Costs of Base-isolation and Earthquake Insurance in New Zealand

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ABSTRACT: The first phase of the study addresses the costs and savings associated with base-isolating a building, compared to those of a fixed-base building. Four relatively new base-isolated public hospital buildings were chosen as case studies. Each building was visited, and as many of the design and construction team members as possible, including client, structural engineer, quantity surveyor, architect and contractor were interviewed. In addition, several manufacturers of base-isolation bearings provided information. From this phase, not only are some actual costs determined but the key factors affecting the construction cost of base-isolation are indentified.

The study then focuses upon earthquake insurance. This phase consisted of interviewing several experienced earthquake insurance industry personnel. Based upon their knowledge, approximate insurance premium rates for fixed-base buildings are provided and future trends in earthquake insurance and implications for base-isolated buildings are discussed. Some of these issues should be considered by building owners and their design teams.

1 INTRODUCTION

Base-isolation or seismic-isolation is a simple concept allowing buildings to withstand earthquakes. It involves separating a building superstructure from its substructure which remains on the shaking ground, thus protecting the building and its non structural elements from damage. It can’t claim to make a building “earthquake proof”, but it reduces considerably the forces and interstorey drifts within a building and so limits damage. The isolators are the key elements of this technology that achieve the decoupling effect. In order that a building superstructure can move freely with respect to the ground, a moat or rattle-space is provided all around the building. Nothing must interfere and obstruct horizontal movement, so all elements crossing the isolation plane, such as services, are designed for flexibility.

The direct advantages of base-isolation apart from eliminating or at least greatly reducing earthquake casualties are the few repairs needed after an earthquake, no disruption of building function and protection of contents. To date, base-isolation has been mainly used in buildings needing to remain operative directly after an earthquake, such as hospitals.

Determining the increased or decreased cost of a base-isolated building as compared to a fixed-base building is difficult. Figures range from plus 10% to less than 0% of the construction cost. Many factors must be taken into account and infrequent use of base-isolation complicates the task. The approach taken in this study involved investigating the cost of base-isolation from the perspectives of architects and building owners, as well as design and construction team members. The research draws upon information collected through articles, questionnaires, interviews, as well as investigations of several existing base-isolated buildings through visits, and architectural and engineering plans.

The focus of the research is four relatively new base-isolated buildings; specifically, four hospitals built within the last six years. This selection allows for a basis of comparison within the same building type, and because the buildings are new, factors specific to older construction are avoided. By treating this subject not only through the exclusive point of view of construction cost but also by incorporating earthquake insurance aspects, the global financial implications of the construction costs of base-isolation can be assessed.

The limitations of research reported here need to be outlined. Many arose due to the work-load
currently experienced by building industry professionals in the aftermath of the Christchurch earthquakes. This has meant incomplete information such as, accurate break-down of costs and full structural design information. Most significantly, an inability to determine the structural savings for base-isolated buildings’ structural and non-structural superstructure elements due to the lower seismic design loads, ductile detailing requirements, and interstorey drifts have limited the effectiveness of this study. Most of the information reported was obtained through interviews and questionnaires whose respondents remain anonymous.

2 DESCRIPTIONS OF THE FOUR HOSPITALS

2.1 Wellington Hospital

The new Wellington Hospital was completed in December 2008 at a total construction cost of NZ$ 165 million (Fig. 1). It is a seven storey building incorporating a two-storey podium with a total floor area of 44,700 m². It is designed to withstand a Magnitude 7.8 earthquake on the Wellington-Hutt fault, as well as a Magnitude 8.3 on the Wairarapa fault. The lateral load-resisting systems comprise reinforced concrete moment frames which are suitable for health space-planning. The building is expected to move up to 300 mm in any direction during a 1-in-500 year earthquake, and up to 600 mm during a 1-in-2500 year event. Flexible connections and loops cross the isolation plane to allow unrestricted horizontal movement. The isolation plane has been placed in the basement of the building, used as a car park (Fig. 2). Two types of isolators are mounted on top of the basement columns: 135 lead rubber bearings (of six different designs) and 132 slider bearings.

The seismic gap and isolation plane around the building is treated:

- Horizontally as a joint filled with flexible sealant and as a metal flashing.
- On some areas around the building, especially at the main entry area, the seismic gap is hidden under paving.
- Vertically with sacrificial steel concertina flashing or light cladding between the base-isolated and non base-isolated buildings.

Each lift shaft hangs below the isolation plane. At the basement level oversized lift pits allow +/- 600 mm movement due to the rattle-spaces around them that are covered by steel plates. Stairs are disconnected at the isolation plane, the lower parts tied to the ground (basement) and the upper sections move with the building.

2.2 Christchurch Women’s Hospital

The new Christchurch Women’s Hospital was completed in 2005 at a total construction cost of NZ$ 50 million (Fig. 3). Located in the Christchurch Public Hospital Campus, it is a 9-level building (including two levels underground and a top floor reserved for services) with a total area of 20,000 m² and a 2432 m² footprint. It has been designed to withstand a Magnitude 8 earthquake on the Alpine Fault.

The building possesses two structural systems: perimeter reinforced concrete moment frames resist longitudinal forces, and moment frames plus two partial-height steel K-braced frames adjacent to the lift core at the centre of the building resist transverse forces. The building can move +/- 420 mm in any direction during a major earthquake. Forty-one lead rubber bearings and four slider bearings are
placed in the basement. A longitudinal trench allows all the services and some of the isolators to be checked easily (Fig. 4). Isolators around the perimeter can also be inspected, but from a crawl space. The new hospital design was constrained by the city plan, especially concerning the maximum high limit. The site was excavated below water table and required a retaining wall around it.

![Fig. 3: Christchurch Women’s Hospital](image1)

![Fig. 4: Trench and LRB isolators](image2)

The seismic gap appears in various ways:

- Most of the seismic gap is treated horizontally as “pop-out” steel plates and sacrificial steel flashing.
- The new building is linked to the existing central hospital facilities. Seismic gaps between the base-isolated building and the others (not base-isolated) are treated vertically with a sacrificial steel concertina flashing on the exterior, and sacrificial flooring, wall panels and ceilings on the inside.
- The pedestrian path on the right of the main entrance cantilevers over the narrow seismic gap of the horizontal isolation plane.

The two lift shafts emerge in the basement but no access to them there is provided. They hang below the isolation plane and are connected to columns resting on lead-rubber bearings. The stairs are treated just like those at the Wellington Public Hospital.

### 2.3 Lower Hutt Hospital

![Fig. 5: Lower Hutt Hospital from the street](image3)

![Fig. 6: Services and water tanks (basement)](image4)

The Hutt Hospital will very soon be completed at a construction cost of NZ$ 35 million (Fig. 5.). It consists of a rattle/basement space (3417 m²), a ground floor (3346 m²), a first floor and a second floor plant room (1201 m²) leading to a total area of 11,220 m². It has been designed to withstand the Maximum Credible Earthquake (MCE) that may occur in the region. The superstructure is mainly composed of reinforced concrete moment frames but also includes steel frames in the top floor. The base-isolation system comprises 32 lead rubber bearings and 32 sliders bearings, allowing a +/- 500 mm displacement capacity. The building is adjacent to an existing building which is also base-isolated (30 years ago), so to prevent damage from pounding a relatively wide gap allowing circulation between the two buildings has been created. The isolation plane is placed in the basement which can be considered as a crawl space, and a trench allows easy inspection of the services and water tanks (Fig. 6).

Since the level of the ground floor of the new building had to match that of the adjacent building, the ground level has been raised up on two sides of the building, resulting in two different treatments of the seismic gap and isolation plane:
On half of the new building the isolation plane appears as a horizontal strip of flexible sealant with a concrete skirt above it and precast panels underneath.

Along the remainder of the building perimeter the seismic gap is treated horizontally as “pop-out” slabs that form a pavement surface.

Two lift shafts hang below the isolation plane but don’t provide access to the basement. There are no internal stairs crossing the isolation plane but several external stairs are attached to the building and have been designed to slide with it. Some extra space has been provided preventing damage to the stairs during a small earthquake but for the MCE event, sacrificial elements were designed.

2.4 Whanganui Hospital

Completed in 2008 with a total construction cost of NZ$ 18 million, the Whanganui Hospital possesses two new single-storey buildings base-isolated with 97 RoGlider isolators (Fig. 7). These bearings, suitable for light loads and large displacements, provide high damping performance as well as an elastic restoring force. Superstructure lateral loads are resisted by reinforced concrete moment frames in one direction and braced frames in the other. In order to match the existing floor levels of the existing buildings and due to the natural ground level, the two new base-isolated buildings possess basements in which the isolation system is housed. Some isolators are installed on top of columns and others on footings below steel braced columns but at the same level (Fig. 8). Part of the basement accommodates the multiples services needed, while the other is an unused crawl space over soil. This area can be excavated for future basement expansion.

The seismic gap and isolation plane appear in various ways:

- Between the base-isolated buildings and bridges from the existing buildings vertical gaps are covered with flexible rubber concertinas.
- The isolation plane is hidden by sacrificial Hardiplank flashing.
- In the ambulance park area, steel plate flashings cover the seismic gap.
- At the main entrance of one of the two buildings, a “pop-out” plate is provided.

3 FACTORS INFLUENCING CONSTRUCTION COSTS OF BASE-ISOLATED BUILDINGS

Before reporting on the construction cost increases associated with the base-isolation of the four buildings, factors leading to both potential construction savings and increases are listed below in Table 1. They were identified during the building site visits, discussions with design and construction team members, and information from isolator manufacturers.

Of course the height, weight and shape of a building as well as the seismicity of the area, proximity to nearest fault and maximum displacement for a design level event influence the choice of the isolators and the overall system design.
### Table 1. Summary of the factors influencing construction costs of base-isolation

<table>
<thead>
<tr>
<th></th>
<th>Reduced Costs</th>
<th>Increased Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landscaping / Rattle space</strong></td>
<td>Lowering the ground level around the building to be below the isolation plane avoids the need of a rattle space.</td>
<td></td>
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<tr>
<td><strong>Structure</strong></td>
<td>Base-isolation allows a reduction in structural element sizes. Less ductile detailing is needed and since seismic isolation reduces overturning moments, lighter foundations can be designed.</td>
<td>The more services that cross the isolation plane, the more flexible joints and loops are needed. Gather services together above the isolation plane to reduce the number of flexible couplings.</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td></td>
<td>The more elements crossing the isolation plane or the junction between an isolated building and a non-isolated building (stairs, lift shafts, etc.), more detailing will be needed leading to additional time during the design phase, and time and material during the construction phase.</td>
</tr>
<tr>
<td><strong>Supply of Isolators</strong></td>
<td>By purchasing the isolators directly, rather than through the main contractor, the client can reduce construction time and save between 5% and 10% of the cost of the isolators.</td>
<td></td>
</tr>
<tr>
<td><strong>Isolator manufacturer</strong></td>
<td>Close isolator manufacturer and design team collaboration (especially the structural engineer) early in the design phase can reduce the cost of the isolators.</td>
<td></td>
</tr>
<tr>
<td><strong>Detailing and extra elements</strong></td>
<td>A basement can provide multiple uses allowing savings (no extra floor needed for the services) and even additional income (car park). Also it can allow for greatly enhanced flexibility for likely future relocation of services.</td>
<td>The more floors in a building, as a percentage of total floor area the costs of isolators and rattle space will reduce.</td>
</tr>
<tr>
<td><strong>Basement</strong></td>
<td>A basement can provide multiple uses allowing savings (no extra floor needed for the services) and even additional income (car park). Also it can allow for greatly enhanced flexibility for likely future relocation of services.</td>
<td>Depending on the height of the isolation plane, base-isolation may require a suspended ground floor slab with additional beams rather than a cheaper slab on grade.</td>
</tr>
<tr>
<td><strong>Experience of the design team members</strong></td>
<td>The experience gained on previous base-isolated buildings by members of the design team is useful. It not only can reduce time during the design phase (by using former details, for example) but can also lead to cheaper solutions.</td>
<td></td>
</tr>
<tr>
<td><strong>Fees</strong></td>
<td>Since base-isolation requires additional analysis and detailing, extra design fees may be charged.</td>
<td></td>
</tr>
<tr>
<td><strong>Prototype isolator testing</strong></td>
<td>Prototype testing is proportionally less expensive for big projects as usually two to four prototype bearings are made and tested to destruction. Absorbing that cost over many bearings has less of an effect than absorbing it over few bearings.</td>
<td></td>
</tr>
</tbody>
</table>

4 CONSTRUCTION COSTS OF BASE-ISOLATION

4.1 Wellington Hospital

According to the quantity surveyor and services engineer, the extra cost of the flexible services was between one and three percent of the total services costs compared to a same sized non-isolated project, and therefore is insignificant. Although there was potential for some savings in restraint of
services due to lower floor accelerations in a base-isolated building, none were reported on this project.

Regarding different costs of the fitout of partitions, finishes and cladding between the Wellington Hospital and a same sized non-isolated building, the engineer and quantity surveyor agreed costs were almost the same, even with the advantage of lesser interstorey drifts and damage from base-isolation. The most obvious difference between the Wellington Hospital compared to the three other case-studies is that its basement is used as a car park. The total cost of the base-isolation and basement reached a total of 8% of the construction cost. This figure can be broken down as 5% for the car park and 3% for the base-isolation system. The isolators cost 1%, the rattle space 0.4% and the basement 1.6%.

4.2 Christchurch Women’s Hospital

Many documents concerning the cost of base-isolation were lost during the Christchurch February 2011 earthquake. Only the cost of the isolators (1.3% of the construction cost) could be accurately confirmed.

4.3 Hutt Hospital

The total cost of the isolators, including the two manufactured prototypes (as well as their tests), and their supply corresponded to approximately 1% of the construction cost. This includes the 5% to 10% savings accrued due to the client, instead of the main contractor, purchasing the isolators.

4.4 Whanganui Hospital

Since this project comprises two single-storey buildings, more isolators than usual were needed compared to a single multi-storey building with the same floor area. The cost of the isolators was approximately 2% of the construction cost. Due to the low surrounding ground level almost no rattle space was needed. The total cost of base-isolation was 3% of the construction cost.

Table 2 provides a summary of the base-isolation costs for the case-study buildings.

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Cost of construction (NZ$ millions)</th>
<th>Total floor area (m²)</th>
<th>Cost of the isolators</th>
<th>Cost of rattle space</th>
<th>Other Costs: suspended floor, retaining walls, etc</th>
<th>Total cost of base-isolation</th>
<th>Cost of base-isolation (NZ$/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellington Hospital</td>
<td>165</td>
<td>44,700</td>
<td>1%</td>
<td>0.4%</td>
<td>Isolation system generates a usable basement: 1.6%</td>
<td>3%</td>
<td>110</td>
</tr>
<tr>
<td>Chch W’s Hospital</td>
<td>50</td>
<td>20,000</td>
<td>1.3%</td>
<td></td>
<td>No information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hutt Hospital</td>
<td>35</td>
<td>11,220</td>
<td>1%</td>
<td></td>
<td>Estimation of client representative: 1.7%</td>
<td>2.7%</td>
<td>84</td>
</tr>
<tr>
<td>Whanganui Hospital</td>
<td>18</td>
<td>1740 +2800= 4,500</td>
<td>2%</td>
<td>Negligible</td>
<td>1%</td>
<td>3%</td>
<td>140</td>
</tr>
</tbody>
</table>
5 INSURANCE AND BASE-ISOLATION IN NEW ZEALAND

5.1 General comments

This section of the paper discusses the current building insurance climate for new buildings in New Zealand and then considers possible benefits of base-isolation in terms of earthquake insurance. The material reported upon has been gathered during anonymous interviews with four experienced insurance industry personnel.

As has been well-reported in the media during 2011, the Canterbury earthquakes of September 2010 and February 2012 have had a huge effect on earthquake insurance. The February quake has been described as a “market-changing event”. There is now a real issue of insurance availability. Two insurers have recently withdrawn from Wellington, and all insurers are currently reviewing their exposure in Wellington and possibly other cities, with a view to reducing exposure. A new large building might now require more than one insurer to provide full cover. And if another damaging quake was to strike in the interim then availability would certainly be a very serious issue. However, in a climate where insurance is hard to arrange, base-isolated buildings will be the first to be insured and the last to lose their existing insurance.

The most obvious outcome of the recent earthquakes has been a sharp increase in the costs of insurance. Premiums have increased, deductibles have increased and overall conditions are a lot tighter. Premiums are expected to continue to rise in the foreseeable future. Whereas insurance companies had purchased reinsurance based upon a Maximum Probably Loss event that had a 250 year return period, it is expected that future reinsurance will be based on a 1 in 1000 year event. Premiums which will also continue to rise in keeping with growing construction costs are indicated in Table 3.

The deductible, or the amount a client must pay prior to receiving an insurance payout, has already risen and also may increase further. The deductible for Christchurch prior to the recent quakes was 2.5% but now it is 10% of the site value, including buildings and contents.

Table 3. Earthquake insurance premiums for new buildings

<table>
<thead>
<tr>
<th>City</th>
<th>Premium</th>
<th>Deductible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wellington</td>
<td>0.3% – 0.4%</td>
<td>5%</td>
</tr>
<tr>
<td>Christchurch</td>
<td>0.35% and greater</td>
<td>10%</td>
</tr>
<tr>
<td>Whanganui</td>
<td>0.15%</td>
<td>5%</td>
</tr>
</tbody>
</table>

On the basis of the premium rates for new buildings in Wellington and Christchurch, and the finding that the initial capital cost of base-isolating a building is in the order of 3% of the total cost of construction, the payback period is less than ten years, but greater than the three years that has been reported elsewhere (Leung-wai 2004). If a building contains expensive contents, the payback period could be considerably less. Unfortunately, we were unable to determine the value of contents for the four buildings studied, but it is likely they are between 20% and 40% of the construction costs.

Among other recent changes in the provision of earthquake insurance, the former twelve month period for coverage for building interruption costs is tending to increase to two years. There is also a closer scrutiny of soil conditions and building standards, with geotechnical and structural reports becoming more common. Prior to September 2010, premiums were mainly based upon regional location, but now soil and foundation type, age of construction, type of construction and percentage of New Building Standard are becoming the norm.

5.2 Base-isolation and earthquake insurance

The current view is that the insurance industry in general is not sophisticated enough to consider a significant premium reduction for a base-isolated building compared to one with a fixed-base. Certainly, as noted above, insurers will be far more interested in insuring a base-isolated building than one that is more conventional, but any discount is expected to be small – in the range of 5% - 20%, but there could be some room for negotiation regarding the deductible. This discount is far less than the
30% enjoyed by Japanese apartment owners (Ward 2011). For some institutional building owners, like universities and District Health Boards, the grouping together of a mix of buildings before determining insurance conditions may prevent any significant benefit by way of reduced premiums arising from their single or several base-isolated buildings.

Ironically, it is possible that without careful negotiation with an insurance company, base-isolation could prove a liability. First, insurance policies will not respond to an undamaged building in an access-denied area. The second reason behind this anomaly is that without any building damage, no claim can be made for business interruption costs arising from external sources over the deductible.

Given that base-isolated buildings have survived and are designed to survive moderate to strong shaking without significant structural or non-structural damage, it is unlikely damage costs would approach a deductible of say 5% of the site value (cost of reconstruction and value of contents). Further, as noted above, there is a likelihood of base-isolation actually preventing recovery of business interruption costs. These factors suggest that self-insurance is a potential way forward. It certainly should be considered by organisations and institutions large enough not to require a mortgage, for before a mortgage is approved lenders usually require full insurance cover. It is difficult to see a way around this dilemma, except there is at least one U.S. precedent of a lender agreeing to waive earthquake insurance on the basis of enhanced seismic performance (Comartin 2003).

6 CONCLUSIONS

Although a number of the design and construction team members of the four case-study base-isolated buildings were unavailable to be interviewed and to provide cost and other information, the study was able to identify a number of factors that can result in lower construction costs of base-isolated buildings. It can also confirm that, neglecting any cost savings from lighter superstructure and foundation components due to base-isolation, the additional construction costs of base-isolation compared to equivalent conventional construction was less than or equal to 3% of the construction cost in three of the four buildings studied.

Regarding earthquake insurance, it is clear that base-isolation will overcome any potential insurance availability issues in future projects, however significant premium discounts or deductible reductions are unlikely in the near future. Self-insurance is certainly an option for some building owners but special attention would need to be paid to insurance policies’ fine print.

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REFERENCES:

