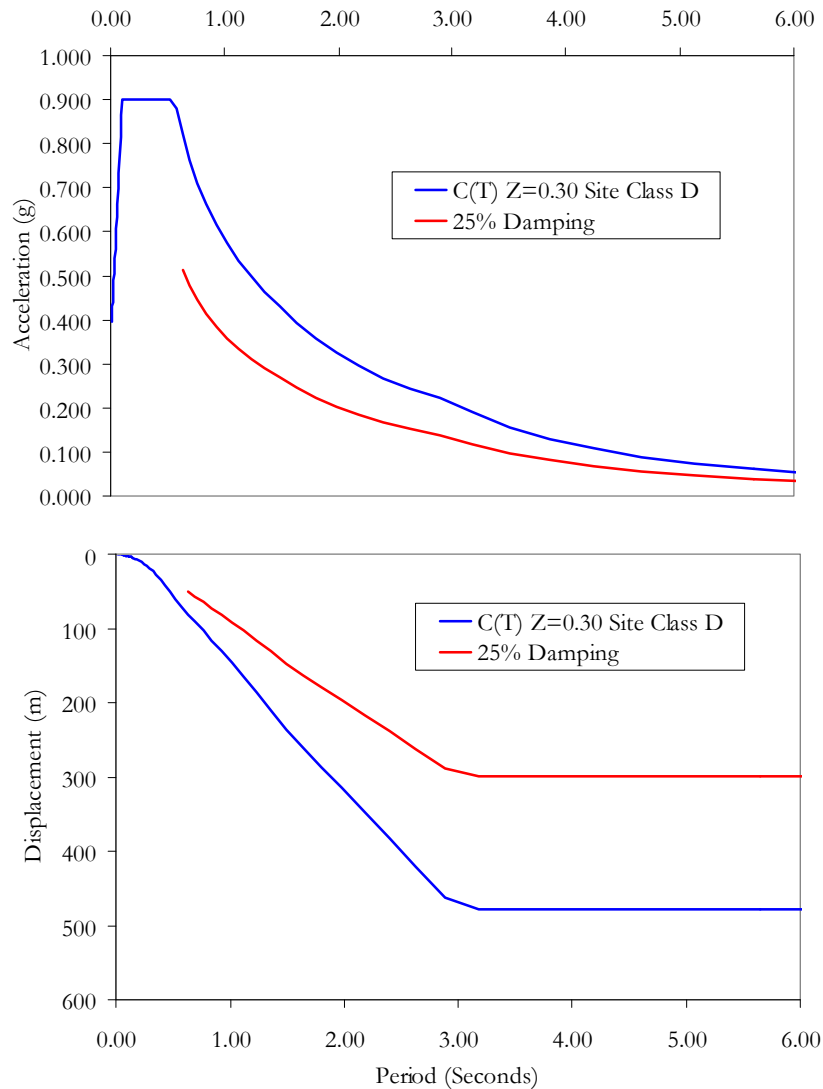
Period Shift



- Increase the period of response from (for example) 0.50 seconds to 2.50 seconds.
- The acceleration in the building reduces from 0.90g to 0.30 g (Christchurch example).
- The displacement increases from 40 mm to 400 mm
- The displacement now occurs in the base isolation devices, not in the structure
- Analogous to the effect of springs on an automobile.



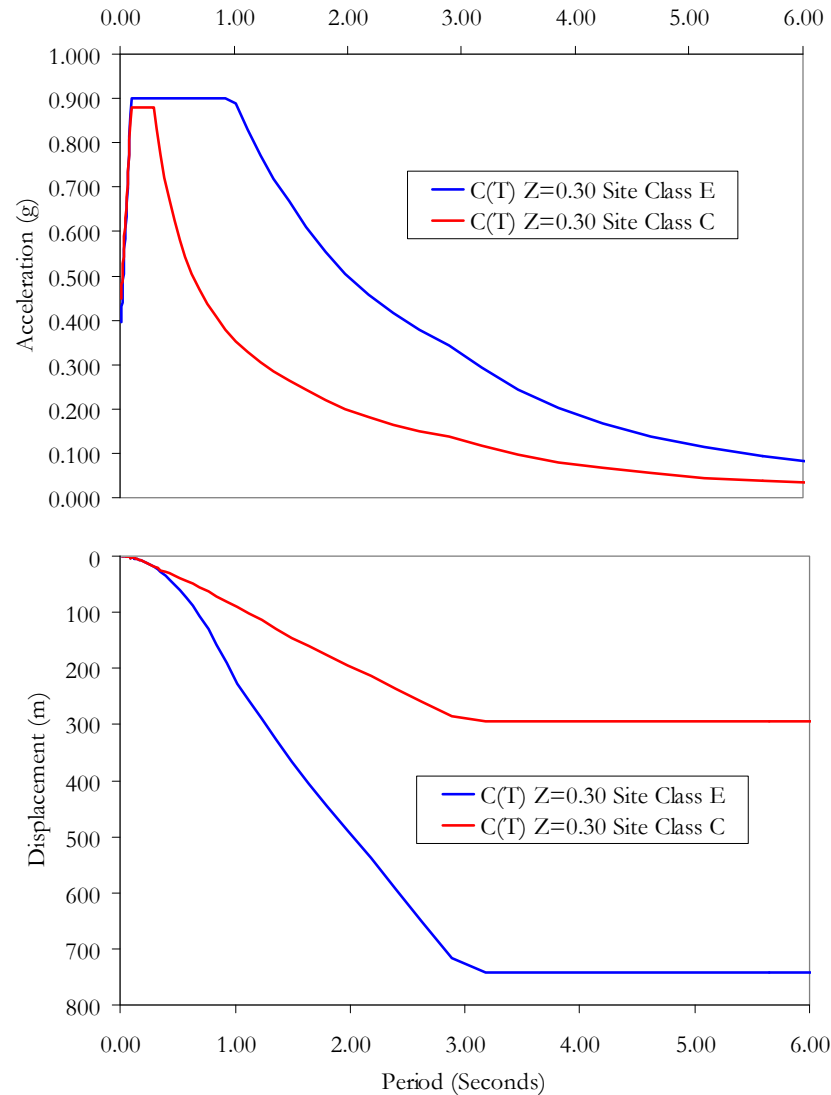
Damping



- Damping is added to the devices to control displacements.
- Increasing damping from (for example) 5% in a non-isolated structure to 25% in an isolated structure has two effects:
 - Reduces acceleration, from 0.30 to 0.20
 - Reduces displacements from 400 mm to 250 mm.
- Analogous to the effect of shock absorbers on an automobile.



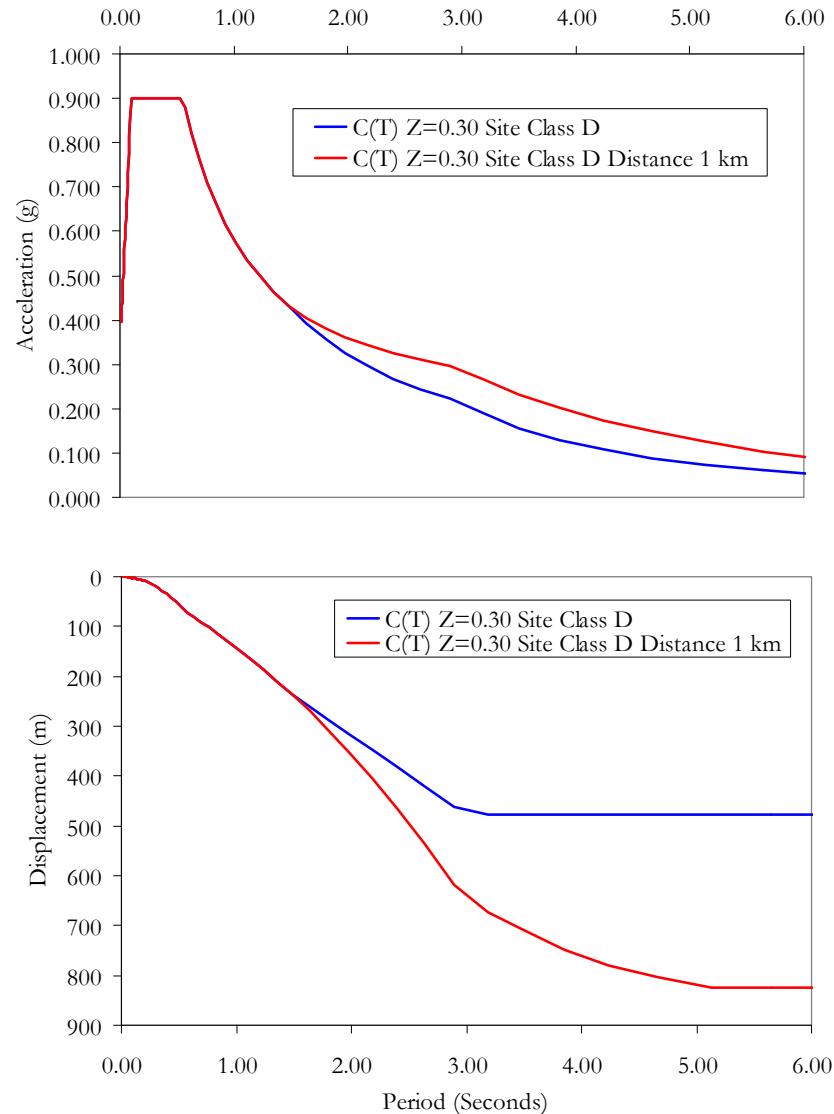
Soil Type Effect



- Soft soils transmit more earthquake energy in the long period range and so isolation is less effective.
- For a 2.50 second isolated period, the stiff soil (Class C) acceleration is 0.16g and displacement 250 mm.
- At the same isolated period on the softest soil type (Class E) both acceleration and displacement are over two times as high (0.40g and 620 mm).



Near Fault Effect



- Near fault effects occur when the earthquake epicentre is within 20 km of the building.
- The effect is to increase both accelerations and displacements for longer period structures (periods greater than 1.5 seconds).
- Near fault effects increase response in most isolated buildings as the period is almost always greater than 1.5 seconds.



Suitability for Isolation

- These features of base isolation response lead naturally to parameters which determine whether a project is suitable for base isolation or not:
 - **Building** : The non-isolated building should be relatively stiff, with an elastic period usually less than 1.0 second. This is because the benefits of period shift reduce when the non-isolated period is long. Also, resonance can occur if the isolated period and non-isolated period are similar.

Isolation devices do not function well under tension loads. Buildings with overturning moments causing tension are not good candidates. This tends to rule out tall slender buildings.
 - **Site**: It is preferable to have firm soil conditions. The softer the soil type the less effective the isolation and the larger the displacements. Some subsoil conditions have a site period in the isolated period range (e.g. Mexico City) and isolation could actually increase response.
 - **Space**. The compromise with isolation is that reduced forces result in increased displacements so it is a fundamental requirement that there be no abutting structures. Typical clearance requirements are from 250 mm to 1000 mm or even more.

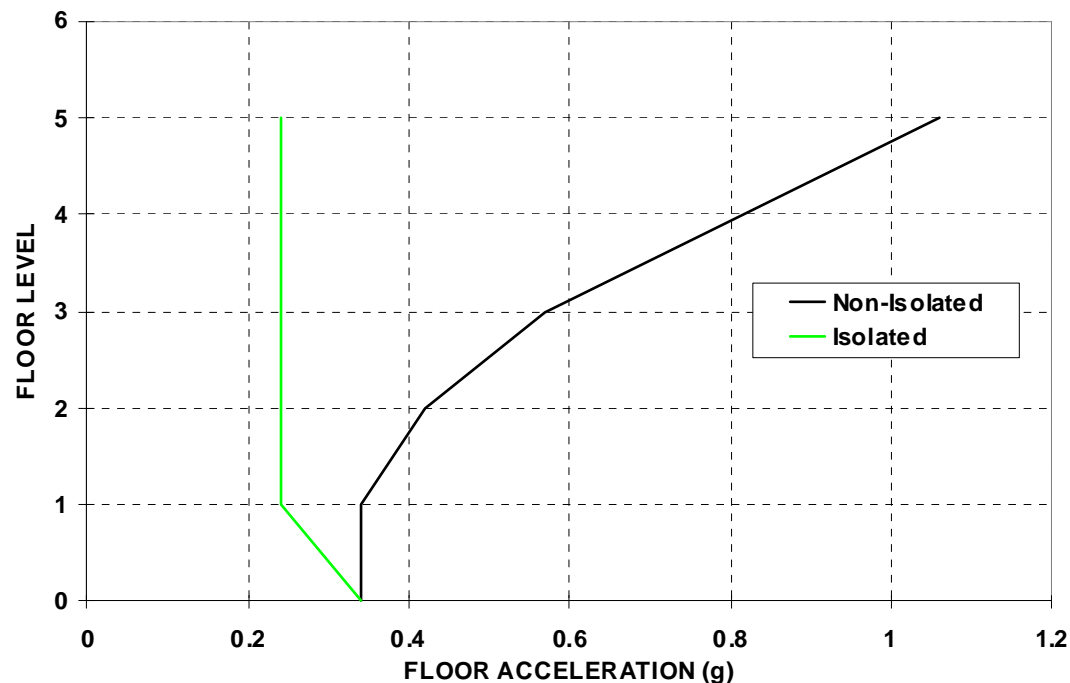


Benefits of Isolation

- Base isolation reduces the amplitude of the motions which are transmitted from the ground into the building. This has two effects:
 - Reduced inertia loads result in reduced forces in the structural elements.
 - Reduced accelerations within the building result in reduced contents damage and lower forces on non-structural components.



Parliament Building Floor Accelerations



- Parliament building was an ideal candidate (stiff building on stiff site)
- Without isolation ground accelerations of 0.35g would increase up the building to over 1 g at roof level.
- With isolation the ground accelerations of 0.35 g decrease to 0.25 g at all levels above the isolators.



Disadvantages of Isolation

- **Displacements of isolators.** The building needs to have clearance on all sides so the building does not impact on anything. This space needs to be kept clear for the life of the building.
- **Flexibility of services and utilities.** The building will move up to 1 metre relative to the ground so any connections between the ground and building need to be able to accommodate this. This includes sewer pipes, water supply, elevators and stairs etc.
- **Installation .** Particularly for an existing building, physically installing the isolators can be a major undertaking. The building has to be supported while it is cut off from the foundations and the isolators installed.



First Cost

- As for all building innovations, the first question is almost always “How much will it save?”. The expectation is that earthquake forces reduced by a factor of 3 or 4 will result in a cheaper building.
- For a new building, the answer is almost always “Nothing”.
- Why no cost savings? In a word, ductility.



The Reality of Seismic Design

- Installation of base isolation reduces forces by a factor of up to 4.
- However, in a non-isolated structure ductility is used to reduce forces by factors up to 6.
- Isolated structures are not permitted to use the same ductility as non-isolated structures because period lengthening may result in resonance.
- The end result for a new, ductile building is that design forces are similar for the isolated and non-isolated structures.
- Some savings in less stringent ductile detailing but these are countered by the costs of installing the isolation system.



So, why use isolation?

- Increased safety. Forces and accelerations are much less, resulting in a greatly reduced life safety hazard.
- Performance. The fact is that
$$\text{Ductility} = \text{Damage}$$
and this damage may not be repairable.
- Existing buildings may have no available ductility (e.g. historic buildings)
- Protection of contents. Reduced floor accelerations and structural deformations reduce the damage to building parts and contents.
- Continuous functionality. The absence of structural damage permits the building to function during and immediately after the earthquake event.



Best Candidates

- The characteristics and advantages of base isolation lead to natural candidates for isolation: Buildings where continuing function is important, buildings where ductility is not available or buildings where contents are important. These fall into five main categories:

Essential Facilities	Functionality High Return Period Factor, R
Health Care Facilities	Functionality High Return Period Factor, R
Historic Older Buildings	Preservation Low Ductility
Museums	Valuable Contents
Manufacturing	Continued Functionality High Value Contents



Valuable Contents



Te Papa – Museum of NZ

- The Museum of New Zealand, Te Papa was constructed on a raft sitting on lead rubber bearings and Teflon sliding bearings. A visitor gallery provides access to view the isolators. The isolator flexibility allowed the base slab to be constructed with no joints and the isolators have moved about 25 mm with time to accommodate shrinkage of the concrete slab.



Historic Building



NZ Parliament Buildings

- The main Parliament building, General Assembly Library West Wing and Library East wing were base isolated in the early 1990's. These historic buildings were fragile and added concrete walls in the superstructure were required in addition to the base isolation system.
- Other historic buildings isolated in Wellington include the Old BNZ Arcade, the Maritime Museum and the Supreme Court.



Health Care



St Johns Hospital, CA

- A new building isolated on lead-rubber bearings. This is a replacement facility for a hospital irreparably damaged in the 1994 Northridge earthquake.



Vulnerable Bridge



Benicia/Martinez Bridge, CA

- The Benicia-Martinez bridge forms one of the San Francisco Bay crossings. The superstructure is being base isolated to reduce earthquake vulnerability and ensure functionality.



Valuable Contents

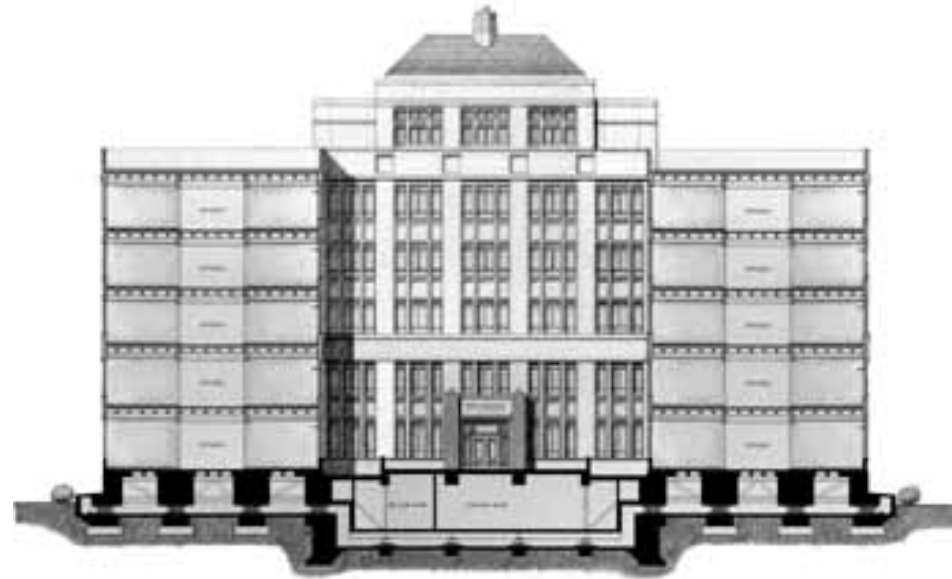


Missouri Botanical Garden, MI

- This herbarium contains a collection of some of the world's rarest plants and books about plants. Missouri has infrequent earthquakes but historically the largest US earthquakes have occurred in this region. The new building was isolated on high damping rubber bearings.



Historic Building



Berkley Civic Centre, CA

- The Berkeley Civic Centre is one of a number of municipal buildings in California which are historic but very fragile (URM construction). Other examples include the Oakland, San Francisco, Los Angeles and Hayward City Halls. Structural strengthening in addition to isolation is almost invariably required.



Non-Ductile New Building



Union House

- The only base isolated building in Auckland, and one of the first in NZ (early 1980's) is a highly visible office building by the waterfront. This used an innovative sleeved pile / steel cantilever isolation system. Reduction in forces achieved with isolation permitted a non-ductile structural system.



Existing Viaduct



- Lead rubber bearings being installed in an existing motorway viaduct in Istanbul, Turkey.



Requirements of a Practical System

- Flexibility. The basic of isolation is to increase the period of response and so flexibility is a prime requirement.
- Damping is not essential but preferred in order to reduce displacements and also to reduce sensitivity to different types of earthquake.
- Rigidity under service loads (wind or traffic) is required so that building occupants are not alarmed by frequent movement.

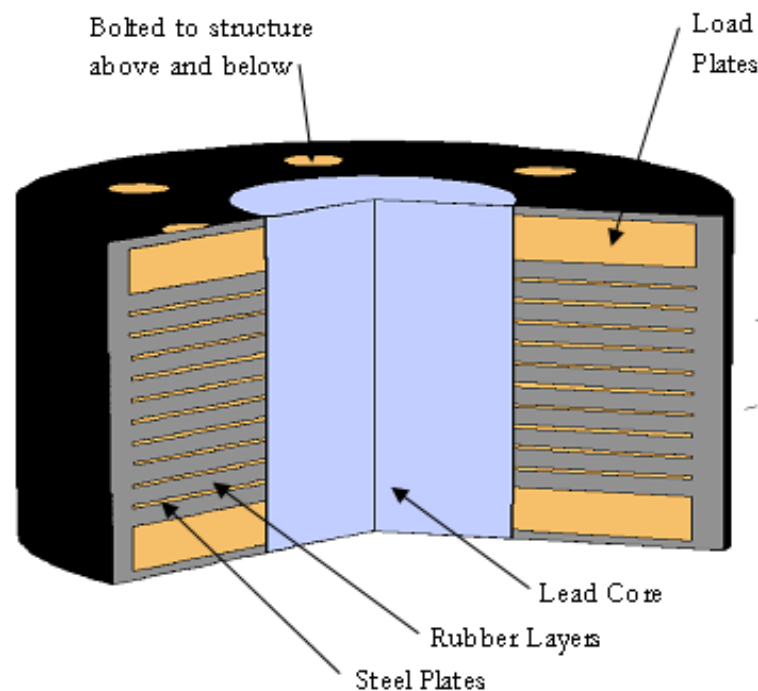


TYPES OF BASE ISOLATORS

- **Lead Rubber Bearings** – most common type used in NZ. An elastomeric bearing (layers of rubber and steel) with a lead core forced into a hole down the centre to provide damping. (e.g. Te Papa, Parliament, Maritime Museum, Petone Press Hall,
- **High Damping Rubber Bearings** – elastomeric bearings with special rubber compounding to provide internal damping (e.g. Parliament).
- **Flat Sliding bearings**, usually Teflon on stainless steel. Need other devices to return to initial position after an earthquake.
- **Inverted Pendulums**. A Teflon bearing sliding in a dish instead of a flat plate so it returns to their initial position. Used extensively in the US but not in NZ.
- **Sleeved Piles** are piles which can move within a sleeve. Provide flexibility but are rarely used (e.g. Union House).
- **Lead Extruders** as similar to an automobile shock absorber but with lead instead of a fluid. Use to provide damping (e.g. Wellington Central Police Station).
- **Yielding Steel Cantilevers**. Provide damping (e.g. Union House).



Lead Rubber Bearing

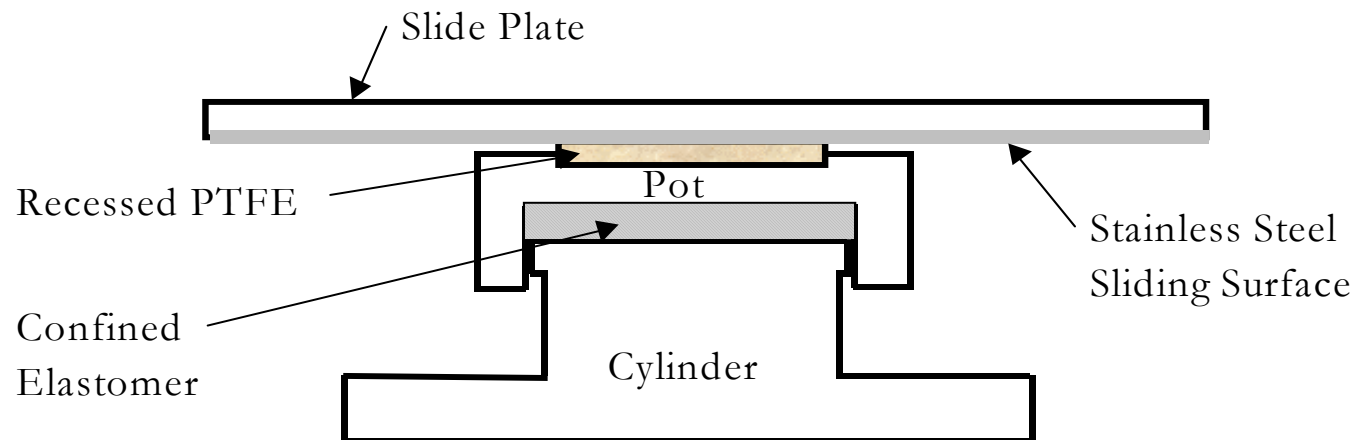


- May be square or circular.
- Load plates may be oversize for flange connection.
- Typical dimensions 350 mm – 1200 mm plan size; 200 mm – 800 mm high; lead core 75 mm – 300 mm diameter
- Bearing is moulded under heat and pressure.
- Lead core is press fitted after moulding.
- High damping rubber bearing is similar construction except for absence of lead core.



Flat Sliding Bearings

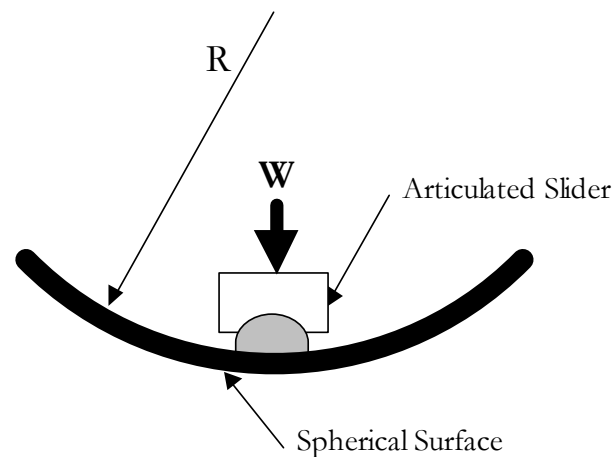
- Usually PTFE (Teflon) sliding on stainless steel.
- Pot / Cylinder variation shown permits rotation.
- Slide plate separates from pad if uplift loads occur.
- Has no restoring force.
- Friction provides very efficient damping





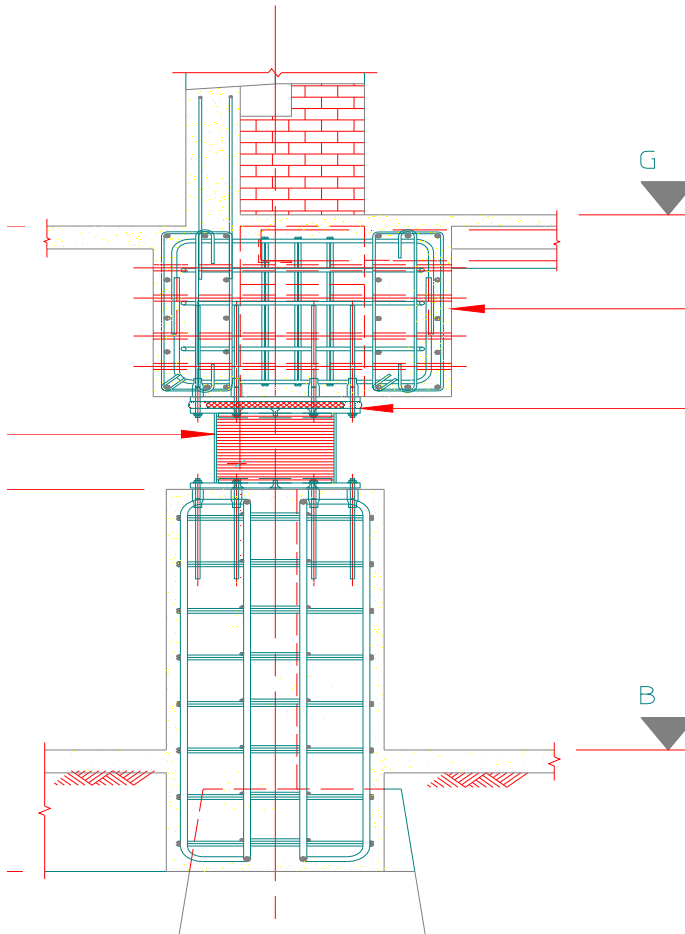
Friction Pendulum Bearing

- A variation of the flat sliding bearing.
- Spherical sliding surface provides a restoring force.
- Has large market share in US (probably 20% - 30%) and some other Middle East markets.
- Is efficient for buildings with an eccentric mass distribution.





Installation



- Usually at top or bottom of basement level.
- Existing buildings require strengthening above and below the isolators to resist seismic forces.
- Example shown in from Parliament Buildings.



Implementation Issues

- As with all new technologies, there are impediments to widespread adoption. For base isolation, these include:
 - Codes, in particular specification of:
 - Design Ground Motion
 - Type of Analysis
 - Building Ductility
 - Foundations
 - Installation
 - Device Selection and Design
 - Device Testing and Supply
 - Cost

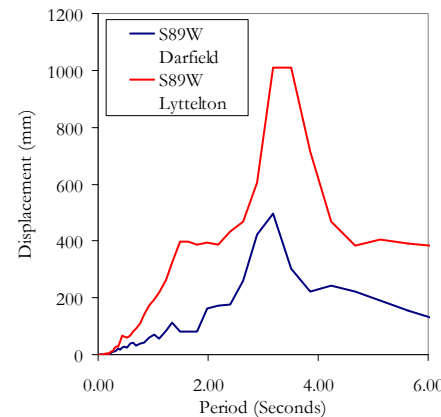
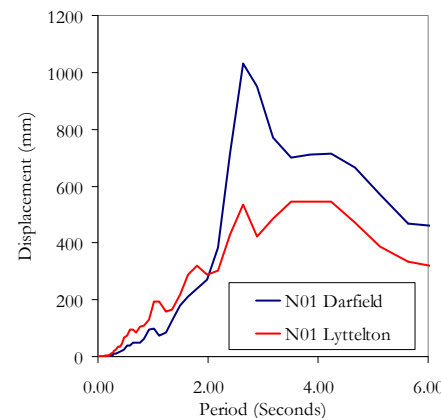
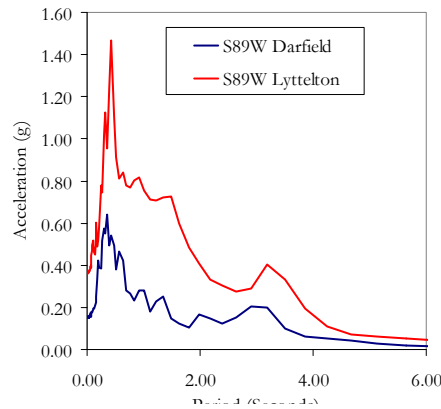
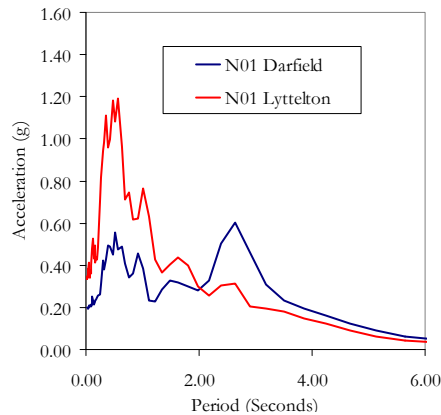


Codes

- Surprisingly, although practical isolation systems were developed in NZ we do not have any codes of practice.
- NZ structural design codes and material codes do not prohibit isolation but neither do they provide guidance.
- We commonly adopt US codes (UBC for buildings, AASHTO for bridges).
- Some projects use Eurocode provisions.
- Not a satisfactory situation as there are differences in structural engineering practice between NZ and the US or Europe.



Site Seismicity- Christchurch Hospital



- Isolation relies on the reduction in acceleration with increased period.
- Some soil types and near fault events do not exhibit this.
- The isolation may move the building period into harm's way instead of out of harm's way.
- Some Christchurch events showed this characteristic. The hospital spectra show large displacement peaks at about 2.5 seconds.
- Site or near fault effect?
Needs further explanation.



Foundations

- The isolation devices apply discrete loads to the foundations. This may change the soil pressure distribution on existing buildings with strip footings.
- The distribution of loads to isolators requires a diaphragm. For buildings without a basement (e.g. houses which would be usually be constructed on a slab on grade) this will involve the cost of an additional suspended floor.
- Secondary forces (P-delta effects) are high because of the large isolator displacements. This can require substantial beams above and below the isolators to resist these moments.



Installation

- The primary feature of isolation is separation of the building from the ground.
- All building services, stairs, elevators etc. must maintain this separation.
- As the building has a moat all around, it is in some ways like a ship at sea – the entrances must be constructed much like gangways.
- Installation may be complex and expensive for existing buildings.



Isolation System Selection & Design

- Most structural engineers are not conversant with the basis for isolator selection and device design.
- Reliance placed on suppliers for technical advice and design assistance.
- Often conflicting advice will be obtained and it may be difficult to resolve these conflicts.



Isolator Testing



- Prototype tests are required on full size isolators using test sequence equal to multiple DBE plus an MCE.
- Prototype bearings are not used in the structure so impose an additional cost.
- Test loads and displacements require high capacity equipment.
- Production tests also add a cost.



Cost Factors

- Isolators 10k-20k Each
- Christchurch Women's Isolators little under \$1m
- Architectural changes may be expensive (stairs, elevators, moat)
- Utility costs are higher
- Engineering costs are higher
- Need suspended floor above isolators



The Future of Isolation in NZ

- Will continue to be used for specific types of project (usually publicly funded buildings, of high importance or a fragile historic nature).
- Use may extend to other types of building as impediments are removed. However, no evidence of this as yet.
- Any implementation requires a high degree of coordination and cooperation between all parties:
 - Owner, to pay for it.
 - Architect, to accept restrictions on access etc.
 - Engineer, to design and detail the isolation system.
 - Quantity Surveyor, to provide accurate costing.
 - Project Manager, to manage purchase, supply and testing.