

THE INFLUENCE OF EARTHQUAKE FAULT-LINES ON TOWN PLANNING

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ABSTRACT

This paper is an edited version of a decision by the Planning Tribunal concerning alterations to a building now known to be situated directly on the Wellington Fault. The Tribunal considered the requirements of the relevant zoning in the Wellington City district planning scheme and heard evidence from a number of people, including two structural engineers and a geologist. While the engineering evidence was in conflict, the geological evidence about the Wellington Fault is of general interest and is included here for the benefit of the wider readership.

INTRODUCTION

Towards the end of 1986, the Planning Tribunal heard an appeal by the Ministry of Works and Development concerning an earlier decision by the Wellington City Council to allow the alteration of an existing building at 12-22 Harriet Street, Wellington by converting it into eight residential units.

The decision of the Planning Tribunal was significant in that the appeal concerned the right to build, or otherwise, in the vicinity of a known fault zone. In this case the Tribunal allowed the appeal and thus cancelled the original City Council decision to allow the building conversion to be carried out.

Evidence presented to the Tribunal included geological information about the Wellington Fault together with evidence from two Engineers. The engineering evidence highlighted the uncertainties, or is it simply our lack of understanding of the problems, of building on or near faultlines as one engineer supported the Council decision to allow the building alterations while the other was opposed to it.

BACKGROUND

The existing building is "one of some substance" having been built for commercial-industrial purposes in 1955. The proposals put forward by the applicant came under the conditional use provisions of the Residential C2 Zone of Wellington City wherein the building was situated. The building was unused at the time and had an "ugly utilitarian appearance of multi-storey square slabs hard to the Harriet St frontage and stepping down as the building follows the steep slope of that street."

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In its decision the Tribunal noted that it would normally commend an applicant for proposing to build high quality residential accommodation that was in accord with the general objectives of the zone. However, the Residential C2 zone has a major developmental restraint that is recognised in the Code namely the presence of the Wellington faultline which is active and expected to move with sufficient frequency that it represents an important planning consideration.

THE DISTRICT SCHEME

The objectives of the Residential C2 Zone are (among other things):

"To discourage buildings or uses or additions to buildings or uses that would allow more people to occupy or use land within 20 metres of the Wellington faultline as indicated on the planning maps. The faultline has been indicated as accurately as possible, and, in considering any applications within 20 metres of that line, council will require to be satisfied that either:-

- 1 The faultline can be shown to be not within 20 metres of the site of the application; or

- 2 The application will not increase or intensify the use of the area and that the design of the building is such that they (sic) can be safely erected on the site."

With regard to this particular zoning, the Tribunal notes that in order to enable the council to examine the situation, any use which could otherwise be considered to be a predominant one, but for the fact that it is situated within 20 metres of the faultline, becomes a conditional use. They also note that while word "discourage" is not particularly forceful, it does indicate

that conditional uses will not be considered favourably.

In the view of the Tribunal, the ordinances are framed in a manner which enables the council to accord the development "predominant use status" only if the faultline is proven to be more than 20 metres from the development. If it is within 20 metres, as is the present case, it is caught by the conditional use requirement. While the clause refers to the position of the faultline as "indicated on the planning maps", the Tribunal felt that some flexibility was possible in that the Council could decide in individual cases that the planning maps were incorrect. In addition, the second exception given is a conjunctive clause, namely that the application will not increase or intensify the use of the area and that the design of the building is such that they(sic) can be safely erected on the site.

From this it seems that the clause contemplates (a) a future building and (b) no intensification of site use. In the present case, the Tribunal decided:-

- (a) That the building is squarely on the faultline
- (b) That the proposed residential unit development will increase the intensity of the residential use of the area.
- (c) That the present structure, although strong and sound, is not built to modern earthquake standards. Those standards in any event are not designed to control design of buildings constructed on a faultline. The standards may cope with adjacent or nearby shake effects but could not possibly cope with the shear effect of a fault movement.

In view of this, "The Proposal must therefore be regarded as a conditional use and elements of public safety are undoubtedly paramount in consideration of that use in the present case."

CONCLUSIONS

In reaching their conclusions, the Tribunal noted that the main issue was one of public safety - a concern that was identified within the provisions of the District Scheme.

The matter the Tribunal had to determine was one that fell within a narrow framework. This was should they permit an existing substantial and heavily-reinforced building that had not been constructed to the requirements of modern earthquake codes be converted into residential units having regard to the fact that it straddles a faultline that has recently been plotted with precision. The zoning for the site identified the faultline and sought to discourage any more intensive use of the site.

In trying to resolve this question, the Tribunal noted that the engineering evidence was conflicting though it given by "two highly experienced engineers". The specialist geological evidence about the Wellington Fault that was given to the

tribunal pointed out that in a Force 7 Richter magnitude earthquake, the fault would move with a shearing movement of 3-5 metres (see Appendix A).

The evidence about the Wellington fault indicated that it was regarded as active with probable movement in a Force 7 Richter magnitude earthquake at every point along its length at intervals that were of planning significance. Any such earthquake could be expected to generate high Modified Mercalli shaking near the appeal site (and in most of the central business area) in the vicinity of MM10+. Present day NZ earthquake standards are strict and designed to enable the construction of buildings that will withstand shaking. However, the problem in this case was the shearing action that would give rise to an almost instantaneous movement of 3-5 m. One engineer maintained that the building would not collapse, though it would need to be demolished afterwards. Residents would not be crushed though there may be some falls of concrete caused by the absence of stirrups. The second engineer believed that the movement of the fault and the shaking would damage the foundations, especially the foundation beams that ran at right angles to the fault.

The tribunal went on to point out that even though the present owner of the building may have bought the building without finding out about the nature of the special zoning, the preservation of human life was more important than the the financial implications to the owner. Future occupants of the building would be unlikely to be able to base their use of the building on the sort of evidence heard by the tribunal.

In their conclusions, the Tribunal ended by saying :

"In the present circumstances we are not prepared to adjudicate between the conflicting evidence of two engineers. That being the case we are not satisfied that the building will remain intact in an earthquake of magnitude which is likely to occur in this area. To permit renovation and residential use of a building which does not comply with current earthquake standards would make a mockery of the fault line provisions of the Residential C2 Zone, unless we can be satisfied beyond doubt that the occupants are not subjected to undue danger.

"The appeal is therefore allowed and the decision of the Council cancelled."

The basis of the decision by the Planning Tribunal is worth noting by the Engineering profession, namely, that where there is a conflict in the expert evidence, then that course that best preserves public safety is the one that should be followed.

REFERENCE.

Planning Tribunal, Decision W82/86 in the matter of the Town and Country Planning Act 1977 and in the matter of an appeal under sect.69 of the Act between the Minister of Works and Development (Appeal 212/86) (Appellant) and Wellington City Council (Respondent) and Freemont Construction Limited (Applicant), TCP212/86, October 1986, Wellington.

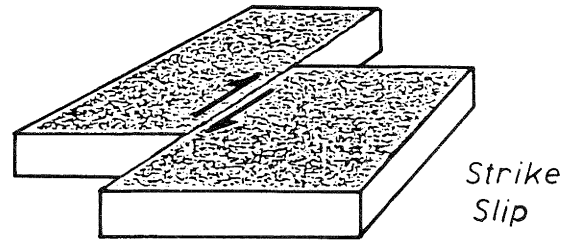


FIGURE 1 BLOCK DIAGRAM, ILLUSTRATING THE STYLE OF MOVEMENT ON STRIKE-SLIP FAULTS SUCH AS THE WELLINGTON FAULT. ROCKS ON ONE SIDE OF THE FAULT ARE SHIFTED HORIZONTALLY IN RELATION TO THE OPPOSITE SIDE.

APPENDIX A

THE WELLINGTON FAULT

This is an edited version of the technical evidence supplied to the Planning Tribunal hearing by K. Berryman, of the N.Z. Geological Survey, D.S.I.R..

INTRODUCTION.

The site that is subject to this Planning Tribunal Hearing straddles the Wellington Fault in Harriet Street, Wellington City. The fault is however a long (more than 300 km), linear, structural discontinuity of the earth that extends a considerable distance away from the site. Information gathered from several locations along the fault are used in this submission to quantify the recent history of movement which in turn has been used in a statistical probability analysis.

REGIONAL CONTEXT.

The Wellington Fault is dominantly a strike-slip fault. During movement along the fault, ground on either side of the fault moves horizontally past ground on the other side with only a small component of vertical movement (see Figure 1). Because of the predominant horizontal sense of movement, landscape features such as streams (see Figure 2) and ridges are displaced and other fault related features formed (see Figure 3).

The major portion of movement on strike-slip faults occurs within a relatively narrow (up to 5 metres) zone of crushed rock and fault gouge. Distortions of the ground do occur with decreasing amplitude away from the plane of primary movement. In several trenches across the Wellington Fault in Upper Hutt the zone of secondary deformation has been seen up to 20 metres from the primary line displacement. Thus a 20 metre wide zone either side of the primary line of displacement is recommended, in the absence of local site information, as a building set-back distance to keep structures for human occupancy outside the zone of intense deformation associated with fault rupture.



FIGURE 2 HORIZONTAL OFFSET OF STREAMS BY THE WELLINGTON FAULT (ARROWED) ABOUT 20 KM SOUTHWEST OF WOODVILLE.

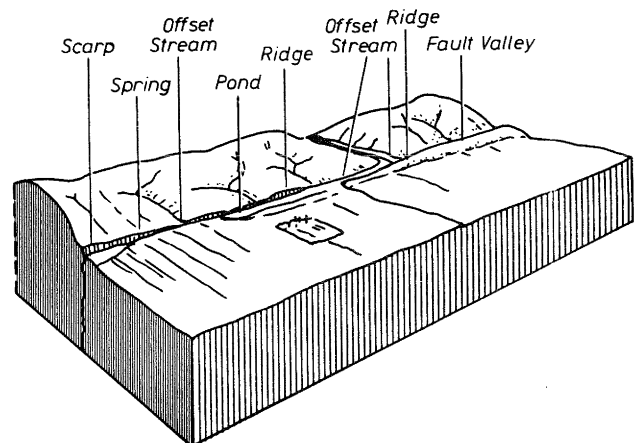


FIGURE 3 LANDFORMS TYPICALLY DEVELOPED ALONG ACTIVE STRIKE-SLIP FAULTS. MANY OF THESE FEATURES CAN BE FOUND ALONG THE WELLINGTON FAULT IN RURAL AREAS OF THE HUTT VALLEY BUT HAVE BEEN SIGNIFICANTLY MODIFIED IN URBAN AREAS.

Another characteristic of strike-slip faults is the continuity over long distances. Although side-steps and bends in strike-slip faults do occur at regional scales, they are remarkably linear features in detail.

The Wellington Fault is a regionally significant feature that has been mapped from the Wellington south coast as far north as Hawkes Bay and with less certainty to the Bay of Plenty. It is classified as a Class I active fault, this being the classification for the most active faults in New Zealand (Ota et al.1981).

The present phase of strike-slip movement on the Wellington Fault began less than 5 million years ago and perhaps less than about 1 million years ago.

LOCATION OF THE WELLINGTON FAULT.

The position of the Wellington Fault, as shown on Wellington City district scheme maps and geological maps published by the DSIR, has been determined by evaluation of the topography disrupted by movement along the fault as illustrated in Figures 2 and 3. At several locations the position of the fault as determined by topographic evaluation has been confirmed by exposure of broken, sheared rock below the surface trace. Such an exposure occurs at the eastern entrance to the Karori tunnel and other observations come from the Hutt Valley.

Within Wellington City urbanisation in the last 140 years has modified and destroyed the surface expression of the Wellington Fault in many places. However, in the vicinity of Harriet Street the fault has been located immediately southwest of Pitarua Street with an estimated accuracy of ± 5 m. Drilling at George Street has revealed a step in rock levels that has been used to locate the fault to ± 18 m. At Burnell Avenue, a surface scarp of the fault has been recorded. Between these isolated locations no positive evidence of the position of the fault is known, but,

considering linear continuity which is characteristic of much of the fault, it is probable that the fault exists as a continuous narrow zone of disruption between Pitarua Street and Burnell Avenue. The position of the fault in this region is shown in figure 4.

CHARACTERISTICS OF FAULT RUPTURE ON THE WELLINGTON FAULT.

There exists considerable topographic evidence along the Wellington Fault that movement takes place episodically, with none of the creep movement that occurs on some faults in California such as on segments of the San Andreas Fault. All historic examples of surface fault rupture in New Zealand have generated large magnitude earthquakes and support the view that fault movement is episodic interspersed between relatively long periods of stability.

Knowledge of long-term average rates of movement and the average or modal size of individual movements along the fault enable estimation of the average recurrence interval of faulting. At Emerald Hill, in Upper Hutt, the Wellington Fault displaces a sequence of river terraces considered to range in age from a few hundred to 140,000 years. The terraces are offset by progressively larger amounts on higher and older terraces. Rates of movement calculated from offsets of several terraces are remarkably consistent at 7.1 ± 1.6 mm/yr. Immediately north of Emerald Hill at Te Marua there is a sequence of low level terraces that record rather small movements along the fault. The smallest, on a low terrace about 2 m above river level is 3.2 m horizontal and is inferred to be the latest movement on the fault. A lower terrace above the modern floodplain is not displaced and although undated is estimated to be several hundred years old. Slightly higher terraces in the same sequence are offset by 7.8, 12.0, 12.4 and 20.0 metres. Differences are the size of successive fault movements which are

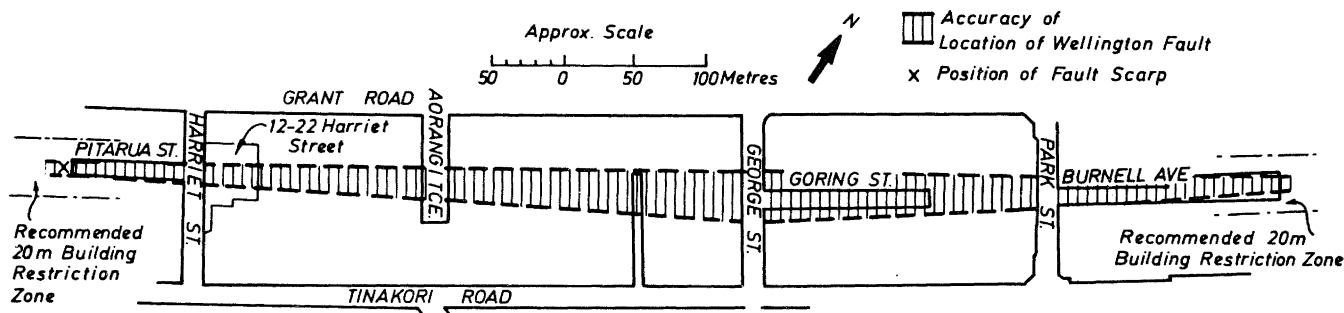


FIGURE 4 STREET PLAN OF THORDON SHOWING THE POSITION OF THE WELLINGTON FAULT FROM PITARUA STREET TO BURNELL AVENUE. THE WIDTH OF A ZONE OF UNCERTAINTY IN THE EXACT LOCATION OF THE FAULT IS SHOWN AS IS THE RECOMMENDED 20 M WIDE BUILDING RESTRICTION ZONE IN THOSE AREAS WHERE THE FAULT HAS BEEN LOCATED.

3.2, 4.6, 4.4, and 8.0 (probably 2 events of c. 4.0) metres from youngest to oldest. An average value of 3.9 ± 0.7 metres displacement per event is therefore assessed as the common or characteristic increment of faulting. Combining these data with an average slip rate of 7.1 ± 1.6 mm/yr yields an average recurrence interval of faulting in the range of 370-840 years with a preferred value of about 560 years.

Another important implication of the large offsets at Emerald Hill is the recurrence of faulting for over 140,000 years along the same plane of weakness, the Wellington Fault. The 900 m offset at Emerald Hill may represent as many as 225, 4 m increments of faulting, all within a narrow zone of dislocation only a few metres wide.

Although these data are obtained from Upper Hutt, approximately 35 km northeast of Wellington City, they are pertinent to the assessment of hazard at the Harriet Street site since, for the size of the fault movements suggested, 60-100 km of the Wellington Fault could be expected to rupture at any one time.

PROBABILITY OF FUTURE MOVEMENT OF THE WELLINGTON FAULT.

The analysis of earthquake fault hazard probabilities has, in the scientific literature, usually considered that the probability of occurrence of an earthquake is constant with time. The probability is therefore estimated as the reciprocal of the average recurrence interval of the event, multiplied by the time interval of the period of interest. The equation would take the form

$$p = \frac{1}{R} \times T \quad (1)$$

where p is the probability of the occurrence of an event, R is the average recurrence interval of that event, and T is the time period of interest (commonly 100 years for residential construction, longer for critical construction up to perhaps 1000 years for nuclear power plants).

However detailed studies of the history of movement along active faults have shown a different behaviour, with regular spacing of fault movement events through time. The history of the Wellington Fault, as described above, fits this pattern of fault behaviour. Therefore the hazard of fault rupture will vary with time and depend on the time that has elapsed since that most recent fault movement (the elapsed time). Rhoades and Millar (1983) presented a methodology for calculating faulting probabilities taking into account the characteristic fault rupture model as exemplified by the data presented by Ando (1975) from the Nankai Trough in Japan and by Sieh (1978) from the San Andreas Fault in California. The probability equation takes the general form

$$p = \frac{K}{R} \times T \quad (2)$$

where p , R and T are the same as in equation 1 and K is a variable that enhances the probability dependent on the time interval

since the most recent fault movement. The variable K has a value of 1 when the elapsed time is about 0.5 times the average recurrence interval, increases to 2 when the elapsed time equals the average recurrence interval and has an upper limit of about 5 for elapsed times of at least 1.5 times the average recurrence interval.

Data to establish the elapsed time since the last movement on the Wellington Fault in the Wellington region are sparse. Certainly there has been no movement since European settlement about 140 years ago and it is subjectively assessed that river terraces that cross the fault in Upper Hutt and that are not displaced are probably several hundred years old. At Petone, the Wellington Fault is mapped as far south as the beach ridge formed at about 1460 AD (Stevens 1974, see Figure 5). The most recent fault movement was therefore at least about 530 years ago. Values of the variable K may therefore be $1 < K < 5$. Corresponding probability estimates of fault rupture in the next 100 years are presented in Table 1. Values range from at least 12% to perhaps more than 80% with a preferred value of at least 36%.

COMPARISON OF FAULTING HAZARD WITH OTHER NATURAL HAZARDS -

WHAT IS AN ACCEPTABLE RISK ?

The probability of occurrence of earthquakes and fault movement provide a valid insight into appropriate levels at which fault movements should be dealt with in planning.

In Canada, building codes have been developed so as to accommodate ground shaking from the largest earthquakes that have a probability of about 10% in 50 years (Basham et al. 1982). Similarly the Seismic

TABLE 1 : PROBABILITY ESTIMATES OF RUPTURE ON THE WELLINGTON FAULT IN THE NEXT 100 YEARS.

Average Recurrence Interval (yrs) ⁽¹⁾	Elapsed time (yrs)	K ⁽²⁾	Probability (%) ⁽³⁾
370	>530	5	>80
560 ⁽⁴⁾	>530	2	>36 ⁽⁴⁾
840	>530	1	>12

NOTES

- (1) from section on the characteristics of fault rupture on the Wellington Fault;
- (2) all values of K are minimum values since only a minimum value for elapsed time is known;
- (3) probabilities are minimum values;
- (4) preferred value.

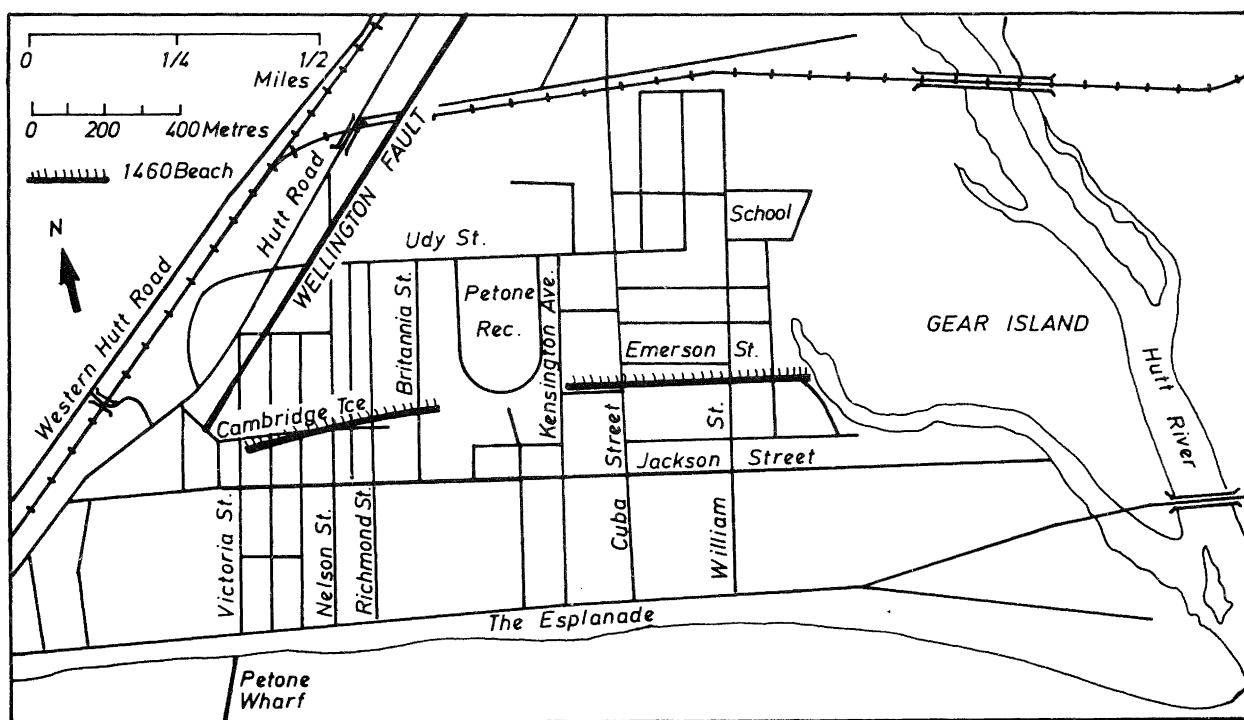


FIGURE 5 SKETCH MAP OF PETONE SHOWING THE LOCATION OF THE PROMINENT SHORELINE FEATURE CONSIDERED TO DATE FROM AD1460 (AFTER STEVENS 1974) AND THE EXTENT OF THE WELLINGTON FAULT. THE FIGURE SHOWS THAT THE WELLINGTON FAULT CANNOT BE FOUND SEAWARD OF THE AD1460 SHORELINE INDICATING THAT THE WELLINGTON FAULT HAS NOT MOVED SINCE THAT TIME, ABOUT 530 YEARS AGO.

Risk Subcommittee of the New Zealand Standards Association has recommended that the hazard presented by the maximum surface magnitude earthquake with a 450 year return period should form the basis of seismic loading aspects of the current review of building codes (Matuschka et al. 1985). Using statistical relationships of earthquake recurrence in New Zealand developed by Smith and Berryman (1983) this 450 year return period earthquake has a probability of occurrence of 5-10% in 50 years. Thus the levels of earthquake hazard accepted by society in both Canada and New Zealand are in the range of 5-10% probability of occurrence in 50 years.

The probability of rupture on the Wellington Fault in the next 100 years is in the range 11-88% with the preferred value of about 36% or 18% in 50 years. Clearly if the hazard from earthquake shaking is to be routinely dealt with by society by the implementation of building codes to protect those people at risk then the hazard presented by rupture on the Wellington Fault must also be dealt with. The hazard due to faulting is not as widespread as the hazard due to earthquake shaking, it is localised to the immediate vicinity of the surface rupture but the results are more predictable and the only mitigation measure is the avoidance of developing structures for human occupancy on that linear parcel of land that will be disrupted by faulting.

The Curtis Building at Harriet Street, Wellington is within the linear strip of land at risk from movement of the Wellington Fault. The probability of occurrence of fault rupture is of the same order as other hazards, such as earthquake shaking, that society has in general considered it must mitigate against.

CONCLUSIONS

1. The Wellington Fault is a major, Class I active, strike-slip fault.
2. The Wellington Fault passes, with a high degree of certainty, beneath the Curtis Building at 12-22 Harriet Street, Wellington.
3. Characteristic movement along the Wellington Fault is episodic with rupture of about 4 metres occurring at time intervals in the range 370-840 years with a preferred recurrence interval of 560 years.
4. Recurrent movement on the Wellington Fault, at several sites in the Hutt Valley, has been restricted to a narrow zone of primary dislocation only a few metres wide and a zone of secondary deformation extending approximately 20 metres either side of the primary rupture. These characteristics are expected to also apply to the fault in the vicinity of Harriet Street.

5. The probability of rupture on the Wellington Fault in the next 100 years is assessed to fall in the range of at least 12% to possibly more than 80% with a preferred estimate of at least 36%.

6. The probability of fault rupture in the time span of the development proposed at the Curtis Building is comparable to the probability of the level of earthquake shaking that is mitigated against by building design codes.

7. The hazard of movement along the Wellington Fault should also be mitigated against since it is an identifiable hazard of a level similar to other earthquake related hazards that society in New Zealand has considered it must protect itself from.

8. Mitigation of the fault rupture hazard involves avoidance of the linear strip of land, for human occupancy, in the immediate (20 metres) vicinity of the active fault.

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