# E410

## AS/NZS1170 loading standard cost benefit analysis


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# Contents

# AS/NZS1170 loading standard cost benefit analysis

## 1. CLIENT

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## 2. SUMMARY

This study analyses the costs and benefits of the proposed new building design loading code AS/NZS1170. The standard is intended to supersede an existing standard, NZS 4203, and this report identifies the initial cost impacts of the changes between the two standards. There are expected to be on going cost savings and benefits, which have been identified, and estimated where possible.

The cost changes, which include earthquake, wind and other loading changes, are summarised in Table 1. The cost of the proposed change is expected to add about $35 million to the cost of all new buildings constructed each year. This is a cost increase of about 0.4% of the value of new buildings in a year. An upper estimate was also calculated ($82 million) using more conservative assumptions. Savings from reduced damage and maintenance, less business disruption after a disaster event, and injuries and lives saved through stronger building design are estimated at $115 million for each year of additions to the building stock, assuming a Wellington earthquake.

The net present value (costs less benefits, discounted to present values) depends on when the design loading events occur. The table indicates that if a Wellington design earthquake occurs within the next 45 years there are net benefits. If other design loading events occur in addition to the Wellington earthquake the net savings will be higher than shown.

**Table 1 Summary of costs and benefits**

| **National costs, and Wellington design event savings** | | |
|---|---|---|
| **Building Costs** | $Million/ year of new bldgs | High estimate |
| Initial cost increase = | 35.0 | 82.4 $M |
| Average % building cost increase (1) = | 0.4% | 0.9% |
| **Benefits** | | |
| Maintenance reduction | 0.1 | |
| Damage reduction (Wellington event) | 34.0 | |
| Business disruption savings (Wellington event) | 67.9 | |
| Injuries/fatalities reductions (Wellington event) | 13.4 | |
| | 115.4 | |
| Time ahead to the Wellington event | **Net present value** (2) | |
| 5 years | 302 | $Million, |
| 20 years | 450 | positive values |
| 40 years | 88 | are net savings. |
| 50 years | -99 | |
| 60 years | -253 | |
| 80 years | -464 | |
| 100 years | -578 | |
| (1) Assume $8.7 billion of new buildings per year. | | |
| (2) Discount rate is 5% | | |

# 3. APPROACH

Earlier work (Jury 2005) analysed the changes between the two standards, clause by clause, identified the nature of the change, and assessed whether the impact is low, medium or high. That work provided a template for selected structural designers to redesign a sample of buildings to the new standard that they had originally designed to the old standard. There were a number of design changes for most buildings, which were costed, and expressed as a percentage of the total construction cost. Typically the cost changes were between +1% and -1% of the original initial cost and a summary of the buildings redesigned, the cost changes, and further data is in the Appendix.

The most significant changes in the new standard are to earthquake and wind loads which determine the lateral strength of the building. There are also some minor changes to the vertical loads in combination with lateral loads, but generally it is the latter that determines the overall building design. Typically earthquake loadings have declined for the upper North Island, increased for the lower North Island, remained approximately the same for northern and eastern South Island, and increased in other parts of the South Island. These changes are due to re-zoning of a number of regions into different seismicity zones. Wind loads have increased in Bay of Plenty/Waikato and Wellington for some building types and terrain categories, and in the other regions the changes depend on the building type. In addition, essential disaster recovery buildings have load increases due to the "risk" factor (NZS4203) or "importance level" factor (AS/NZS1170) being increased significantly.

Which load case governs depends on an individual building's characteristics. Generally, timber framed buildings are governed by wind load, while taller and heavier buildings are governed by earthquake loads. There are also changes to loads on building components, which affect costs. For example, the fixing of panels under earthquake load now needs to be stronger, roof imposed live and snow loads are larger in some cases, and the higher wind loads in some locations may require strengthened window design.

Given the variety of influences it is difficult to generalise on cost impacts even for particular types of building. To assist in the calculation of the national cost the results from the building re-designs were used. The re-designed buildings were selected in 6 main categories, chosen to represent categories thought to adequately cover the different types of changes proposed in the new standard. These buildings (and their % of total annual new building value), are:

- Low rise residential (40%)
- Medium/ high rise residential (7%)
- Low rise light industrial/retail/farm construction (20%)
- Public and/ or "essential" buildings (14%)
- Low-rise commercial (5%)
- Medium/ high rise commercial. (4%)

Residential is the largest sector and a typical new house was redesigned for Auckland, Tauranga, Wellington and Christchurch (Beattie 2006). A nine storey apartment in Wellington was also analysed. The next largest sector, low rise industrial/ retail had three sample buildings, in Auckland and Wellington (2 buildings). Public buildings include education, social, cultural and essential buildings such as hospitals. Two school designs in each of Auckland, Wellington and Christchurch were analysed. A hospital building in Auckland was also redesigned. Last, two office buildings (Christchurch, 4 storeys) and Auckland (30 storeys) were redesigned. The results, including changes to initial costs are in the Appendix.

Wind and earthquake loads vary with region and 5 load zones were used consisting of the following regional councils (% share of NZ total):

Auckland – Northland , Auckland. (45%)
Waikato/BOP - Waikato, Bay of Plenty, Thames- Coromandel, Taranaki (18%)
Wellington – rest of North Island. (16%)
Canterbury – All South island except Southland region and Lakes District. (18%)
Southland/ Lakes. (3%)

# 4. DESIGN CHANGE IMPLICATIONS

## 4.1 Earthquake design

Figures 1 to 3 show the seismic (ultimate limit state) design changes between the two standards for different Importance Levels of buildings. The changes are shown as a ratio and represent the proportional change in loading. The period on the horizontal axis is the natural period of lateral vibration of the building. Housing tends to be around 0.5 seconds, and the taller the building the longer the period. The 30 storey office building in the study has a period of about 3 seconds.

The Importance Level (IL) is a measure of the crowd loading (number of persons per building) and of how important the building is to disaster response services and for the subsequent recovery. Housing, industrial buildings and some commercial buildings are typically IL2, education, most commercial and social/cultural buildings are typically IL=3, and hospitals, and emergency services (police, fire, and other designated response buildings) are typically IL=4.

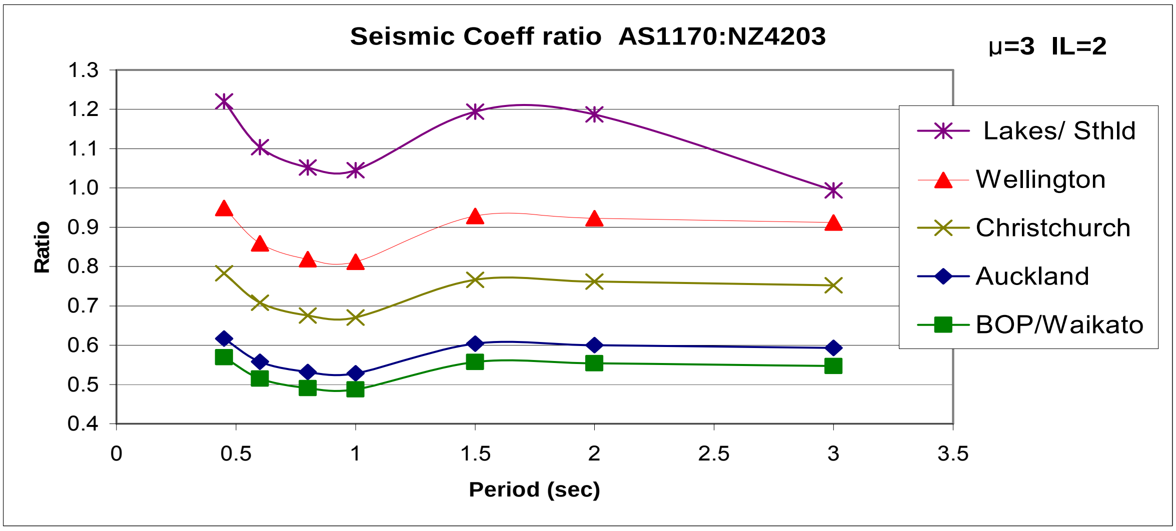
The charts are drawn for two levels of ductility (μ), which is typically about 3 for timber framed buildings. Steel and concrete buildings have a range of ductilities ranging from 1 up to 6 or higher, but tend to be below 3 in the sample buildings.

To calculate the ratios the following cities/towns were used to represent the regions:
Lakes/Southland/West Coast region – Queenstown.
Wellington/ Taranaki/ Hawkes Bay region – Wellington City (exclude near fault factor).
Canterbury/ Nelson region – Christchurch City.
Auckland/ Northland region – Auckland City.
BOP/ Waikato region – Tauranga City.

Figure 1 indicates:
Housing and other timber framed structures (IL=2, μ=3, period approximately 0.5sec) have load increases in Southland/ Lakes, no change in Wellington, and reductions elsewhere.
Non-ductile (μ=1.25) industrial/ retail and small commercial buildings have 40% load increases in Southland/Lakes, a 20% increase in Wellington, and no change or reductions elsewhere.

Figure 2 indicates:
Ductile larger commercial buildings have load increases of about 20% in Southland/Lakes, and load decreases elsewhere.
For low ductility large commercial structures (μ=1.25) in Wellington the loading increases by about 20%, and 50% in Southland/Lakes.

**Figure 1 Seismic load changes. IL=2, Soil C /Intermediate.**



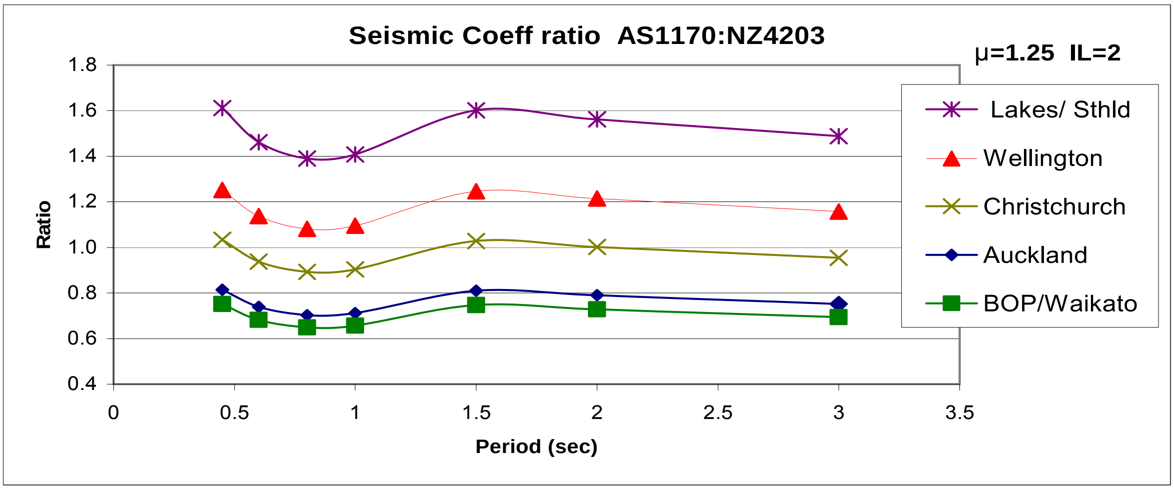
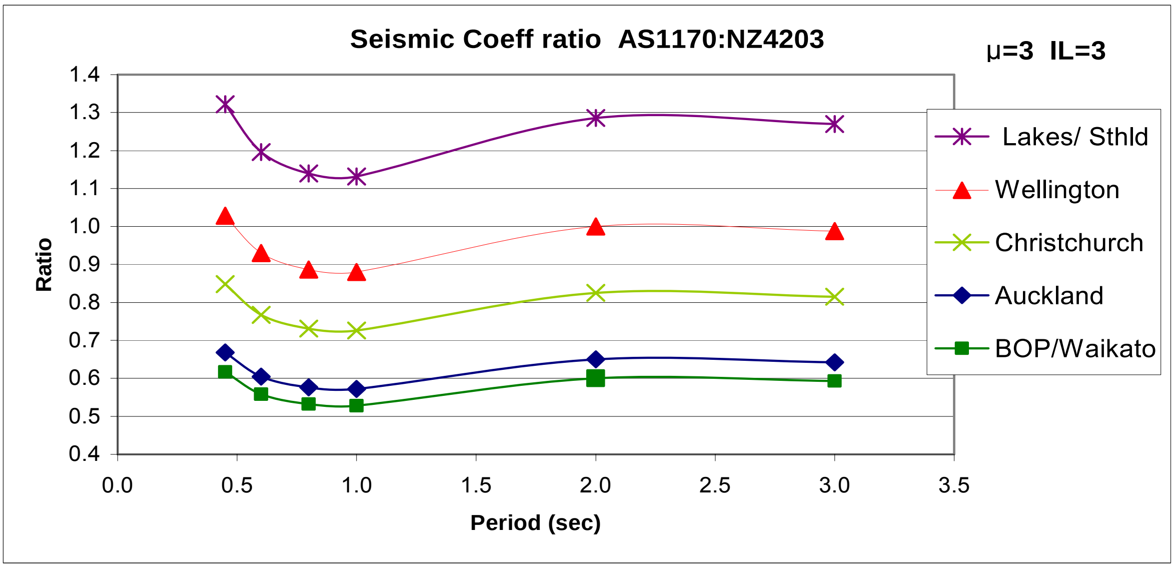
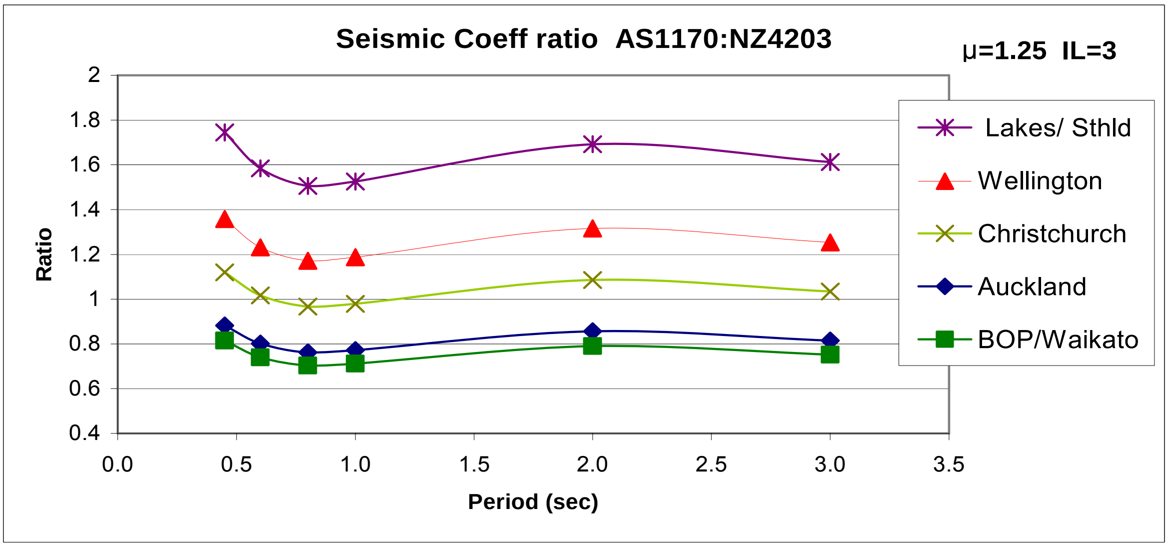



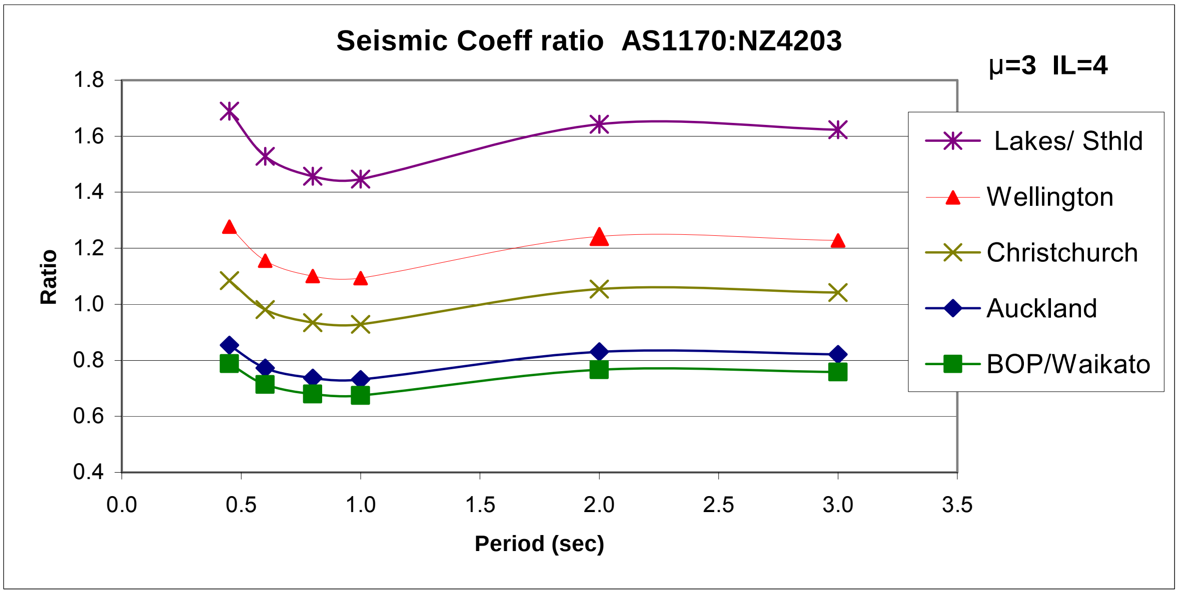
**Figure 2 Seismic load changes. IL=3, Soil C /Intermediate**

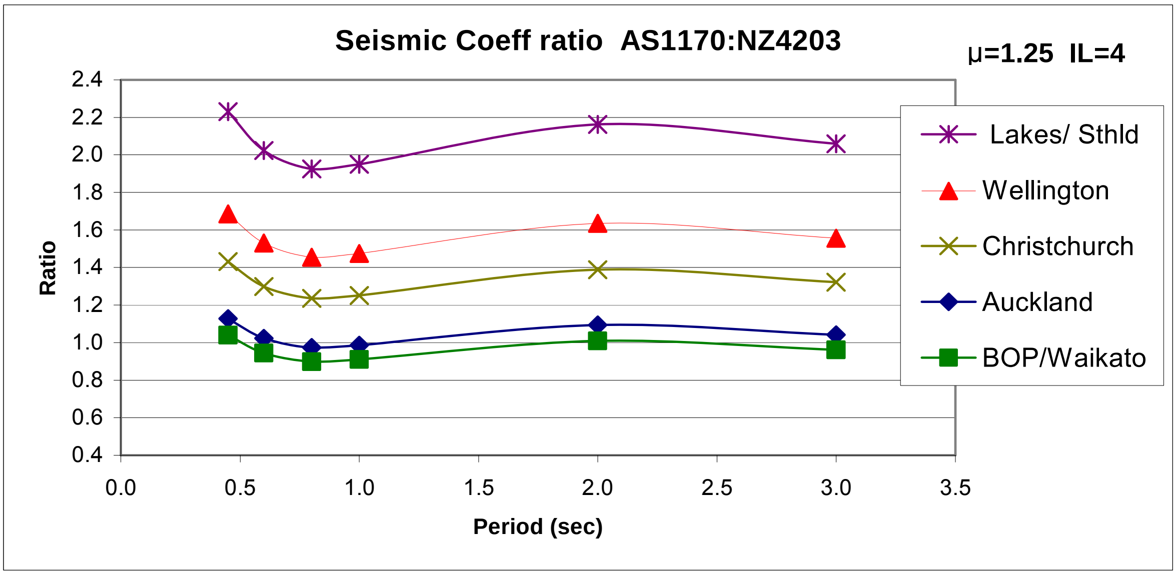



The IL=4 category covers hospitals, police and fire stations, and community civil defence buildings (some education and social/cultural buildings). Figure 3 indicates outside the upper North Island they have load increases of between 0% and 60% depending on ductility, and in Southland /Lakes the increase is over 60%.

**Figure 3 Seismic load changes IL=4, Soil C/Intermediate**

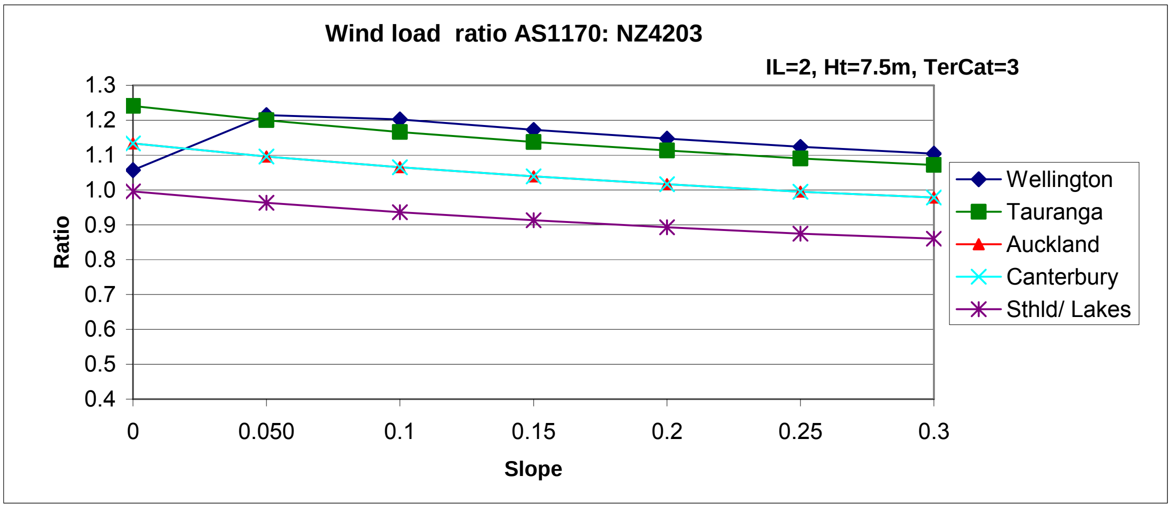



## 4.2 Wind Design

The changes in wind loading are shown in Figures 4 to 6. The charts indicate increases in BOP/Waikato and Wellington of between 10% and 30%, depending on the building type, for low rise buildings. Auckland and Canterbury/ Otago have changes of between 10% and -15% depending on the building type, while Southland/ lakes has zero change or decreases in wind loading, depending on the building type.

**Figure 4 Wind load changes.  Crest zone, IL=2.**



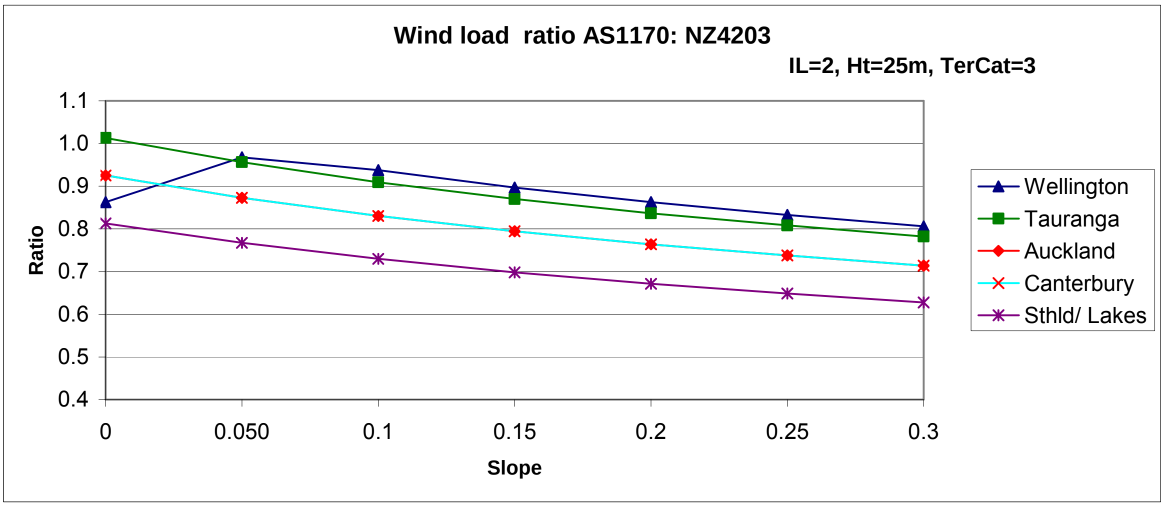
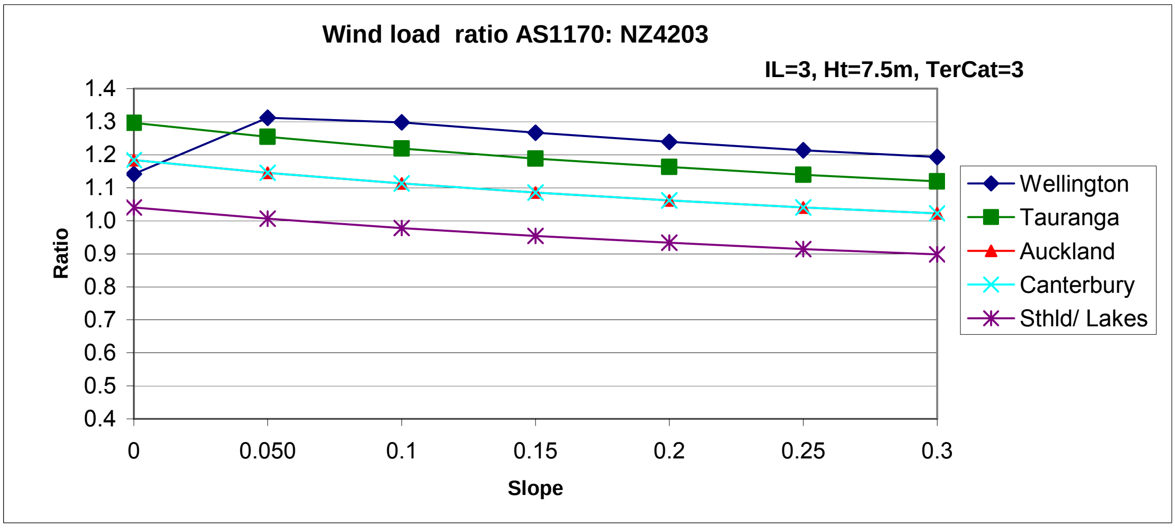



**Figure 5 Wind load changes.  Crest zone, IL=3.**



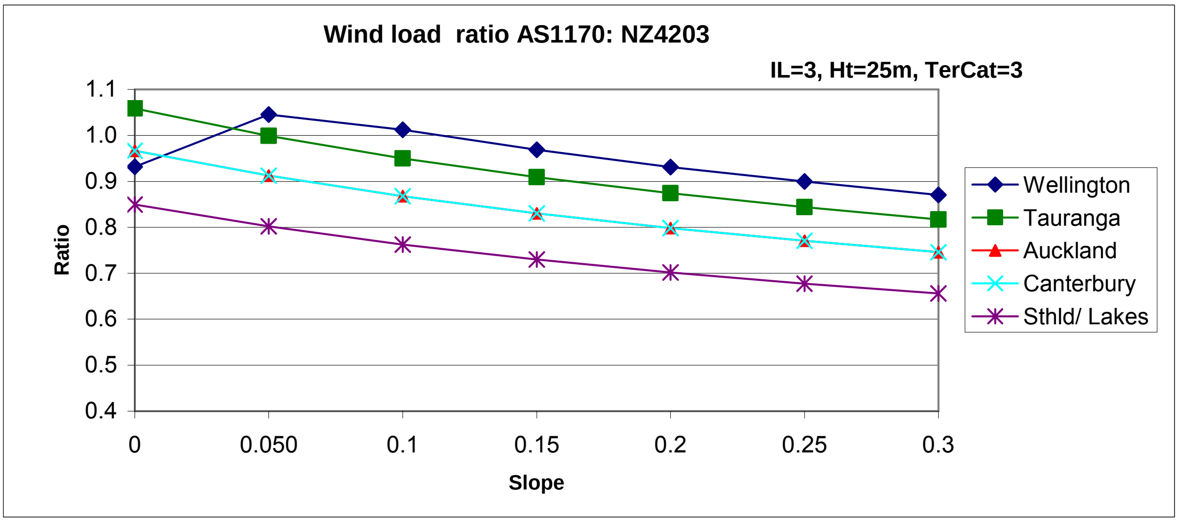
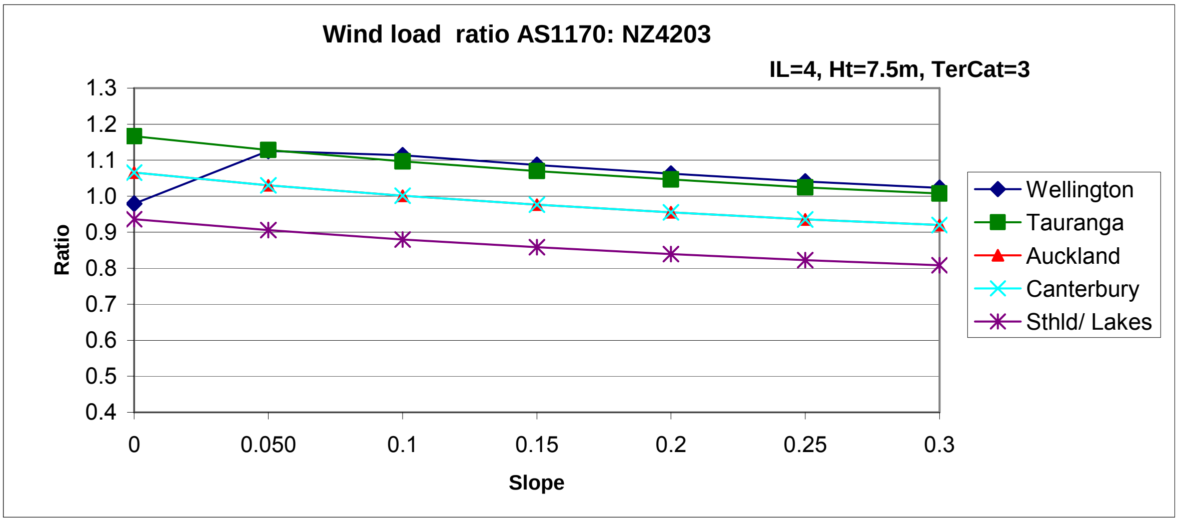
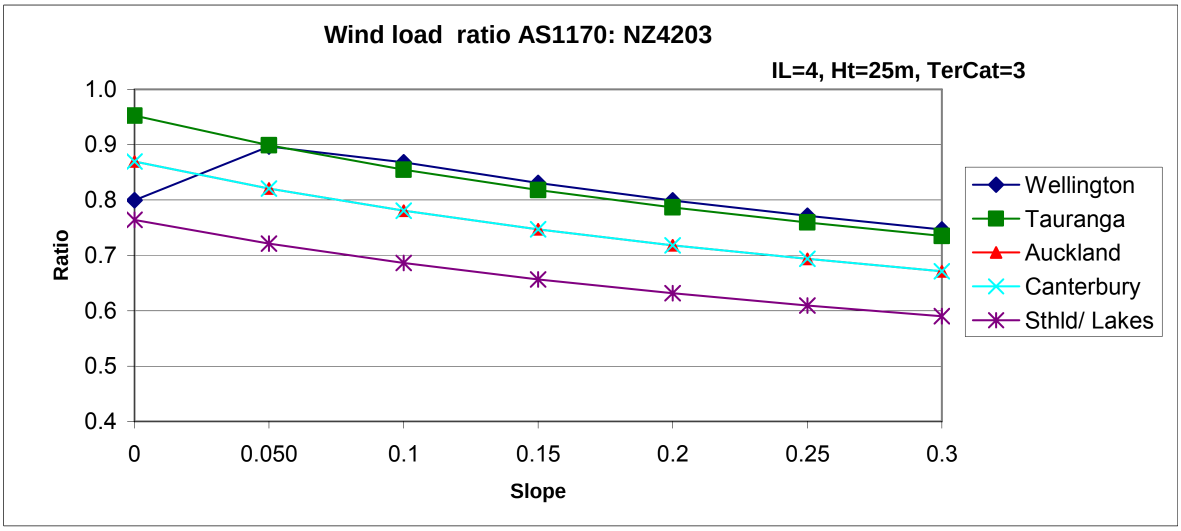



**Figure 6 Wind load changes. Crest zone, IL=4.**




# 5. CHANGES IN BUILDING COSTS

## 5.1 Earthquake and wind loading provisions

Additional charts similar to those in Figures 1 to 6 were produced for other combinations of structural ductility, importance level, soil type, building height, and type of terrain. The charts were calculated for the ultimate limit state (ULS). Exclusive use of these charts to determine loading changes is not totally correct since in some re-designed buildings the serviceability limit state condition governed. However ULS governed in the majority of the sample buildings.

The charts, building type and location were taken into consideration in assessing the loading change and the governing load case percentages (earthquake or wind) are shown in Tables 2 and 3. In addition, the results of the sample building cost studies were used to guide the choice of percentage cost changes. These assessments are in Table 2 and the model of the cost changes by region and building type in Table 3.

## Table 2 Percentage cost changes by building type and location

**Loading coefficients, cost changes, and design reports.**

| Building type | Location | **Percent change in loading coefficient** Governing load case EQ | Wind | **Percentage change in costs** Governing load case EQ | Wind | Upper estimate Governing load case EQ | Wind | **Comment** (See Appendix Table 7 for Reports summary) |
|---|---|---|---|---|---|---|---|---|
| Housing =<3 storeys | Auckld | -40 | 10 | -0.2 | 0.5 | 0.3 | 1.0 | Reports 5 to 8 |
| | BOP/Waikato | -40 | 20 | -0.2 | 0.5 | 0.3 | 1.0 | (Exemplar house 4 centres) |
| | Wellington | 0 | 20 | 0.1 | 0.5 | 0.6 | 1.0 | |
| | Cant/Otago/Nelson | -20 | 10 | 0.0 | 0.5 | 0.5 | 1.0 | |
| | Sthld/Lakes | 20 | 0 | 0.5 | 0.1 | 1.0 | 0.6 | |
| Housing > 3 storeys | Auckld | -30 | -15 | -0.2 | 0.0 | 0.3 | 0.5 | Report 10 |
| | BOP/Waikato | -30 | 0 | -0.2 | 0.1 | 0.3 | 0.6 | (Apartment 9 storey, Wellington) |
| | Wellington | 20 | 0 | 0.5 | 0.1 | 1.0 | 0.6 | |
| | Cant/Otago/Nelson | 0 | -15 | 0.1 | 0.0 | 0.6 | 0.5 | |
| | Sthld/Lakes | 40 | -15 | 1.5 | 0.0 | 2.0 | 0.5 | |
| Industrial/ retail | Auckld | -30 | 10 | -0.2 | 0.5 | 0.3 | 1.0 | Reports 3,9,11 |
| | BOP/Waikato | -30 | 20 | -0.2 | 0.5 | 0.3 | 1.0 | (Retail Botany Downs |
| | Wellington | 20 | 20 | 0.5 | 0.5 | 1.0 | 1.0 | Retail LHutt, |
| | Cant/Otago/Nelson | 0 | 10 | 0.1 | 0.5 | 0.6 | 1.0 | Retail Rongotai) |
| | Sthld/Lakes | 40 | 0 | 1.5 | 0.1 | 2.0 | 0.6 | |
| Public bldgs | Auckld | 0 | 0 | 0.1 | 0.1 | 0.6 | 0.6 | Reports 1, 12-17 |
| | BOP/Waikato | 0 | 10 | 0.1 | 0.5 | 0.6 | 1.0 | (Hospital Auckland, 2 Schools 3 centres) |
| | Wellington | 40 | 10 | 1.5 | 0.5 | 2.0 | 1.0 | ( Public buildings group include prisons, |
| | Cant/Otago/Nelson | 20 | 0 | 0.5 | 0.1 | 1.0 | 0.6 | hospitals, education,&social cultural bldgs. |
| | Sthld/Lakes | 80 | -10 | 2.0 | 0.0 | 2.5 | 0.5 | Assume that all are IL=4.) |
| Commercial< =3 storeys | Auckld | -30 | 15 | -0.2 | 0.5 | 0.3 | 1.0 | Report 2, 4,10 |
| | BOP/Waikato | -30 | 30 | -0.2 | 1.0 | 0.3 | 1.5 | ( 4 storey office Chch, |
| | Wellington | 0 | 30 | 0.1 | 1.0 | 0.6 | 1.5 | , 30storey office Auckland) |
| | Cant/Otago | -20 | 15 | 0.0 | 0.5 | 0.5 | 1.0 | |
| | Sthld/Lakes | 20 | 0 | 0.5 | 0.1 | 1.0 | 0.6 | |
| Commercial> 3 storeys | Auckld | -20 | -10 | 0.0 | 0.0 | 0.5 | 0.5 | |
| | BOP/Waikato | -20 | 0 | 0.0 | 0.1 | 0.5 | 0.6 | |
| | Wellington | 20 | 0 | 0.5 | 0.1 | 1.0 | 0.6 | |
| | Cant/Otago/Nelson | 0 | -10 | 0.1 | 0.0 | 0.6 | 0.5 | |
| | Sthld/Lakes | 50 | -20 | 1.5 | 0.0 | 2.0 | 0.5 | |

Cost changes:

| % Chg in load coefficients | % cost change |
|---|---|
| 40+ | 1.5 |
| 39-30 | 1 |
| 29-10 | 0.5 |
| 9 to 0 | 0.1 |
| -20 to -1 | 0 |
| <-20 | -0.2 |

Industrial/ retail includes retail, warehouses, factories, farm and miscellaneous.
Public buildings include hostel, prisons, health, education and social/ cultural buildings.
Commercial includes hotels, motels, office and administration buildings.

## Table 3 Initial cost change model

### Cost Implication Analysis

| Location | Type | % of NZ total | $M by Type | Governing case % EQ | Governing case % Wind | Governing case % Tot | % change in costs EQ | % change in costs Wind | Cost change $M EQ | Cost change $M Wind | Cost change $M Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Auckland** | **Residential** | | | | | | | | | | |
| | Housing <=3 storeys | 23.5 | 2046 | 10 | 90 | 100 | -0.2 | 0.5 | -0.4 | 9.2 | 8.8 |
| | Housing >3 storeys) | 3.9 | 341 | 50 | 50 | 100 | -0.2 | 0 | -0.3 | 0.0 | -0.3 |
| (incl Northland) | | | 2387 | | | | | | | | |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 7.8 | 680 | 50 | 50 | 100 | -0.2 | 0.5 | -0.7 | 1.7 | 1.0 |
| | Public Bldgs | 5.8 | 509 | 60 | 40 | 100 | 0.1 | 0.1 | 0.3 | 0.2 | 0.5 |
| | Commercial (<4 storeys) | 2.5 | 222 | 30 | 70 | 100 | -0.2 | 0.5 | -0.1 | 0.8 | 0.6 |
| | Commercial (>3 storeys) | 1.7 | 148 | 50 | 50 | 100 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 1558 | | | | | | -0.5 | 2.7 | 2.2 |
| | All buildings | 45.3 | 3945 | | | | | | | | |
| **BOP-Waikato** | **Residential** | | | | | | | | | | |
| | Housing <=3 storeys | 9.1 | 793 | 20 | 80 | 100 | -0.2 | 0.5 | -0.3 | 3.17 | 2.9 |
| | Housing >3 storeys) | 1.5 | 132 | 50 | 50 | 100 | -0.2 | 0.1 | -0.1 | 0.1 | -0.1 |
| | | | 925 | | | | | | | | |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 4.1 | 361 | 40 | 60 | 100 | -0.2 | 0.5 | -0.3 | 1.1 | 0.8 |
| | Public Bldgs | 2.2 | 191 | 60 | 40 | 100 | 0.1 | 0.5 | 0.1 | 0.4 | 0.5 |
| | Commercial (<4 storeys) | 0.6 | 53 | 60 | 40 | 100 | -0.2 | 1 | -0.1 | 0.2 | 0.1 |
| | Commercial (>3 storeys) | 0.4 | 35 | 50 | 50 | 100 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| | | | 640 | | | | | | -0.2 | 1.7 | 1.5 |
| | All buildings | 18.0 | 1566 | | | | | | | | |
| **Wellington** | **Residential** | | | | | | | | | | |
| (incl rest of North Is) | Housing <=3 storeys | 6.7 | 585 | 60 | 40 | 100 | 0.1 | 0.5 | 0.4 | 1.2 | 1.52 |
| | Housing >3 storeys) | 1.1 | 97 | 85 | 15 | 100 | 0.5 | 0.1 | 0.4 | 0.0 | 0.4 |
| | | | 682 | | | | | | | | |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 3.1 | 272 | 60 | 40 | 100 | 0.5 | 0.5 | 0.8 | 0.5 | 1.4 |
| | Public Bldgs | 3.2 | 275 | 70 | 30 | 100 | 1.5 | 0.5 | 2.9 | 0.4 | 3.3 |
| | Commercial (<4 storeys) | 1.3 | 110 | 65 | 35 | 100 | 0.1 | 1 | 0.1 | 0.4 | 0.5 |
| | Commercial (>3 storeys) | 0.8 | 73 | 80 | 20 | 100 | 0.5 | 0.1 | 0.3 | 0.0 | 0.3 |
| | | | 731 | | | | | | 4.1 | 1.4 | 5.4 |
| | All buildings | 16.2 | 1413 | | | | | | | | |
| **Nel/Cant/Otago** | **Residential** | | | | | | | | | | |
| incl Marlborough | Housing <=3 storeys | 7.7 | 668 | 60 | 40 | 100 | 0 | 0.5 | 0.0 | 1.3 | 1.3 |
| & Tasman. | Housing >3 storeys) | 1.3 | 111 | 70 | 30 | 100 | 0.1 | 0 | 0.1 | 0.0 | 0.1 |
| | | | 779 | | | | | | | | |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 4.5 | 389 | 50 | 50 | 100 | 0.1 | 0.5 | 0.2 | 1.0 | 1.2 |
| | Public Bldgs | 2.6 | 229 | 60 | 40 | 100 | 0.5 | 0.1 | 0.7 | 0.1 | 0.8 |
| | Commercial (<4 storeys) | 0.9 | 76 | 70 | 30 | 100 | 0 | 0.5 | 0.0 | 0.1 | 0.1 |
| | Commercial (>3 storeys) | 0.6 | 51 | 70 | 30 | 100 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 745 | | | | | | 0.9 | 1.2 | 2.1 |
| | All buildings | 17.5 | 1524 | | | | | | | | |
| **Sthld/ Lakes** | **Residential** | | | | | | | | | | |
| (incl West Coast) | Housing <=3 storeys | 1.0 | 84 | 60 | 40 | 100 | 0.5 | 0.1 | 0.3 | 0.0 | 0.3 |
| | Housing >3 storeys) | 0.2 | 14 | 50 | 50 | 100 | 1.5 | 0 | 0.1 | 0.0 | 0.1 |
| | | | 97 | | | | | | | | |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 0.9 | 83 | 60 | 40 | 100 | 1.5 | 0.1 | 0.7 | 0.0 | 0.8 |
| | Public Bldgs | 0.6 | 51 | 60 | 40 | 100 | 2.0 | 0.0 | 0.6 | 0.0 | 0.6 |
| | Commercial (<4 storeys) | 0.2 | 16 | 60 | 40 | 100 | 0.5 | 0.1 | 0.0 | 0.0 | 0.1 |
| | Commercial (>3 storeys) | 0.1 | 11 | 60 | 40 | 100 | 1.5 | 0.0 | 0.1 | 0.0 | 0.1 |
| | | | 161 | | | | | | 1.5 | 0.0 | 1.5 |
| | All buildings | 3.0 | 258 | | | | | | | | |
| | | % market share | | | | | | | | | |
| **All Centres** | **Residential** | | | | | | | | | | |
| | Housing <=3 storeys | 48.0 | 4175 | | | | | | -0.1 | 14.9 | 14.8 |
| | Housing >3 storeys) | 8.0 | 696 | | | | | | 0.1 | 0.1 | 0.2 |
| | **Other buildings** | | | | | | | | | | |
| | Industrial/ Retail | 20.5 | 1784 | | | | | | 0.8 | 4.3 | 5.1 |
| | Public Bldgs | 14.4 | 1256 | | | | | | 4.6 | 1.1 | 5.7 |
| | Commercial (<4 storeys) | 5.5 | 477 | | | | | | -0.1 | 1.5 | 1.4 |
| | Commercial (>3 storeys) | 3.7 | 318 | | | | | | 0.4 | 0.0 | 0.5 |
| | | 100.0 | 3835 | | | | | | 5.7 | 21.9 | 27.7 |
| | **All buildings** | | 8706 | | | | | | Initial cost increase = | | 0.32% |

Table 3 indicates that for all buildings and locations the total initial building cost increase is approximately $28 million per year, or a 0.3% cost increase. This assumes an average of $8.7 billion of new buildings per year, as discussed further in the Appendix. Given the approximations involved in assessing the governing load cases, and in calculating the cost changes for particular building types, a more conservative estimate was also derived, using the second set of percentages in Table 2. When these are applied in Table 3 we get a total initial cost change of $71 million per year, or a 0.8% cost change.

## 5.2 Roof framing and other provisions

In addition to the frame loads the new standard has changes to purlin design and domestic windows. Initial work by BRANZ suggest that the imposed load on tributary areas less than 13 sqm governs the purlin design in many buildings, including purlins for concrete tile roofs and for purlins spanning between portals in industrial buildings (Beattie 2006). Table 4 calculates these costs at approximately $4.7M. Snow loading also increases and the cost effect is estimated at about $0.5 million per year. Increases in wind loads will affect window design. For domestic windows the load increase is at least 25%, and while manufacturers currently tend to design for the current high wind zone, some of these windows will now move into a very high wind zone, or into the specific design category. The cost effect is estimated at approximately $1.0 million per year, with an upper estimate of $2.0M per year. There are also other costs, including designer familiarisation of about $1.0 million. When these are added to the costs from Table 3 the total is $35 million per year (or $82 million for the high estimate).

**Table 4 Cost changes by building type**

**Estimated changes in building costs - All Categories**

| | EQ and Wind load cost changes/yr Governing load case | | Costs $ Million per year Purlins Live ld | Snow | Domestic windows | Other costs (one-off) | Total | % cost Increase |
|---|---|---|---|---|---|---|---|---|
| **Residential** | EQ | Wind | | | | | | |
| Housing <=3 storeys | -0.1 | 14.9 | 2.1 | 0.2 | 1.0 | | | |
| Housing >3 storeys) | 0.1 | 0.1 | 0.2 | 0.0 | | | | |
| **Other buildings** | | | | | | | | |
| Industrial/ Retail | 0.8 | 4.3 | 1.8 | 0.1 | | | | |
| Public Bldgs | 4.6 | 1.1 | 0.4 | 0.1 | | | | |
| Commercial (<4 storeys) | -0.1 | 1.5 | 0.1 | 0.0 | | | | |
| Commercial (>3 storeys) | 0.4 | 0.0 | 0.1 | 0.0 | | | | |
| | 5.7 | 21.9 | 4.7 | 0.5 | 1.0 | 1.1 | 35.0 | 0.4 |
| High estimate | 24.1 | 47.1 | 7.1 | 0.9 | 2.1 | 1.1 | 82.4 | 0.9 |

Purlin imposed loading increases for tributary areas below 13 sqm.
In housing heavy roofs have typical purlin increase from 50 x 50 mm to 100 x50mm @ 400 ctrs, 900 mm span.
Cost increase is $1.05/m =$3/sqm allowing for slope = 0.25 % cost incr. Applies to 20% of new houses (i.e. concrete tile roof).
Industrial purlins NZS4203, 200 x 50 @ 800 ctrs, 6m span. For AS1170 need 250 x50 purlin. i.e. $3/m extra or $4/ sqm.
Industrial bldg cost is $800/sqm giving 0.5% cost increase on an estimated 20% of industrial bldgs. (High est 40% of bldgs).
For Public and Commercial bldgs assume 0.3% cost increase on 10% of buildings. (High est, 20% of bldgs).

Purlin snow loading increases.
For South Island only, assume 0.2% cost increase on 10% of bldgs. (High est 20% of bldgs)

Domestic windows. Allow for increased wind loads. Non-residential window cost changes are included in column 2.
Assume that 10% of windows need strengthening (High est, 20% of windows), i.e wind zone change or specific design) & the cost increase is 5%.
Windows are 5% content of house. Hence cost increase = 1.044 $ million

Other. Includes designer familiarisation of the new standard, and costs to prepare flow-on changes to NZS3604, E2 approved solution and NZS4211 (one-offs).
Familiarisation 11,000 designers in B&C . Assume 10% involved in structural design @ 5 hrs each @ $120/hr = 0.66 $M
Revise NZS3604, E2, and NZS4211 assume $0.4M.

Maintenance costs. Reduction in costs due to reduced roof indentation, and reduced ceiling textured linings cracking.
Indentation - mainly industrial bldgs = 1.78 million sqm
90% roofs are metal & assume 5% of roof areas needs repair in their lifetime= 0.080 M sqm $M
Assume roof repair/ replacement @ $60/sqm Value = 4.82 $M/ yr of new bldgs. As an annual cost= 0.120
Textured ceiling cracking - Public/Commercial bldgs only = 2051 $M = 1.465 M sqm
Say 5% ceilings are textured and50% are affected by cracking in their life = 36.6 (000) sqm
Repair cost say $30/sqm = 1.10 $M/ yr of new bldgs. As an annual cost= 0.027

# 6. BENEFITS OF CHANGES IN STRUCTURAL PERFORMANCE

## 6.1 General

The proposed changes to the structural loading standard will result in changes in structural performance. Where the new standard requires increased design coefficients, compared with the existing one, there will be comparative benefits in reduced damage, casualties and business interruption when a design event occurs. The converse applies where the new standard requires reductions in coefficients. These benefits and disbenefits have been estimated for each region and each building category for selected events and aggregated into regional and national totals, as indicated in the following sections.

Benefits were estimated assuming the occurrence of a single earthquake event matching the design level intensity. No attempt was made to quantify benefits or disbenefits for wind loading events. In estimating the effects for an earthquake event, a distinction has been made between those buildings for which earthquake provisions dictate the level of change with the new provisions, and those for which wind provisions dictate the level of change. However, it should be noted that when an earthquake occurs, benefits will result from buildings that have an increased coefficient, regardless of which provision dictated the increase.

## 6.2 Damage savings

The benefits of building strengthening is expressed in terms of reduced damage ratios, and is a common technique in earthquake studies. The damage ratio (DR) is the value of building repairs as a percentage of the total replacement cost of the building. The Appendix contains an analysis of how the DR is expected to change with changes in the seismic loading coefficient. The result of this analysis is that the DR reduces by approximately 0.15% per 1% increase in the lateral load coefficients shown in Figures 1 to 6. In contrast, when lateral loads decrease the DR increases by 0.08% per 1% decrease in the coefficient.

The details of the benefit calculations are in Table 5 for Wellington region only, and the other regions are in the Appendix.

The first panel of Table 5 estimates the damage cost saved for the design event, which is an earthquake. For example, with the design earthquake in Wellington, the increased loading provisions of AS/NZS1170 are estimated to avoid building damage repair costs of $20.7 million for each year's stock of new buildings, for buildings whose governing design load is the earthquake. Those buildings that are governed by wind design have savings in earthquake damage of $13.3 million. So the total savings for the design earthquake event in the Wellington region are $34 million, for each year's addition of new building stock.

Table 5 also shows expected benefits of avoided business disruption, and those of avoided injuries and fatalities. These are commonly expressed as a ratio of the physical damage to the building. Hopkins(2002) states that a ratio of two is a conservative assessment for business disruption, and this is discussed later.

The overall benefits of reduction in injury and fatality costs are estimated as shown in Table 5. The likelihood of collapse of a building is related to the damage ratio as per Spence et al (1998). The reference also has injury/ fatality percentages for various types of construction (i.e. timber frame, shear wall, steel frame, etc) and the building types in the table have been allocated to different fatality groups. Application of these ratios gives injuries saved at 0.3 persons, and fatalities at 5.3 persons per year of new buildings. With injuries valued at $0.25M and fatalities at $2.5M this represents a saving of about $13 million for a year of new buildings. The savings are summarised in the bottom panel in Table 5, and indicate that damage reduction and business disruption savings are the major contributor to the benefits.

**Table 5 Damage reduction, and other benefits – Wellington region.**

**Building damage, Business disruption and Injury/ fatality changes for the design earthquake event in Wellington.**

**Changes in seismic and wind loading coefficients**

| | Governing case: EARTHQUAKE | | Governing case: WIND | |
|---|---|---|---|---|
| **Residential** | Chg coeff | Governing | Chg coeff | Governing |
| Housing <=3 storeys | 0% | 60% | 20% | 40% |
| Housing >3 storeys) | 20% | 85% | 0% | 15% |
| **Other buildings** | | | | |
| Industrial/ Retail | 20% | 60% | 20% | 40% |
| Public Bldgs | 40% | 70% | 10% | 30% |
| Commercial (<4 storeys) | 0% | 65% | 30% | 35% |
| Commercial (>3 storeys) | 20% | 80% | 0% | 20% |

**Damage cost changes are (1):** (positive values are savings, -ve values are increased damage)

| | **EQ** | **Wind** | **Total** $M per year |
|---|---|---|---|
| **Residential** | $M | $M | of new bldgs |
| Housing <=3 storeys | 0.0 | 7.0 | 7.0 |
| Housing >3 storeys) | 2.5 | 0.0 | 2.5 |
| **Other buildings** | | | |
| Industrial/ Retail | 4.9 | 3.3 | 8.2 |
| Public Bldgs | 11.6 | 1.2 | 12.8 |
| Commercial (<4 storeys) | 0.0 | 1.7 | 1.7 |
| Commercial (>3 storeys) | 1.8 | 0.0 | 1.8 |
| | 20.7 | 13.3 | 34.0 |

**Business disruption and indirect cost savings, (see text).**

| % of bldg damage | | |
|---|---|---|
| 200 | For Wellington event = | 67.9 $M/ year of new bldgs. |

**Injuries /fatalities saved in the Wellington design event.**

| | New buildings (000 sqm/ year) | Persons per sqm | Number of persons at risk | Collapse likelihood at DR=20% (2) | Reduction in damage ratio (DR) (3) % | Collapse likelihood with AS1170 (2) | In event of collapse: Death rate (4) % | In event of collapse: Injury rate (4) % | Personal injuries and deaths saved: Fatalities (5) | Personal injuries and deaths saved: Injury (5) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | | | | | | | | | |
| Housing <=3 storeys | 292 | 0.014 | 4092 | 0.011 | 1.2 | 0.010 | 0.6 | 0.2 | 0.0 | 0.0 |
| Housing >3 storeys) | 39 | 0.02 | 780 | 0.011 | 2.6 | 0.008 | 20.0 | 1.0 | 0.5 | 0.0 |
| **Other buildings** | | | | | | | | | | |
| Industrial/ Retail | 182 | 0.005 | 908 | 0.011 | 3.0 | 0.007 | 16.0 | 0.6 | 0.5 | 0.0 |
| Public Bldgs | 110 | 0.05 | 5506 | 0.011 | 4.7 | 0.006 | 10.0 | 0.5 | 2.9 | 0.1 |
| Commercial (<4 storeys) | 44 | 0.05 | 2197 | 0.011 | 1.6 | 0.009 | 16.0 | 0.6 | 0.7 | 0.0 |
| Commercial (>3 storeys) | 24 | 0.05 | 1220 | 0.011 | 2.4 | 0.008 | 20.0 | 1.0 | 0.7 | 0.0 |
| | | | 14702 | | | | | | 5.3 | 0.3 |

| **Total savings for Wellington event** | $M for one year of new building | |
|---|---|---|
| Damage reduction | 34.0 | |
| Business disruption, flow-ons | 67.9 | |
| Injuries saved | 0.1 | assume $0.25M per injury |
| Fatalities saved | 13.3 | assume $2.5M per fatality. |
| | 115.3 | $M for one year of new buildings. |

(1) Assume 0.15% decrease (0.08% increase) in damage ratio for every 1% increase (1% decrease) in seismic & wind loading coef, (see text).
(2) Collapse likelihoood is 0.87*DR^2.7, from Spencer et al , see text.
(3)The % change in the damage ratio is the % change in loading coefficient x 0.15 (or 0.08) x probability of load condition, see text.
(4) Death and injury rates from Spence et al, see text.
(5) Fatalities/injuries saved (lost) by load increase (decrease)= 0.9 x persons at risk x chg in collapse likelihood x death/injury rate.
0.9 factor allows for the proportion of the population indoors at the time of the design event.

Table 5 is duplicated for all regions in the Appendix.

## 6.3 Roof and ceiling access damage savings

A new measure in AS/NZS1170 is the requirement of a larger roof access design load to reduce the incidence of damage to roof cladding from movement of maintenance persons. This reduction in damage is estimated to be valued at about $0.12 million per year, per one year's addition of industrial buildings. Another change is reduced deflection limits for textured ceilings to reduce the amount of cracking now occurring in these linings. This change is expected to save about $0.03 million per year for each year's addition of public and commercial buildings, see Table 4.

## 6.4 Timing of design events

The net benefit from the proposed change is greatly affected by the timing of damaging events. The new provisions are designed to reduce the risk due to extreme wind and earthquake events, and better balance the probabilities of acceptable performance around the country. Because the location, timing, and intensity of such events is unknown, it was decided to calculate the net present value (NPV) assuming the occurrence of a single earthquake event equal to the design level for the location, and to vary the time at which the event occurs. For the national case, a Wellington earthquake event was used to calculate benefits, using a range of years to when the Wellington design event occurs, as shown in Table 6.

It is important to note that for this table building costs shown are for new buildings in all regions, for all years up to the period indicated, while the benefits are calculated assuming the occurrence of a design earthquake in Wellington only. The table indicates net savings if the event occurs within the next 45 years, with benefit-cost ratios ranging from 3.0 to 0.2, depending on the timing. Note that in calculating the net present value, a discount rate of 5% was used.

Events in other regions have different present values and benefit-cost ratios and Figure 7 provides a summary of these regions.

To provide a comparison of benefits and costs, both are plotted as positive quantities. National costs are those for changes to all new buildings (less national maintenance savings). Benefits by region comprise reduced damage, business disruption and fatalities saved due to the design changes required by the proposed new provisions. Initially the benefits rise as upgraded new buildings are added to the stock, but as the design event is delayed the benefits become heavily discounted. The chart shows that the Wellington region has net benefits up to 45 years (i.e. a single design earthquake event in Wellington within 45 years would result in benefits that exceed the national costs). Similarly, a single design event in the BOP/Waikato region would show benefits which cover the national costs if it occurred in the first 15 years. No other regional event, on its own, has benefits that cover the national costs.

The plots in Figure 7 make it possible to assess the additional benefits of the occurrence of more than one event within the time period, and to compare these with the national costs. For example, two design events, in BOP/Waikato and Wellington within 55 years would cover the national costs.

The above analysis is for national costs but the results are different if each region is considered in isolation, as shown in Figure 8. Here the local building costs has been subtracted from the local benefits. For example, in the Canterbury/ Otago/ Nelson region the additional building costs less maintenance savings in the region are covered if the earthquake occurs within 40 years (i.e. the NPV is positive within 45 years).

It should be noted that the choice of discount factor has a significant effect on the time at which costs exceed benefits. This is discussed in below and shown in Figure 9.

**Figure 7 National costs versus benefits from a single design event in the region**

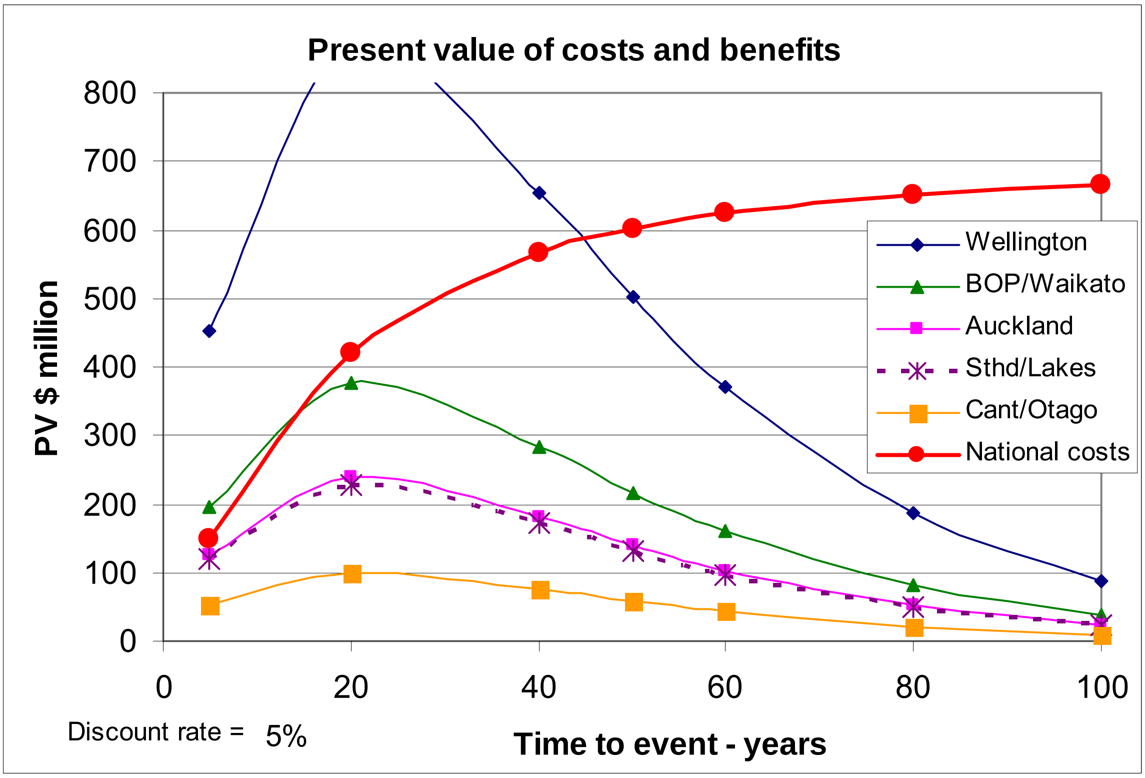
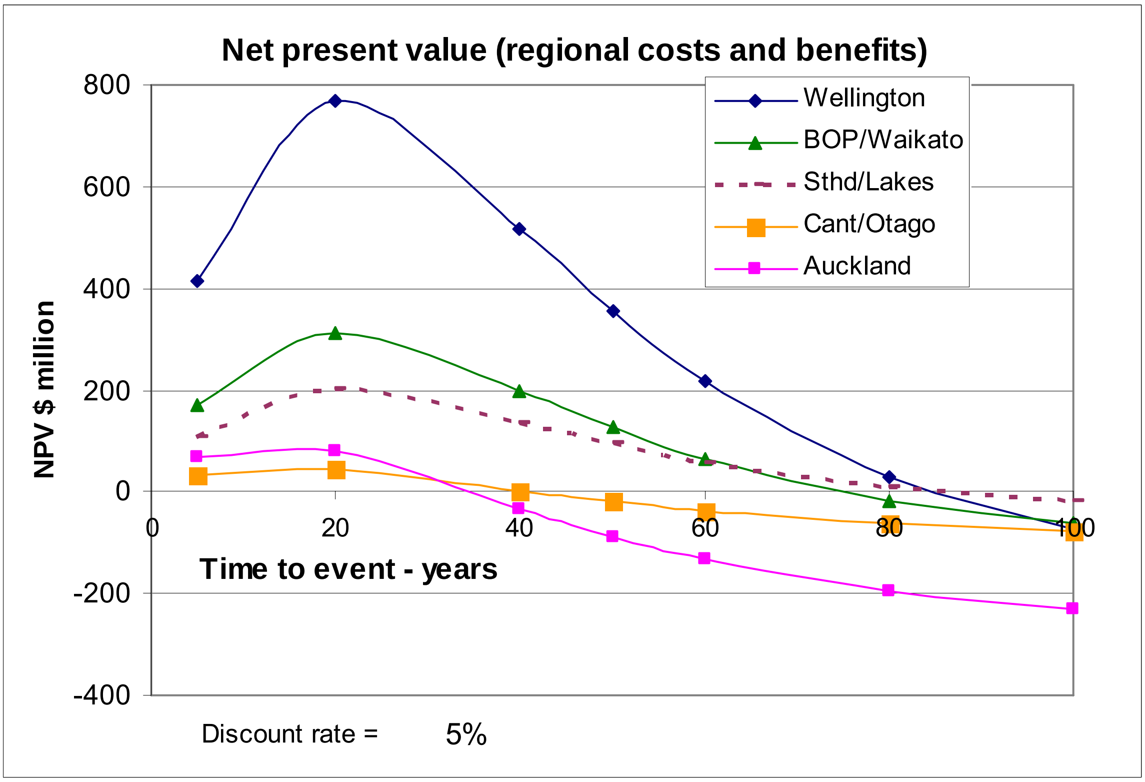



**Figure 8 Regional costs and benefits**




In the Auckland region the event needs to occur within 35 years to cover regional costs, while in Wellington and Southland/ Lakes the events needs to occur within 85 years to cover local costs.

**Table 6 NPV and benefit cost ratios for Wellington event.**

**Present value calculations for Wellington design event.**

**National costs and Wellington event benefits**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 35.0 | 4.329 | 151 | 15 | 1.9 | 115.3 | 0.784 | 454 | 302 | 3.00 |
| 20 | 35.0 | 12.462 | 436 | 210 | 16.2 | 115.3 | 0.377 | 885 | 450 | 2.03 |
| 40 | 35.0 | 17.159 | 600 | 820 | 32.8 | 115.3 | 0.142 | 688 | 88 | 1.15 |
| 50 | 35.0 | 18.256 | 638 | 1275 | 36.8 | 115.3 | 0.087 | 539 | -99 | 0.85 |
| 60 | 35.0 | 18.929 | 662 | 1830 | 38.1 | 115.3 | 0.054 | 408 | -253 | 0.62 |
| 80 | 35.0 | 19.596 | 685 | 3240 | 35.1 | 115.3 | 0.020 | 221 | -464 | 0.32 |
| 100 | 35.0 | 19.848 | 694 | 5050 | 28.4 | 115.3 | 0.008 | 116 | -578 | 0.17 |

(1) From Table 4, for all NZ.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings, in Wellington only, constructed in the period given $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual saving 0.15
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Savings at the time of the design event in Wellington only. From Table 5.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

Table 6 shows the NPV for the Wellington design event and includes New Zealand wide costs less maintenance savings, and the local damage, business and fatality savings. The same tables for other regions are in the Appendix. The NPV and benefit cost ratio is more favourable when only the local costs are included, and these results for all regions are in the Appendix, and are summarised in Figure 8.

## 7. DISCUSSION

The additional initial cost for new buildings due to the proposed AS/NZS1170 adoption is estimated to add about 0.4% to building costs per year or $35 million per year.

Where seismic loading increases have occurred they are in Wellington and the South Island, particularly for low ductility buildings and public buildings. The analysis assumes all buildings in the public building category (education, health, social/ cultural, prisons, administration, fire, police) are essential for post-disaster recovery and hence have an Importance Level of 4 in AS/NZS1170. This is a conservative assumption as some of these buildings will not be classed as essential.

Some initial cost impacts occur in the apparently minor code changes, relating to roof member tributary areas, the increased earthquake loading on building parts such as panels particularly the connections, and in domestic window design. This report has attempted to estimate these cost changes, but further structural studies would possibly be useful to better quantify these impacts.

It has proved challenging to allocate the percentage cost changes to the building types and regions as shown in Table 2 because we have a limited re-design sample, and to extrapolate them to all new buildings constructed in a year is a big step. To allow for this uncertainty readers may wish to use the upper estimate shown in Tables 1 and 2.

The derivation of the benefits of the proposed changes have used estimates of business disruption costs. In particular, these avoided costs were assumed to be twice those of the building damage savings, based on Hopkins (2002), and this reference notes that factors as high as 15 times the physical damage have been quoted for business disruption, which includes the flow-on effects on national economic growth. In contrast, research on industrial fires in New Zealand (BERL 2002) found a quite low factor, about 50% of the direct physical damage. However these were for localised fires in industrial buildings, and widespread damage, such as would occur in an earthquake or storm event would have wider flow-on effects than individual fires. Cochrane (1995) derived a factor of 1.4 for a Wellington earthquake but considered a limited range of impacts. So we conclude that a factor of 2 is not unreasonable for assessing business disruption and economy wide flow-on losses avoided by the new standard.

The preceding analysis has allowed for damage avoidance, and other benefits, due to strengthened buildings as a result of higher design loads for some building type-location combinations. However for some buildings/ location/ governing load combinations the design loads are reduced from the existing NZS4203. We have assumed these buildings are now more susceptible to damage with AS/NZS1170 and have increased damage costs, business disruption and injuries costs, which need to be included in the cost-benefit analysis. The damage they suffer in the expected event when designed to AS/NZS1170 is acceptable in terms of the injury/fatalities rate but it will be slightly greater than would have occurred when designed to NZS4203. This increased damage repair cost has thus been included in the cost-benefit analysis. This provides a consistent approach in that we are counting the benefits of reduced damage in regions requiring a load increase, and also counting the costs of increased damage in regions where the load is decreased.

One of the regions where the AS/NZS1170 requirements are less is Auckland, and the Appendix (section 10.7) contains an analysis assuming the occurrence of an Auckland design event. This shows that if the event is an earthquake those buildings governed by earthquake load design actually have an increase in damage amounting to $22 million. However these costs are more than offset by buildings governed by wind design which have been strengthened to meet the governing wind load, which at the same time reduces damage in the earthquake event.

The damage ratio analyses need well defined DR – loading curves, matched to earthquake intensity. However there is not a large amount of data for NZ events upon which to construct the DR- MMI curves. Given the number of parameters and approximations involved it is suggested that the calculated values for changes in the value of damage, business disruption and injuries/fatalities be used with caution.

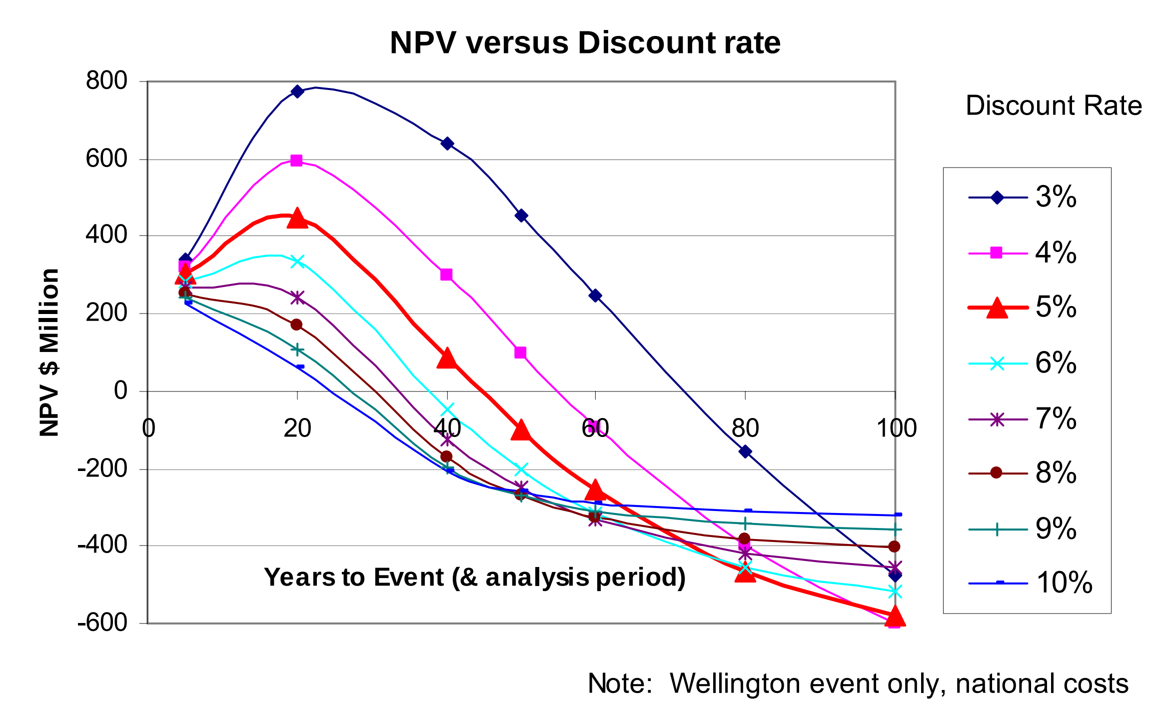
Table 6 calculates net present values for a Wellington design load event, which varies depending on when the event occurs. AS/NZS1170 has different loading event return periods, from 500 years to 2500 years depending on the building's Importance Level. The expected (or average) years to occurrence is half the return period, and this is obviously well outside the periods used in Table 6. Various authors have noted that NPV analysis based on average values is not appropriate in the design of engineering systems (Smith 2003). For example, roads, communications systems, and emergency services are not designed for average demand but use the extremes of the demand distribution. In earthquake engineering the 95 percentile is commonly used in a Monte Carlo simulation to find the NPV distribution, rather than a mean. A Monte Carlo analysis was not carried out for this project, but as an approximation we note there is a 5% chance for the design loading in a IL=2 building, (return period 500 years) to occur within 25 years, and Table 6 indicates a positive NPV at 45 years, well within the 5% percentile. Even a IL=3 building (return period 2000 years) has a 50 year horizon at the 5% level, close to the period for positive NPV for the Wellington event.

The proposed new standard applies to the whole country and hence the additional national costs need to be included for comparison with the benefits of a major design event(s).

It is also of interest to compare the costs and benefits within each region in isolation. This is done in Appendix (and Figure 8), where it is shown that all regions have a positive NPV, though the time within which the design event needs to occur varies between regions. The benefit cost ratios are quite high in some locations. For example, the ratio is over 3 in Wellington for a design event within 50 years, and in BOP/ Waikato within 40 years, see Tables 21 to 25.

A 5% discount rate was used in Table 6 and was chosen to represent a real rate of return (after inflation and taxes) that business could expect. The sensitivity of the NPV to the discount rate is shown in Figure 9, for the Wellington event. At 3% and 4% discount rates the NPV is positive for the design event below 55 years. For the 6% and 7% range the event needs to occur within about 35 years for a positive NPV, and for an 8% to 10% discount rate the event needs to occur within about 25 years for a net benefit, covering the national costs.

**Figure 9 NPV versus discount rate and analysis period.**




## 8. CONCLUSIONS

The initial cost of the proposed loading standard change adds approximately 0.4%, or $35 million to the cost of the typical mix of buildings constructed in any one year. This is a small increase to accommodate the technical advances and changes in societal expectations of building risk that have driven the new standard. These costs are offset by the benefits of improved safety and damage reduction, the volume of the benefits depending on assumptions, as discussed in the previous sections.

For a major earthquake event Wellington is generally considered the most likely location and if it occurs within 45 years the benefits completely cover the additional initial building costs nationwide. Considering only the regional costs and benefits the range for net benefits is 35 years in Auckland, up to 85 years in Wellington and Southland/ Lakes. Any additional design events within these periods increase the benefits of the changes, but do not alter the costs.

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# 10. APPENDIX

This appendix contains:

- Table 7 showing a summary of the design and cost studies carried out for 17 building/location combinations.
- Design changes template.
- Purlin design.
- Building activity forecasts.
- Calculation of change in damage ratios with changes in lateral loading coefficients.
- Relation of injury/fatality rates to damage ratios.
- Tables of regional damage/ business/fatality savings
- Tables of NPV.

## 10.1 Summary of re-designs for 17 buildings/ locations

### Table 7 Detail building cost studies

**Summary of Detailed Building Studies**

| | | | | | | | Changes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Building** | **Height** | **Location** | **Ru** | **Structural Type** | **U** | **Soil** | **EQ Seis Coeff** | **Wind** | **Gravity Load** | **SLS2** | **Main** | **Overall Cost Affect** | **Design Change Governs** | **Other issues signific but not in study** | **Consult't** | **Comments** |
| 1 | Hospital | 4storey | Auck | 1.8 (IC4) | 2 way rc moment frame | 1.25 | rock | high +35% frame +71% st roof | low 41m/s | low | only just < ULS | Reinf't +20%beam +10%col | +1.3% bldg +6.5% struct | | heavier parts more affect | Holmes | Calc error corrected |
| 2 | Office | 4 storey | ChCh | 1 | rc moment frame NS rc coupled shear walls EW | 6 bw | soft D | +3% -15% | low 38m/s 41m/s | low | NA | concrete savings | -0.3% bldg -1.1% struc | SLS now governs over ULS NS only | | Holmes | shorter period in EW could have resulted in '+20% increase 17% increase in snow loads but no impact on struct |
| 3 | Retail (Botany) | 1 storey | Auck | 1 (IL3) | rc cant cols rc cant walls | 3 1.25 | int C | -30% ULS +20% SLS cols +8% walls | | -3% | NA | concrete member savings | not yet available | No | | Buller George | T< 1.25 +360% carpark barriers |
| 4 | Office (Lumley) | 30 storey | Auck | 1 (IL3) | rc frame and shear walls | 1.25 | rock B | no change ULS -29% SLS | high +24% ULS &SLS | low = 0 | | | +2% struct +18% glass | no change seismic governs struct BUT sig change to curtain wall | | Buller George | T = 3.1 and 3.6s |
| 5 | Housing | 1.5 storey 200m2 | Auck | 1 | Wall bracing | 3 | int | -38% | -6% | low +LL roof | NA | -bracing | negligible | Change to wind on flat | | BRANZ | |
| 6 | Housing | 1.5 storey 200m2 | Tauranga | 1 | Wall bracing | 3 | int | -35% | +13% | low +LL roof | | -bracing | negligible | no change | | BRANZ | |
| 7 | Housing | | Wellington | 1 | | | int | -6% | +16% | low +LL roof | | +&'- bracing | negligible | change to wind on hill | | BRANZ | |
| 8 | Housing | | ChCh | 1 | | | int | -22% | -6% | low +LL roof | | - bracing | neg | no change | | BRANZ | |
| 9 | Retail (Mitre10 Mega) | single storey | Wellington | 1 | steel portal brac frames | 3 1.25 | Int C | -20% ULS | -20% ULS -10% SLS | +7% to mezzanine | NA | +rafter size -knee size | -0.2% | no change | | Spencer Holmes | |

## Table 7 (continued).

| | | | | | | | Changes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Building | Height | Location | Ru | Structural Type | U | Soil | | Wind | Gravity Load | SLS2 | Main | Overall Cost Affect | Design Change Governs | Other issues signific but not in study | Consult't | Comments |
| 10 | Apartment Building (Jessie St) | 9 storey | Wellington | 1 | rc frame<br>rc walls | 3<br>1.25 | Int<br>C | -11/9% ULS<br>+26/21% SLS<br>Parts +100% | +5% SLS | +5% | NA | -reinf frame<br>+reinf walls | +0.6% | | | Spencer Holmes | |
| 11 | Retail (Rongotai) | 1 storey | Wellington | 1 | steel portal | | int | nc | -4% | nc except canopies<br>0 | NA | btm p/c fixings | +$1500 | | | Beca | |
| 12 | School (Rangiora) | 1 Storey | Auck | 1.3 | NS steel portal<br>EW timber frame brace walls | 1<br>3 | flex D | +5% E<br>+7% LD | -22% | low | NA | nc | nc | no change to seismic governed | nc | Connell Wagner | |
| 13 | School (Rangiora) | | Wellington | 1.3 | | | | +62% E<br>+42% LD | +41% | low | NA | +bracing walls<br>+purlins<br>+portal frame | +0.42% | nc seismic governs | | Connell Wagner | |
| 14 | School (Rangiora) | | ChCh | 1.3 | | | | + 60%<br>+27% LD | -22% | low purlins governed by snow | NA | +bracing walls<br>+purlins<br>+portal frame | +0.26% | nc snow governs | | Connell Wagner | |
| 15 | School (Papanui) | 2 storey | Auck | 1.3 | Tilt up 200 walls<br>tilt up 150 walls | 3<br>1 | flex D | -3% E<br>-9% LD | -22% | low | NA | purlin -<br>nc reinf | -0.35% | nc | | Connell Wagner | |
| 16 | School (Papanui) | | Wellington | | | | flex D | +58% E<br>+40% LD | +41% | low | NA | +purlin<br>+reinf | +0.6% | nc | | Connell Wagner | |
| 17 | School (Papanui) | | ChCh | | | | flex D | +31% E<br>+15% LD | -22% | low | NA | nc reinf | nc | nc | | Connell Wagner | |

## 10.2 Design changes template

The Jury work identified approximately 135 clause changes of significance, of which about 81% were estimated to have a low cost impact, 12% a medium impact, 1 % a high impact, and 6% of the changes having obvious savings. The changes, clause by clause, were allocated into categories, which come under 5 broad groups:
*Clarification/ rationalisation/ editorial* – possible confusion in the existing standard is clarified.
*Technical advance* – new knowledge on actual loadings and systems performance has improved - loadings and other requirements may increase or decrease.
*Correction* – an error occurred in the existing standard - loadings and requirements may increase or decrease.
*Aligned with international standards* or Australian standards or an international trend – loadings, analysis methods, and risk levels for various building types are aligned as appropriate - loadings and requirements may increase or decrease.
*Societal expectations* - Performance expectations for certain building types have changed - loadings and requirements may increase.

The structural standards are based on what are the likely loads and the structure is designed to withstand these, first to preserve life and injury in the more extreme events, and second to minimise building damage in more common events. For natural events such as earthquake and wind, historic data and technical knowledge provide return periods for different levels of action. The most significant changes in the new standard are higher wind speeds in some locations, revised seismicity for regions, and a change in the load factor applied to buildings of different levels of importance. In particular, public buildings with crowds have an increase in the importance factor from 1.2 to 1.3, and post-disaster essential buildings from 1.3 to 1.8.

Most of the changes with cost implications were picked up by the designers, including parts and windows support changes and incorporated in the main structural design. However it appears that purlin imposed tributary loads were not adequately considered by these designers, and this report contains a brief study covering purlin design changes next.

## 10.3 Purlin design.

Consider a purlin at 800mm centres, spanning 6m.
U1 = 1.2G + 1.6Q for NZS4203, and 1.2G + 1.5Q for AS/NZS1170
U2 = 0.9G + W

NZS4203 U1 = 1.2x0.1 + 1.6 x 0.25 = 0.52 kPa
AS1170 U1 = 1.2x0.1 + 1.5 x 0.5 = 0.87kPa

W = 0.6 V^2 x Cpe = 0.6x37x37x0.9= 0.74kPa.
So AS/NZS1170 U2 = -0.9x0.1 + 0.74 = 0.65 kPa
Where Wind speed V= V(Region)x M(terrain)=45*0.83=37 m/s
So the imposed live load case governs and the loading has increased for purlins similar to this layout and with a similar external pressure coefficient.

For timber purlins the increase would typically be from 200 x 50 @ 800 ctrs, 6 m span to 250 x 50 purlins. Cost increases of these changes are calculated in Table 4.

### 10.4 Building activity by type

Forecasts of building activity by value are required to calculated the effect of the standard changes on initial building costs. These forecasts, produced by BRANZ, are shown in Tables 8 and 9.

**Table 8 Residential building forecasts**

| BRANZ dwelling forecasts | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | New households (1) 2006 to 2021 | % | Other demand (2) 2006 to 2021 | Total 2021 | % | New residential/ yr House low-rise | High rise | Ave value/unit ($000) House low-rise | High rise | Total value ($M) House low-rise | High rise |
| Northland,Auckland | 152500 | 52.7 | 31700 | 184200 | 51.2 | 10070 | 2210 | 250 | 130 | 2518 | 287 |
| Waikato, BOP, Taranaki | 50600 | 17.5 | 14100 | 64700 | 18.0 | 3540 | 780 | 240 | 110 | 850 | 86 |
| Rest of NI (Well, Hbay, Manaw) | 36400 | 12.6 | 7100 | 43500 | 12.1 | 2380 | 520 | 230 | 120 | 547 | 62 |
| Tasman/ Canterbury/ Otago | 47780 | 16.5 | 14800 | 62580 | 17.4 | 3420 | 750 | 240 | 120 | 821 | 90 |
| W Coast/ Southland/ Lakes | 2220 | 0.8 | 2800 | 5020 | 1.4 | 270 | 60 | 240 | 100 | 65 | 6 |
| Total | 289500 | 100.0 | 70500 | 360000 | 100 | | | | | | |
| Per year | 19300 | | 4700 | 24000 | | 19680 | 4320 | | | 4800 | 532 |

(1) Statistics NZ, Medium household formation scenario
(2) Allows for demolition replacement, holiday or other second homes, and additions to the buffer stock.
(3) Assume high rise apartments as a % of all new dwelling units = 18 % Based on an expected 25% multi-units rate, of which 70% are high-rise.

**Table 9 Non-residential building forecasts**

**BRANZ non-residential building consent trends and forecasts**
Forecasts by BRANZ

**$million Sep05$ New bldgs + A&A bldg consents (1)**

| Calender Year | Industrial/ retail | Public | Commercial | Farm (2) | Misc (2) | Total |
|---|---|---|---|---|---|---|
| 90 | 572 | 286 | 253 | 54 | 64 | 1229 |
| 91 | 455 | 355 | 233 | 59 | 32 | 1133 |
| 92 | 506 | 374 | 378 | 89 | 36 | 1383 |
| 93 | 704 | 684 | 307 | 115 | 94 | 1905 |
| 94 | 882 | 640 | 545 | 135 | 136 | 2337 |
| 95 | 917 | 715 | 538 | 126 | 278 | 2575 |
| 96 | 1234 | 1054 | 660 | 131 | 106 | 3185 |
| 97 | 1131 | 804 | 769 | 102 | 27 | 2834 |
| 98 | 904 | 1200 | 714 | 118 | 42 | 2978 |
| 99 | 1004 | 1009 | 587 | 116 | 45 | 2760 |
| 00 | 1049 | 1009 | 732 | 128 | 25 | 2944 |
| 01 | 1145 | 1179 | 695 | 205 | 35 | 3260 |
| 02 | 1201 | 1091 | 579 | 210 | 29 | 3109 |
| 03 | 1229 | 1104 | 675 | 187 | 36 | 3230 |
| 04 | 1539 | 1190 | 926 | 179 | 33 | 3866 |
| 05 | 1547 | 1454 | 845 | 186 | 70 | 4103 |
| 06 | 1433 | 1338 | 696 | 143 | 70 | 3680 |
| 07 | 1490 | 1163 | 746 | 143 | 70 | 3612 |
| 08 | 1547 | 1338 | 795 | 143 | 70 | 3894 |
| 09 | 1605 | 1163 | 845 | 143 | 70 | 3826 |
| 10 | 1777 | 1279 | 895 | 143 | 70 | 4164 |
| Average 06 to 2010 | 1570 | 1256 | 795 | 143 | 70 | 3835 |

(1) Inflation adjustment to Sep05 $ using the Capital Expenditure Price Index. (for non-residential bldgs.)
(2) Farm and miscalleneous bldgs are later added into the industrial/ retail group.

In order to estimate the regional distribution shown in Table 3, the historic distribution for non-residential consents is assumed to apply. This is shown in Table 10.

**Table 10 Non-residential buildings by region**

| Non-residential building consent values by region<br>1996 to 2005 calender years total | | | | | | |
|---|---|---|---|---|---|---|
| | Industrial/ retail | Public bldgs | Commercial | Industrial/ retail | Public bldgs | Commercial |
| | **Decade total New+ A&A work $M** | | | **Percent** | | |
| Nthld/Auckland | 4,585 | 3,857 | 2,860 | 38 | 41 | 46 |
| Waikato/BOP/ Taranaki | 2,433 | 1,446 | 686 | 20 | 15 | 11 |
| Rest North Island | 1,838 | 2,085 | 1,417 | 15 | 22 | 23 |
| Nelson/ Canterbury/ Otag | 2,622 | 1,736 | 985 | 22 | 18 | 16 |
| West Cst/ Sthld/ Lakes | 558 | 389 | 206 | 5 | 4 | 3 |
| | 12,036 | 9,512 | 6,155 | 100 | 100 | 100 |
| | | | 27,704 | | | |

Source: Statistics NZ, building consent series.
Industrial / retail = warehouse, factory, farm, miscalleneous and retail.
Public bldgs = hostel, prisons, hospitals, education and social/ cultural.
Commercial = office and hotels/ motels.

Note that throughout the report the building values have been expressed in terms of building consent values. The work finally put in place usually exceeds the consent value due to under-reporting at consent application time, contract additions, and cost escalation, typically by about 5%. So the previously used number of $8.7 billion of building work per year will actual be a higher figure in terms of work placed. The percentage cost changes provided in this report will not change since both the original cost and the cost of the changes have been based on consent values. However the cost reported in Table 1 of $35.0 million per year could more correctly be reported as $36.8 million but given the approximations in the analysis this change is not significant.

### 10.5 Calculation of changes in damage ratios with changes in loading coefficients

Recommendation of D Hopkins – Earthquake structural design specialist.

The following be used to assess the shift in damage ratio:

1. Shift is proportional to the shift in coefficient.
2. The rate of shift is different dependent on whether 1170 requires a higher or lower coefficient than 4203
3. The rates of shift to be used are the same for all locations and building types
4. When 1170 calls for a higher coefficient than 4203, the damage ratio increases by 0.15% for every 1% change in coefficient. The difference in damage computed between the two standards is a benefit of introducing 1170. (1170 will result in a building that would perform better than one designed to 4203.)
5. When 1170 calls for a lower coefficient than 4203, the damage ratio decreases by 0.08% for every 1% change in coefficient. The difference in damage computed between the two standards is a disbenefit of introducing 1170. (1170 will result in a building that would not perform as well as one designed to 4203)
6. As an example: If 1170 coefficient is 1.2 times the 4203 coefficient, the change in DR would be 20 (1.2 – 1.0 expressed in percentage terms) times 0 .15% = 3.0%. (times the replacement value of the building)
7. As further example: If 1170 coefficient is 0.8 times the 4203 coefficient, the change in DR would be 20 (1.0 – 0.8 expressed in percentage terms) times 0 .08% = 1.6%. (times the replacement value of the building)

Building these relationships into the cost benefit model would provide a sounder basis for our calculations than currently exist.

As background, and justification of the calculations, refer to the attached figure. Draw a straight line from the origin to a point on the >1976 curve at about MM9.5. This shows a DR of 16%. This is a reasonable point to choose, and for the purposes of the calculations can be taken as representative of the situation for a design to 1170 anywhere in the country.

Then draw a line from that point to the point corresponding to MM12. The change in DR from MM9.5 to MM8.5 is 4% for a 50% change in coefficient. (From 100 to 50, being one-half for every MM level – this has been verified as being correct up to MM10.) This gives 8% change for 100% change in coefficient, or .08% per 1% change in coefficient.

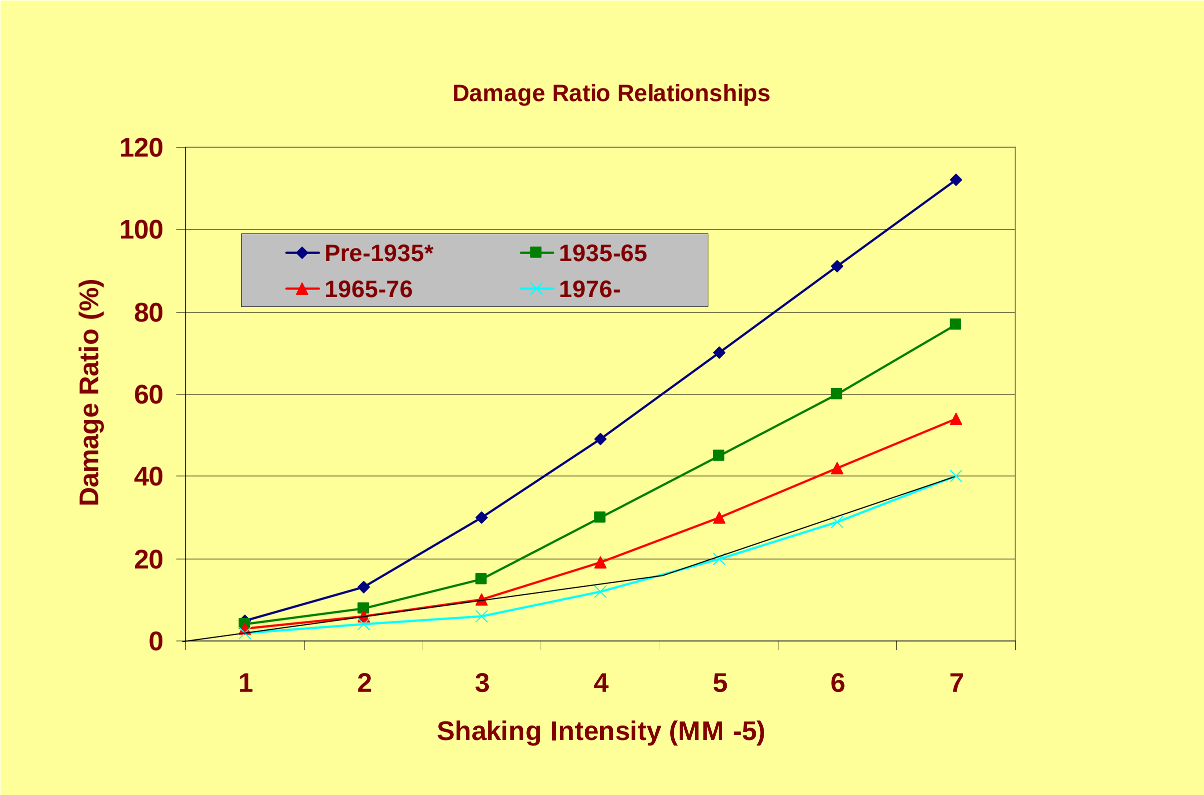
A similar approach is used with the line from MM9.5 to MM12 and take the DR difference between MM9.5 and MM10.5. The difference is 25% minus 16% = 9%. The question is then, what change in coefficient does this represent? Recent seminar notes show the following:

MM4 peak ground acceleration (pga) = .015 to .02g
MM5 .03 to .04
MM6 .06 to .07
MM7 .10 to .15
MM8 .25 to .30
MM9 .50 to .55
MM10 Greater than 0.60 (!)

Note the doubling, at least up to MM10!

So there is no problem with the doubling rule going down from MM9.5, but it is not so clear what to do going up. The DR difference is 9%, which if the doubling rule continued would be 0.09% per 1% change in coefficient. However, there is a clear signal in the numbers for pga above that it flattens off. Thus the 9% difference comes about with a change in coefficient of less than 100%. If we take the increase as being 60% instead of 100%, the shift rate is 9/60 = 0.15% per 1% of coefficient movement.

**Figure 10 Damage ratio v MM index**




D Hopkins notes end here.

From the above it was decided to use a 0.15% reduction in DR for every 1% increase in the load coefficient, applied to both earthquake and wind loads. For every 1% decrease in the load coefficient there is a 0.08% increase in the DR. Cousins (2004) produced a similar chart to Figure 10 though the damage ratios for post-1980 buildings (reinforced concrete only) were lower at all MMs. However his chart gave approximately similar changes in damage ratio between MM 9.5 and MM10.5 as for Hopkins above.

A sensitivity analysis was carried out using different values from the default case of 0.15% reduction in DR per 1% load increase. The results are in Figure 11.

**Figure 11 NPV versus damage ratio factor**

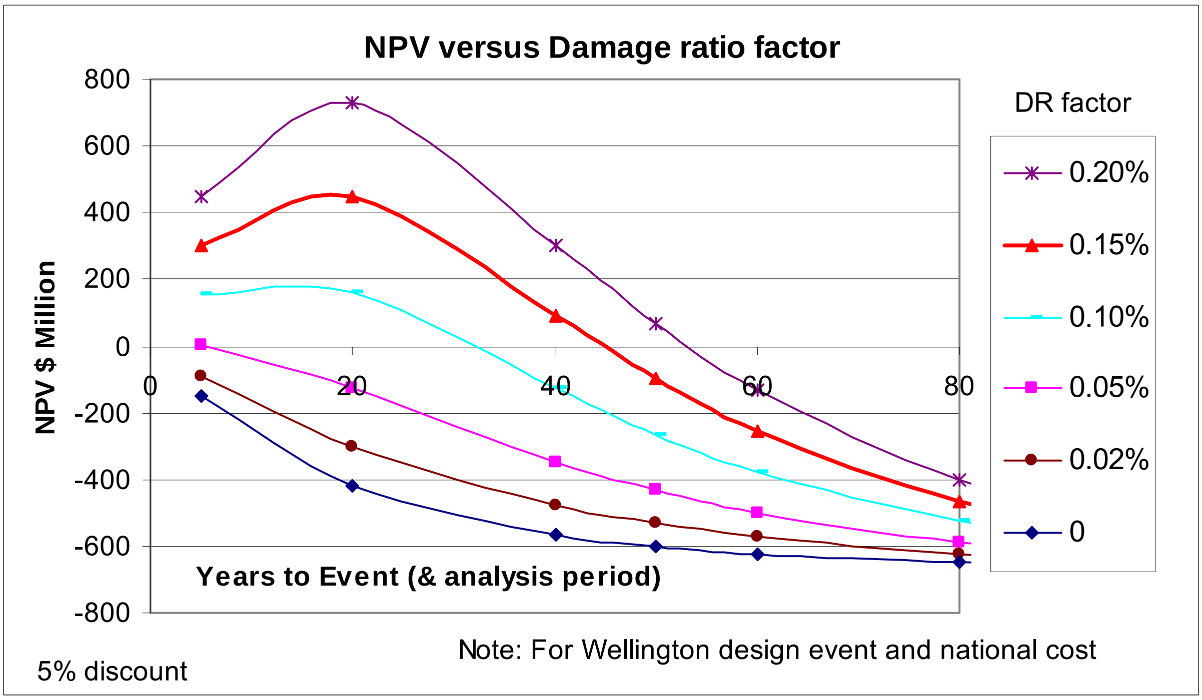



Figure 11 indicates how the net present value varies with changes in the assumed factor (default case 0.15% change in DR for 1% change in loading). For example, if the factor is a 0.10% reduction in the damage ratio for a 1% increase in the design load, then the earthquake needs to occur within 30 years for a positive NPV (compared to within 45 years for the default case). Even with a low value of a 0.05% damage ratio factor there are net benefits if the design event occurs within 5 years in Wellington.

## 10.6 Relationship of injuries/fatalities to damage ratio

Recommendation of D Hopkins – Earthquake structural design specialist

Use the paper by Spence (1998) which postulates a relationship between the damage ratio and percentage of buildings collapsing:

Likelihood of collapse = 0.64DR^2.4 for non-ductile buildings.
= 0.87DR^2.7 for ductile buildings.

The ductile equation was used in the analysis (see Table 5), but the numbers are very similar when using the non-ductile equation.

The paper also includes recommendations for population location by time of the loading event, see the table below. These give 90% of the population within a building at the time of the event.

**Table 11 Location of population by time of day**

| Location | Time of Occurrence | | |
|---|---|---|---|
| | Day | Night | Average |
| | Percentage location | | |
| Residential | 22 | 96 | 59 |
| Non-residential | 58 | 3 | 30.5 |
| Outdoors | 20 | 1 | 10.5 |
| | 100 | 100 | 100 |

The paper also recommends injury and death rates assuming the building collapses, see the table below. Note that death rates are higher than the injury rates, because previous experience of major events has shown persons within a building in the event of collapse are very unlikely to survive.

**Table 12 Injury/death rates in the event of building collapse**

| Class | Death % | Injury% | Types of building |
|---|---|---|---|
| Masonry | 17.5 | 10 | |
| RC Frame | 21 | 0.8 | Hi-rise commercial & apartments & public bldgs |
| RC Shear Wall | 10 | 0.7 | Hi-rise commercial & apartments |
| Steel | 16 | 0.6 | Industrial/retail & low rise commercial & public bldgs |
| Timber | 0.6 | 0.2 | Low rise residential |

Knowing the damage ratio the above information is sufficient to calculate the expected death/ injury rates, as shown in Table 5.

## 10.7 Changes in damage, business disruption and injuries/fatalities due to changes in design loads - by Region.

The analysis in section 5.1 and Table 5 showed the changes in damage, business disruption and injuries/ fatalities for the Wellington design event. This section provides the same analysis for the other regions. The results are in Tables 13 to16 and are the same format as Table 5.

Table 6 showed how the NPV varied for the Wellington event with the number of years ahead to the design event. Tables 17 to 20 below have the same Tables for the other regions.

**Table 13 Damage changes and other cost savings – Auckland region.**

**Building damage, Business disruption and Injury/ fatality changes for the design event in Auckland.**

**Changes in seismic and wind loading coefficients**

| | Governing case | | | |
|---|---|---|---|---|
| | **EARTHQUAKE** | | **WIND** | |
| **Residential** | Chg coeff | Governing | Chg coeff | Governing |
| Housing <=3 storeys | -40% | 10% | 10% | 90% |
| Housing >3 storeys) | -30% | 50% | -15% | 50% |
| **Other buildings** | | | | |
| Industrial/ Retail | -30% | 50% | 10% | 50% |
| Public Bldgs | 0% | 60% | 0% | 40% |
| Commercial (<4 storeys) | -30% | 30% | 15% | 70% |
| Commercial (>3 storeys) | -20% | 50% | -10% | 50% |

**Damage cost changes are (1):** (positive values are savings, -ve values are increased damage)

| | **EQ** | **Wind** | **Total** $M per year |
|---|---|---|---|
| **Residential** | $M | $M | of new bldgs |
| Housing <=3 storeys | -6.5 | 27.6 | 21.1 |
| Housing >3 storeys) | -4.1 | -2.0 | -6.1 |
| **Other buildings** | | | |
| Industrial/ Retail | -8.2 | 5.1 | -3.1 |
| Public Bldgs | 0.0 | 0.0 | 0.0 |
| Commercial (<4 storeys) | -1.6 | 3.5 | 1.9 |
| Commercial (>3 storeys) | -1.2 | -0.6 | -1.8 |
| | -21.6 | 33.6 | 12.0 |

**Business disruption and indirect cost savings, (see text).**

% of bldg damage 200 For Auckland event = 24.0 $M/ year of new bldgs.

**Injuries /fatalities saved in the Auckland design event.**

| | New buildings (000 sqm/ year) | Persons per sqm | Number of persons at risk | Collapse likelihood at DR=20% (2) | Reduction in damage ratio (DR) (3) % | Collapse likelihood with AS1170 (2) | In event of collapse: Death rate (4) % | In event of collapse: Injury rate (4) % | Personal injuries &deaths saved: Fatalities (5) | Personal injuries &deaths saved: Injury (5) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | | | | | | | | | |
| Housing <=3 storeys | 1023 | 0.014 | 14320 | 0.011 | 1.0 | 0.010 | 0.6 | 0.2 | 0.1 | 0.0 |
| Housing >3 storeys) | 136 | 0.02 | 2728 | 0.011 | -1.8 | 0.014 | 20.0 | 1.0 | -1.5 | -0.1 |
| **Other buildings** | | | | | | | | | | |
| Industrial/ Retail | 453 | 0.005 | 2265 | 0.011 | -0.5 | 0.012 | 16.0 | 0.6 | -0.2 | 0.0 |
| Public Bldgs | 204 | 0.05 | 10185 | 0.011 | 0.0 | 0.011 | 10.0 | 0.5 | 0.0 | 0.0 |
| Commercial (<4 storeys) | 89 | 0.05 | 4433 | 0.011 | 0.9 | 0.010 | 16.0 | 0.6 | 0.8 | 0.0 |
| Commercial (>3 storeys) | 49 | 0.05 | 2463 | 0.011 | -1.2 | 0.013 | 20.0 | 1.0 | -0.9 | 0.0 |
| | | | 36395 | | | | | | -1.6 | -0.1 |

-ve number is an increase

**Total savings for Auckland event** $M for one year of new building

| | | |
|---|---|---|
| Damage increase | 12.0 | |
| Business disruption, flow-ons | 24.0 | |
| Injuries caused | 0.0 | assume $0.25M per injury |
| Fatalities caused | -4.0 | assume $2.5M per fatality. |
| | 31.9 | $M for one year of new buildings. |

(1) Assume 0.15% decrease (0.08% increase) in damage ratio for every 1% increase (1% decrease) in seismic & wind loading coef, (see text).
(2) Collapse likelihoood is 0.87*DR^2.7, from Spencer et al , see text.
(3)The % change in the damage ratio is the % change in loading coefficient x 0.15 (or 0.08) x probability of load condition, see text.
(4) Death and injury rates from Spence et al, see text.
(5) Fatalities/injuries saved (lost) by load increase (decrease)= 0.9 x persons at risk x chg in collapse likelihood x death/injury rate.
0.9 factor allows for the proportion of the population indoors at the time of the event.

## Table 14 Damage changes and other cost savings – BOP/ Waikato region.

**Building damage, Business disruption and Injury/ fatality changes for the design event in BOP/Waikato.**

**Changes in seismic and wind loading coefficients**

| | Governing case | | | |
|---|---|---|---|---|
| | EARTHQUAKE | | WIND | |
| **Residential** | Chg coeff | Governing | Chg coeff | Governing |
| Housing <=3 storeys | -40% | 20% | 20% | 80% |
| Housing >3 storeys) | -30% | 50% | 0% | 50% |
| **Other buildings** | | | | |
| Industrial/ Retail | -30% | 40% | 20% | 60% |
| Public Bldgs | 0% | 60% | 10% | 40% |
| Commercial (<4 storeys) | -30% | 60% | 30% | 40% |
| Commercial (>3 storeys) | -20% | 50% | 0% | 50% |

**Damage cost changes are (1):** (positive values are savings, -ve values are increased damage)

| | **EQ** | **Wind** | **Total** $M per year |
|---|---|---|---|
| **Residential** | $M | $M | of new bldgs |
| Housing <=3 storeys | -5.1 | 19.0 | 14.0 |
| Housing >3 storeys) | -1.6 | 0.0 | -1.6 |
| **Other buildings** | 0.0 | 0.0 | |
| Industrial/ Retail | -3.5 | 6.5 | 3.0 |
| Public Bldgs | 0.0 | 1.1 | 1.1 |
| Commercial (<4 storeys) | -0.8 | 1.0 | 0.2 |
| Commercial (>3 storeys) | -0.3 | 0.0 | -0.3 |
| | -11.2 | 27.6 | 16.5 |

**Business disruption and indirect cost savings, (see text).**

| % of bldg damage | | | |
|---|---|---|---|
| 200 | For BOP/Waikato even | 32.9 | $M/ year of new bldgs. |

**Injuries /fatalities saved in the BOP/Waikato design event.**

| | New buildings (000 sqm/ year) | Persons per sqm | Number of persons at risk | Collapse likelihood at DR=20% (2) | Reduction in damage ratio (DR) (3) % | Collapse likelihood with AS1170 (2) | In event of collapse Death rate (4) % | In event of collapse Injury rate (4) % | Personal injuries and deaths saved Fatalities (5) | Personal injuries and deaths saved Injury (5) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | | | | | | | | | |
| Housing <=3 storeys | 397 | 0.014 | 5553 | 0.011 | 1.8 | 0.009 | 0.6 | 0.2 | 0.1 | 0.0 |
| Housing >3 storeys) | 53 | 0.02 | 1058 | 0.011 | -1.2 | 0.013 | 20.0 | 1.0 | -0.4 | 0.0 |
| **Other buildings** | | | | | | | | | | |
| Industrial/ Retail | 240 | 0.005 | 1202 | 0.011 | 0.8 | 0.010 | 16.0 | 0.6 | 0.2 | 0.0 |
| Public Bldgs | 76 | 0.05 | 3819 | 0.011 | 0.6 | 0.010 | 10.0 | 0.5 | 0.3 | 0.0 |
| Commercial (<4 storeys) | 21 | 0.05 | 1064 | 0.011 | 0.4 | 0.011 | 16.0 | 0.6 | 0.1 | 0.0 |
| Commercial (>3 storeys) | 12 | 0.05 | 591 | 0.011 | -0.8 | 0.013 | 20.0 | 1.0 | -0.1 | 0.0 |
| | | | 13287 | | | | | | 0.2 | 0.0 |

| **Total savings for BOP/Waikato event** | $M for one year of new building | | -ve number is an increase |
|---|---|---|---|
| Damage reduction | 16.5 | | |
| Business disruption, flow-ons | 32.9 | | |
| Injuries saved | 0.0 | assume $0.25M per injury | |
| Fatalities saved | 0.4 | assume $2.5M per fatality. | |
| | 49.8 | $M for one year of new buildings. | |

(1) Assume 0.15% decrease (0.08% increase) in damage ratio for every 1% increase (1% decrease) in seismic & wind loading coef, (see text).
(2) Collapse likelihoood is 0.87*DR^2.7, from Spencer et al , see text.
(3)The % change in the damage ratio is the % change in loading coefficient x 0.15 (or 0.08) x probability of load condition, see text.
(4) Death and injury rates from Spence et al, see text.
(5) Fatalities/injuries saved (lost) by load increase (decrease)= 0.9 x persons at risk x chg in collapse likelihood x death/injury rate.
0.9 factor allows for the proportion of the population indoors at the time of the design event.

## Table 15 Damage changes and other cost savings – Canterbury/ Otago region.

**Building damage, Business disruption and Injury/ fatality changes for the design event in Canterbury/Otago.**

**Changes in seismic and wind loading coefficients**

| | Governing case | | | |
|---|---|---|---|---|
| | EARTHQUAKE | | WIND | |
| **Residential** | Chg coeff | Governing | Chg coeff | Governing |
| Housing <=3 storeys | -20% | 60% | 10% | 40% |
| Housing >3 storeys) | 0% | 70% | -15% | 30% |
| **Other buildings** | | | | |
| Industrial/ Retail | 0% | 50% | 10% | 50% |
| Public Bldgs | 20% | 60% | 0% | 40% |
| Commercial (<4 storeys) | -20% | 70% | 15% | 30% |
| Commercial (>3 storeys) | 0% | 70% | -10% | 30% |

**Damage cost changes are (1):** (positive values are savings, -ve values are increased damage)

| | **EQ** | **Wind** | **Total** $M per year |
|---|---|---|---|
| **Residential** | $M | $M | of new bldgs |
| Housing <=3 storeys | -6.4 | 4.0 | -2.4 |
| Housing >3 storeys) | 0.0 | -0.4 | -0.4 |
| **Other buildings** | | | |
| Industrial/ Retail | 0.0 | 2.9 | 2.9 |
| Public Bldgs | 4.1 | 0.0 | 4.1 |
| Commercial (<4 storeys) | -0.9 | 0.5 | -0.3 |
| Commercial (>3 storeys) | 0.0 | -0.2 | -0.2 |
| | -3.1 | 6.8 | 3.7 |

**Business disruption and indirect cost savings, (see text).**

% of bldg damage 200 For Cant/Otago event = 7.3 $M/ year of new bldgs.

**Injuries /fatalities saved in the Cant/Otago design event.**

| | New buildings (000 sqm/ year) | Persons per sqm | Number of persons at risk | Collapse likelihood at DR=20% (2) | Reduction in damage ratio (DR) (3) % | Collapse likelihood with AS1170 (2) | In event of collapse: Death rate (4) % | In event of collapse: Injury rate (4) % | Personal injuries and deaths saved: Fatalities (5) | Personal injuries and deaths saved: Injury (5) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | | | | | | | | | |
| Housing <=3 storeys | 334 | 0.014 | 4676 | 0.011 | -0.4 | 0.012 | 0.6 | 0.2 | 0.0 | 0.0 |
| Housing >3 storeys) | 45 | 0.02 | 891 | 0.011 | -0.4 | 0.012 | 20.0 | 1.0 | -0.1 | 0.0 |
| **Other buildings** | | | | | | | | | | |
| Industrial/ Retail | 259 | 0.005 | 1296 | 0.011 | 0.8 | 0.010 | 16.0 | 0.6 | 0.2 | 0.0 |
| Public Bldgs | 92 | 0.05 | 4583 | 0.011 | 1.8 | 0.009 | 10.0 | 0.5 | 1.0 | 0.1 |
| Commercial (<4 storeys) | 31 | 0.05 | 1527 | 0.011 | -0.4 | 0.012 | 16.0 | 0.6 | -0.2 | 0.0 |
| Commercial (>3 storeys) | 17 | 0.05 | 848 | 0.011 | -0.2 | 0.012 | 20.0 | 1.0 | -0.1 | 0.0 |
| | | | 13821 | | | | | | 0.9 | 0.0 |

**Total savings for Cant/Otago event** $M for one year of new building -ve number is an increase

| | | |
|---|---|---|
| Damage reduction | 3.7 | |
| Business disruption, flow-ons | 7.3 | |
| Injuries saved | 0.0 | assume $0.25M per injury |
| Fatalities saved | 2.4 | assume $2.5M per fatality. |
| | 13.4 | $M for one year of new buildings. |

(1) Assume 0.15% decrease (0.08% increase) in damage ratio for every 1% increase (1% decrease) in seismic & wind loading coef, (see text).
(2) Collapse likelihoood is 0.87*DR^2.7, from Spencer et al , see text.
(3)The % change in the damage ratio is the % change in loading coefficient x 0.15 (or 0.08) x probability of load condition, see text.
(4) Death and injury rates from Spence et al, see text.
(5) Fatalities/injuries saved (lost) by load increase (decrease)= 0.9 x persons at risk x chg in collapse likelihood x death/injury rate.
0.9 factor allows for the proportion of the population indoors at the time of the design event.

## Table 16 Damage changes and other cost savings – Southland/Lakes.

**Building damage, Business disruption and Injury/ fatality changes for the design event in Southland/ Lakes**

**Changes in seismic and wind loading coefficients**

| | Governing case | | | |
|---|---|---|---|---|
| | **EARTHQUAKE** | | **WIND** | |
| **Residential** | Chg coeff | Governing | Chg coeff | Governing |
| Housing <=3 storeys | 20% | 60% | 0% | 40% |
| Housing >3 storeys) | 40% | 50% | -15% | 50% |
| **Other buildings** | | | | |
| Industrial/ Retail | 40% | 60% | 0% | 40% |
| Public Bldgs | 80% | 60% | -10% | 40% |
| Commercial (<4 storeys) | 20% | 60% | 0% | 40% |
| Commercial (>3 storeys) | 50% | 60% | -20% | 40% |

**Damage cost changes are (1):** (positive values are savings, -ve values are increased damage)

| | **EQ** | **Wind** | **Total** $M per year |
|---|---|---|---|
| **Residential** | $M | $M | of new bldgs |
| Housing <=3 storeys | 1.5 | 0.0 | 1.5 |
| Housing >3 storeys) | 0.4 | -0.1 | 0.3 |
| **Other buildings** | | | |
| Industrial/ Retail | 3.0 | 0.0 | 3.0 |
| Public Bldgs | 3.7 | -0.2 | 3.5 |
| Commercial (<4 storeys) | 0.3 | 0.0 | 0.3 |
| Commercial (>3 storeys) | 0.5 | -0.1 | 0.4 |
| | 9.4 | -0.3 | 9.0 |

**Business disruption and indirect cost savings, (see text).**

% of bldg damage 200 For Southld event = 18.1 $M/ year of new bldgs.

**Injuries /fatalities saved in the Sthld/Lakes design event.**

| | New buildings (000 sqm/ year) | Persons per sqm | Number of persons at risk | Collapse likelihood at DR=20% (2) | Reduction in damage ratio (DR) (3) % | Collapse likelihood with AS1170 (2) | In event of collapse Death rate (4) % | In event of collapse Injury rate (4) % | Personal injuries and deaths saved Fatalities (5) | Personal injuries and deaths saved Injury (5) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | | | | | | | | | |
| Housing <=3 storeys | 42 | 0.014 | 585 | 0.011 | 1.8 | 0.009 | 0.6 | 0.2 | 0.0 | 0.0 |
| Housing >3 storeys) | 6 | 0.02 | 111 | 0.011 | 2.4 | 0.008 | 20.0 | 1.0 | 0.1 | 0.0 |
| **Other buildings** | | | | | | | | | | |
| Industrial/ Retail | 55 | 0.005 | 276 | 0.011 | 3.6 | 0.007 | 16.0 | 0.6 | 0.2 | 0.0 |
| Public Bldgs | 21 | 0.05 | 1027 | 0.011 | 6.9 | 0.004 | 10.0 | 0.5 | 0.7 | 0.0 |
| Commercial (<4 storeys) | 6 | 0.05 | 319 | 0.011 | 1.8 | 0.009 | 16.0 | 0.6 | 0.1 | 0.0 |
| Commercial (>3 storeys) | 4 | 0.05 | 177 | 0.011 | 3.9 | 0.006 | 20.0 | 1.0 | 0.2 | 0.0 |
| | | | 2494 | | | | | | 1.2 | 0.1 |

-ve number is an increase

**Total savings for Sthld/Lakes event** $M for one year of new building

| | | |
|---|---|---|
| Damage reduction | 9.0 | |
| Business disruption, flow-ons | 18.1 | |
| Injuries saved | 0.0 | assume $0.25M per injury |
| Fatalities saved | 3.1 | assume $2.5M per fatality. |
| | 30.3 | $M for one year of new buildings. |

(1) Assume 0.15% decrease (0.08% increase) in damage ratio for every 1% increase (1% decrease) in seismic & wind loading coef, (see text).
(2) Collapse likelihoood is 0.87*DR^2.7, from Spencer et al , see text.
(3)The % change in the damage ratio is the % change in loading coefficient x 0.15 (or 0.08) x probability of load condition, see text.
(4) Death and injury rates from Spence et al, see text.
(5) Fatalities/injuries saved (lost) by load increase (decrease)= 0.9 x persons at risk x chg in collapse likelihood x death/injury rate.
0.9 factor allows for the proportion of the population indoors at the time of the design event.

## 10.8 Net present value calculations

The following Tables are the net present values by region for 2 sets of costs:

- Tables 17 to Table 20 (and Table 6) have the national costs
- Tables 21 to 25 have the regional costs.

**Table 17 NPV and benefit cost ratios for the Auckland event**

| Present value calculations for Auckland design event | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | National costs | | | | | | | | | |
| Time of EQ Years ahead | Additional construction costs per year new bldgs | Discount factor annual series | PV Constn costs | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings | Building damage, business disruption injury/fatality savings per year new bldgs | Discount factor single event | PV savings | Net PV | Benefit: cost ratio |
| | $M | | $M | | $M | $M | | $M | $M | |
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 35.0 | 4.329 | 151 | 15 | 1.9 | 31.9 | 0.784 | 127 | -24 | 0.8 |
| 20 | 35.0 | 12.462 | 436 | 210 | 16.2 | 31.9 | 0.377 | 257 | -179 | 0.6 |
| 40 | 35.0 | 17.159 | 600 | 820 | 32.8 | 31.9 | 0.142 | 214 | -386 | 0.4 |
| 50 | 35.0 | 18.256 | 638 | 1275 | 36.8 | 31.9 | 0.087 | 176 | -462 | 0.3 |
| 60 | 35.0 | 18.929 | 662 | 1830 | 38.1 | 31.9 | 0.054 | 141 | -521 | 0.2 |
| 80 | 35.0 | 19.596 | 685 | 3240 | 35.1 | 31.9 | 0.020 | 87 | -598 | 0.13 |
| 100 | 35.0 | 19.848 | 694 | 5050 | 28.4 | 31.9 | 0.008 | 53 | -641 | 0.08 |

(1) From Table 4, for all NZ.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual saving 0.15
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Auckland only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.

Discount rate = 5%

**Table 18 NPV and benefit cost ratios for the BOP/Waikato event**

| Present value calculations for BOP/Waikato design event | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | National costs | | | | | | | | | |
| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 35.0 | 4.329 | 151 | 15 | 1.9 | 49.8 | 0.784 | 197 | 46 | 1.3 |
| 20 | 35.0 | 12.462 | 436 | 210 | 16.2 | 49.8 | 0.377 | 392 | -44 | 0.9 |
| 40 | 35.0 | 17.159 | 600 | 820 | 32.8 | 49.8 | 0.142 | 316 | -284 | 0.5 |
| 50 | 35.0 | 18.256 | 638 | 1275 | 36.8 | 49.8 | 0.087 | 254 | -384 | 0.4 |
| 60 | 35.0 | 18.929 | 662 | 1830 | 38.1 | 49.8 | 0.054 | 198 | -464 | 0.3 |
| 80 | 35.0 | 19.596 | 685 | 3240 | 35.1 | 49.8 | 0.020 | 115 | -570 | 0.17 |
| 100 | 35.0 | 19.848 | 694 | 5050 | 28.4 | 49.8 | 0.008 | 66 | -627 | 0.10 |

(1) From Table 4, for all NZ.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual saving 0.15
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Waik/BOP only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 19 NPV and benefit cost ratios for the Canterbury/ Otago event**

**Present value calculations for Canterbury/ Otago design event**

**National costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 35.0 | 4.329 | 151 | 15 | 1.9 | 13.4 | 0.784 | 54 | -97 | 0.4 |
| 20 | 35.0 | 12.462 | 436 | 210 | 16.2 | 13.4 | 0.377 | 117 | -319 | 0.3 |
| 40 | 35.0 | 17.159 | 600 | 820 | 32.8 | 13.4 | 0.142 | 109 | -491 | 0.2 |
| 50 | 35.0 | 18.256 | 638 | 1275 | 36.8 | 13.4 | 0.087 | 95 | -543 | 0.1 |
| 60 | 35.0 | 18.929 | 662 | 1830 | 38.1 | 13.4 | 0.054 | 81 | -581 | 0.1 |
| 80 | 35.0 | 19.596 | 685 | 3240 | 35.1 | 13.4 | 0.020 | 57 | -628 | 0.08 |
| 100 | 35.0 | 19.848 | 694 | 5050 | 28.4 | 13.4 | 0.008 | 39 | -655 | 0.06 |

(1) From Table 4, for all NZ.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual saving 0.15
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Cant/Otago only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 20 NPV and benefit cost ratios for the Southland/ Lakes event**

**Present value calculations for Southland/ Lakes design event**

**National costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 35.0 | 4.329 | 151 | 15 | 1.9 | 30.3 | 0.784 | 120 | -31 | 0.8 |
| 20 | 35.0 | 12.462 | 436 | 210 | 16.2 | 30.3 | 0.377 | 244 | -191 | 0.6 |
| 40 | 35.0 | 17.159 | 600 | 820 | 32.8 | 30.3 | 0.142 | 205 | -395 | 0.3 |
| 50 | 35.0 | 18.256 | 638 | 1275 | 36.8 | 30.3 | 0.087 | 169 | -469 | 0.3 |
| 60 | 35.0 | 18.929 | 662 | 1830 | 38.1 | 30.3 | 0.054 | 135 | -526 | 0.2 |
| 80 | 35.0 | 19.596 | 685 | 3240 | 35.1 | 30.3 | 0.020 | 84 | -601 | 0.12 |
| 100 | 35.0 | 19.848 | 694 | 5050 | 28.4 | 30.3 | 0.008 | 51 | -642 | 0.07 |

(1) From Table 4, for all NZ.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual saving 0.15
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Sthld/Lakes only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 21 NPV and benefit cost ratios for the Auckland event – local costs**

**Present value calculations for Auckland design event**

**Regional costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 13.4 | 4.329 | 58 | 15 | 0.9 | 31.9 | 0.784 | 126 | 68 | 2.2 |
| 20 | 13.4 | 12.462 | 167 | 210 | 7.3 | 31.9 | 0.377 | 248 | 81 | 1.5 |
| 40 | 13.4 | 17.159 | 230 | 820 | 14.9 | 31.9 | 0.142 | 196 | -34 | 0.9 |
| 50 | 13.4 | 18.256 | 245 | 1275 | 16.7 | 31.9 | 0.087 | 156 | -89 | 0.6 |
| 60 | 13.4 | 18.929 | 254 | 1830 | 17.3 | 31.9 | 0.054 | 120 | -134 | 0.5 |
| 80 | 13.4 | 19.596 | 263 | 3240 | 15.9 | 31.9 | 0.020 | 67 | -196 | 0.26 |
| 100 | 13.4 | 19.848 | 266 | 5050 | 12.9 | 31.9 | 0.008 | 37 | -229 | 0.14 |

(1) From Table 4, for region only, plus proportional purlins & window costs.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual savings are 0.07
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Auckland only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 22 NPV and benefit cost ratios for the BOP/Waikato event – local costs**

| Present value calculations for BOP/Waikato design event | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Regional costs | | | | | | | | |
| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 5.4 | 4.329 | 23 | 15 | 0.3 | 49.8 | 0.784 | 196 | 172 | 8.4 |
| 20 | 5.4 | 12.462 | 67 | 210 | 2.9 | 49.8 | 0.377 | 378 | 312 | 5.7 |
| 40 | 5.4 | 17.159 | 92 | 820 | 5.9 | 49.8 | 0.142 | 289 | 197 | 3.1 |
| 50 | 5.4 | 18.256 | 98 | 1275 | 6.6 | 49.8 | 0.087 | 224 | 126 | 2.3 |
| 60 | 5.4 | 18.929 | 101 | 1830 | 6.8 | 49.8 | 0.054 | 167 | 66 | 1.6 |
| 80 | 5.4 | 19.596 | 105 | 3240 | 6.3 | 49.8 | 0.020 | 87 | -18 | 0.83 |
| 100 | 5.4 | 19.848 | 106 | 5050 | 5.1 | 49.8 | 0.008 | 43 | -63 | 0.40 |

(1) From Table 4, for region only, plus proportional purlins & window costs.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual savings are 0.03
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Waik/BOP only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 23 NPV and benefit cost ratios for the Wellington event – local costs**

**Present value calculations for Wellington design event.**

**Regional costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 8.4 | 4.329 | 36 | 15 | 0.3 | 115.3 | 0.784 | 452 | 416 | 12.5 |
| 20 | 8.4 | 12.462 | 104 | 210 | 2.6 | 115.3 | 0.377 | 872 | 767 | 8.3 |
| 40 | 8.4 | 17.159 | 144 | 820 | 5.3 | 115.3 | 0.142 | 660 | 517 | 4.6 |
| 50 | 8.4 | 18.256 | 153 | 1275 | 6.0 | 115.3 | 0.087 | 509 | 356 | 3.3 |
| 60 | 8.4 | 18.929 | 159 | 1830 | 6.2 | 115.3 | 0.054 | 376 | 218 | 2.4 |
| 80 | 8.4 | 19.596 | 164 | 3240 | 5.7 | 115.3 | 0.020 | 192 | 28 | 1.2 |
| 100 | 8.4 | 19.848 | 166 | 5050 | 4.6 | 115.3 | 0.008 | 92 | -74 | 0.6 |

(1) From Table 4, for region only, plus proportional purlins & window costs.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings, in Wellington only, constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual savings are 0.02
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Savings at the time of the design event in Wellington only. From Table 5.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 24 NPV and benefit cost ratios for the Canterbury/Otago event – local costs**

**Present value calculations for Canterbury/ Otago design event**

**Regional costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 4.6 | 4.329 | 20 | 15 | 0.3 | 13.4 | 0.784 | 53 | 33 | 2.7 |
| 20 | 4.6 | 12.462 | 57 | 210 | 2.8 | 13.4 | 0.377 | 104 | 46 | 1.8 |
| 40 | 4.6 | 17.159 | 79 | 820 | 5.7 | 13.4 | 0.142 | 82 | 3 | 1.0 |
| 50 | 4.6 | 18.256 | 84 | 1275 | 6.4 | 13.4 | 0.087 | 65 | -19 | 0.8 |
| 60 | 4.6 | 18.929 | 87 | 1830 | 6.7 | 13.4 | 0.054 | 50 | -37 | 0.6 |
| 80 | 4.6 | 19.596 | 90 | 3240 | 6.1 | 13.4 | 0.020 | 28 | -62 | 0.31 |
| 100 | 4.6 | 19.848 | 91 | 5050 | 5.0 | 13.4 | 0.008 | 15 | -76 | 0.17 |

(1) From Table 4, for region only, plus proportional purlins & window costs.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual savings are 0.03
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Cant/Otago only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%

**Table 25 NPV and benefit cost ratios for the Southland/Lakes event – local costs**

**Present value calculations for Southland/ Lakes design event**

**Regional costs**

| Time of EQ Years ahead | Additional construction costs per year new bldgs $M | Discount factor annual series | PV Constn costs $M | Maintenance savings. Numb of years of ann savings Cummulative yrs | PV of maintenance savings $M | Building damage, business disruption injury/fatality savings per year new bldgs $M | Discount factor single event | PV savings $M | Net PV $M | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| 5 | 2.1 | 4.329 | 9 | 15 | 0.1 | 30.3 | 0.784 | 119 | 109 | 13.0 |
| 20 | 2.1 | 12.462 | 26 | 210 | 0.5 | 30.3 | 0.377 | 229 | 202 | 8.7 |
| 40 | 2.1 | 17.159 | 36 | 820 | 1.0 | 30.3 | 0.142 | 173 | 137 | 4.8 |
| 50 | 2.1 | 18.256 | 39 | 1275 | 1.1 | 30.3 | 0.087 | 133 | 94 | 3.4 |
| 60 | 2.1 | 18.929 | 40 | 1830 | 1.1 | 30.3 | 0.054 | 98 | 58 | 2.5 |
| 80 | 2.1 | 19.596 | 41 | 3240 | 1.0 | 30.3 | 0.020 | 50 | 8 | 1.20 |
| 100 | 2.1 | 19.848 | 42 | 5050 | 0.8 | 30.3 | 0.008 | 24 | -18 | 0.57 |

(1) From Table 4, for region only, plus proportional purlins & window costs.
(2) Uniform series present worth factor
(3) Present value of additional initial construction costs for all buildings constructed in the period given. $M
(4) Maintenance savings from stronger roof cladding and ceiling linings. For each year of new buildings the annual savings are 0.004
(5) PV of maintenance savings = Ann savings x column(4) /(1+disct%)^(0.67x column(0)). The 0.67 factor on the years is an approximation and allows for the exponential growth of cummulative annual maintenance savings.
(6) Cost increases at the time of the desig event in Sthld/Lakes only.
(7) = Single payment present worth factor
(8) = column(0) x (6) x (7) + (5)
(9) = (8)-(3) = Net present value for all buildings constructed over the given period, positive values are net savings, negative values are net costs.
Discount rate = 5%