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Building Adjacent to Active Faults: A Risk-based Approach

A.B. King

BRANZ Ltd., Porirua

D.R. Brunsdon

Spencer Holmes Ltd, Wellington

R.B. Shephard

Seismic Consultants Ltd., Kapiti

J.E. Kerr & R.J. Van Dissen

Institute of Geological and Nuclear Sciences, Lower Hutt

ABSTRACT: Earthquake fault rupture of the ground surface increases the risk of collapse for buildings which straddle that fault compared with other buildings. The lack of any clear regulatory constraints to control this additional risk was identified as a deficiency in the current building control regime in New Zealand by the Parliamentary Commissioner for the Environment during his investigation into this issue reported in 2001.

A working group was established under the auspices of the Ministry for the Environment to prepare a set of planning guidelines to address this deficiency. This paper discusses the technical considerations used to prepare a risk-based interim guideline which aims to provide planning authorities with a framework to prepare planning controls for this aspect of land development. The paper briefly outlines the seismological issues such as fault recurrence intervals and complexity, the engineering issues relating to building importance classifications and consistency of risk posed by an event, and the proposed mitigation measures, including planning controls on development and land subdivision.

The paper reflects the approach taken in developing the draft Interim Guidelines (hereafter referred to as 'the Guidelines'). As such it portrays 'work in progress' with further amendment and wider consultation expected before the final guideline is available for use by planning authorities to address the issue of building over or adjacent to active faults.

1 INTRODUCTION

In earthquake prone regions such as New Zealand, buildings are usually designed to withstand earthquake ground shaking effects but rarely the effect of surface fault rupture. Neither is it universal for such actions to be considered for planning restrictions which may avoid building in such locations. In those few cases in New Zealand where the issue has been considered within a District Plan, the restrictions imposed have largely been ad hoc with little, if any, consistency between schemes.

An active fault within a building site constitutes an increased hazard to building safety compared to other sites where such a feature is not present. This, along with concerns regarding the inconsistent application of planning constraints allowing subdivision, were the subject of an investigation by the

Parliamentary Commissioner for the Environment in 2000. The key findings and recommendations from the March 2001 PCE report entitled *Building on the Edge – The Use and Development of Land On or Close to Fault Lines* (Parliamentary Commissioner for the Environment, 2001) included:

- Buildings across faults that rupture will be more badly damaged than adjacent buildings and that there is no technology to prevent such damage.
- Despite the responsibilities of territorial authorities for subdivision and land use few identify and plan for seismic hazards.
- Practical guidelines are urgently needed to mitigate the additional risk posed by such features.

In response to the last recommendation, the Ministry for the Environment (MfE), Institute of Geological and Nuclear Sciences (GNS) and the NZ Society for Earthquake Engineering (NZEE) established a project working party to prepare guidelines for policy and consent planners, and technical advisers.

This paper outlines the procedure adopted in the development of the draft Guidelines which, at the time of preparation of this paper, are about to be released for comment to a wider industry interest group. As such, several key parameters mentioned in this paper are expected to be the subject of further discussion and possible change. The approach outlined in this paper is, however, expected to remain unaltered.

2 BACKGROUND

Allowance for the additional risk posed by fault rupture falls between the scope of the Resource Management Act 1991 (RMA) which determines planning constraints on building subdivisions, and the Building Act 1991 which determines, by reference to various engineering standards, design actions which buildings are expected to resist without collapse.

The Building Act provides the regulatory framework for buildings in New Zealand. The New Zealand Building Code (NZBC) is called up within the regulations that accompany the Building Act. It cites various New Zealand standards as verification methods which designers are expected to use to determine the actions imposed on buildings (i.e. the Loading Standard, NZS 4203 (Standards New Zealand 1992)) and their resistance to those actions (i.e. the suite of engineering material standards). Subdivision approval is controlled by the RMA. While the primary consideration of such approval is the effect of the subdivision on the environment, there is an implicit assumption that each site will include a location that is suitable as a building platform. The RMA, through its environmental effects based planning processes, was thus considered the appropriate vehicle to introduce controls relating to safety related near fault effects.

The project working party determined that building safety relating to fault rupture should be considered in a similar context to other extreme loading conditions (e.g. extreme wind loads, earthquake shaking effects). Adoption of a risk-based approach based upon the principles established for other loads in the NZ Loading Standard, NZS 4203 was considered appropriate. Consideration of the recurrence interval of those loads and the acceptable building response to those loads strongly influenced the Recurrence Interval Classes (RIC) subsequently used to classify fault effects (see Section 5.8 Table 3).

A preliminary meeting of interested industry sectors was initiated by the Ministry for the Environment in December 2001. In attendance were representatives from various territorial authorities (from the Wellington, Kapiti and Wairarapa regions), and various technical interest groups from both the geological/seismological sector and the building sector. At a follow-up meeting in February 2002 GNS were charged with project managing the preparation of the Guidelines, and two technical subcommittees were established to provide input for the working group.

3 THE RISK BASED APPROACH TO PLANNING CONTROLS

Although there is general agreement that building across known hazards such as active faults should be avoided, there is no single approach that can be adopted because of the implications of past planning decisions. The Guidelines take this into account by recognising that different approaches are needed to mitigate fault rupture hazard in Greenfield sites compared to those areas that have previously been subdivided or developed (i.e. where there is an expectation to build). This gives rise to the following overarching principles:

Principle 1 - Gather accurate active fault hazard information

Principle 2 - Plan to avoid fault rupture prior to subdivision (Greenfield sites)

Principle 3 - Take a risk-based approach in areas already subdivided or developed

Principle 4 – Communicate risk in built up areas subject to fault rupture

For sites already subdivided or developed, the risk-based approach adopted within the New Zealand Loading Standard, NZS 4203, was adopted as appropriate to address control measures for fault rupture safety. The essence of this approach was that the characteristics of the fault need first be established and, in conjunction with the acceptable risk to the building, would provide a range of control measures which could be used to ensure consistent levels of building safety were achieved.

The Earth Science Subcommittee provided advice on the seismic characteristics of NZ's faults (i.e. average recurrence interval, probable surface dislocation, and displacement extent and character) which enabled them to be grouped into the appropriate Recurrence Interval Class. Their findings are discussed briefly in Section 5 of this paper and in more detail (Van Dissen et al 2003).

The Engineering Subcommittee developed the Near Fault Building Importance Categories which, when taken in conjunction with the Recurrence Interval Class of the fault system present, provide a rational basis upon which appropriate mitigation measures, which may include planning controls, can be developed.

The Guidelines are presented in a manner that takes a risk-based approach to reflect the additional hazard created by the presence of an active fault. It acknowledges that, for faults with a long recurrence interval (i.e. well in excess of the risk posed by other actions) no specific control measures are warranted. In other cases, the control measures presented vary according to Recurrence Interval Class of the fault (see Table 3) and the Building Importance Category (see Table 2). Such measures are expected to range from permitting development without constraint, to controlled or discretionary use (which allows for placing controls on, or refusing, proposed developments and is likely to be influenced by the structural form or additional robustness included in those buildings which straddle the fault as well as site specific conditions) to non complying use where, because of the importance of the building to the community, and the active state of the fault even the remote possibility of surface rupture should be avoided with any development carefully considered and consulted on.

4 GUIDELINE PRINCIPLES

The following principles were used in preparing the Guidelines:

- The guidelines apply to developments within the earthquake fault control zone, (assumed to be within 20m of the fault zone – see Figure 1) when the Recurrence Interval Class of the fault is within the range of significance for the development type and the Building Importance Category which will be permitted.
- The presence of all active faults within this development is to be registered on the Land Information Memorandum (LIM) in sufficient detail to enable to the Fault Recurrence Class interval and its complexity classification to be established if such detail exists.
- Mitigation measures are only required when the Recurrence Interval Class of the fault present

at the site is within the range of significance for buildings within the Building Importance Category for which the development application is being sought.

- The mitigation measures appropriate for a specific site is also influenced by the Complexity of the fault's surface expression, with well defined faults likely to be subjected to greater controls (since their location is well established and avoidance through alternative site layout a realistic option, while expressions which are ill defined or uncertain do not present such an opportunity.
- Mitigation measures include regulatory planning methods, non-regulatory methods or enhanced technical means which can accommodate imposed deformations.

5 FAULT CHARACTERISTICS

5.1 *General*

In the Guidelines, the rupture hazard of a fault at a specific site is characterised by two parameters: a) the average recurrence interval of surface rupture of the fault (i.e. its Recurrence Interval Class), and b) the Complexity of its trace. For more detail regarding these two parameters, and how they are applied in the Guidelines (see Van Dissen *et al*. 2003).

5.2 *Fault recurrence interval*

The average recurrence interval of surface rupture of a fault is the average amount of time (years) between successive surface ruptures on that fault. It is the parameter chosen in the Guidelines to represent/describe the relative likelihood of rupture of the fault, and compared to other parameters such as fault slip rates and timing of past movements, it is the one that relates most directly to the risk-based approach to hazard mitigation adopted in the Guidelines.

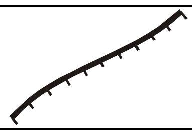
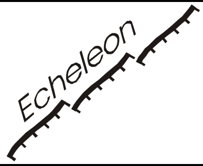
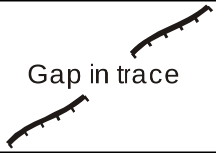
While it is acknowledged that there is some degree of uncertainty in the assessment of fault recurrence interval, especially for faults with long recurrence intervals, the vast majority of earthquake hazard, including rupture hazard, results from movement on the principal active faults in New Zealand (i.e. those faults with average recurrence intervals less than 2000-3500 years, see Van Dissen *et al*. 2003). Fortunately, it is these faults for which there are typically the best recurrence interval information. Nevertheless, assessment of recurrence interval at times embraces significant uncertainty and professional judgement. Thus, while discrete Recurrence Interval Classes are prescribed in the Guidelines, these should be treated with discretion.

Specific fault studies undertaken over recent years indicate that surface rupture will, in the main, re-occur along the location of previous ruptures. Also, the surface rupture characteristics (e.g. amount of displacement, and complexity of rupture) verified during such studies are considered to be a reasonable basis for characterising future events. The influence of the building itself (surcharge pressure and rigidity of the footing) on the surface expression/location of the rupture is not well understood and therefore at this stage has not been addressed in the Guidelines.

5.3 *Fault complexity*

The complexity of surface fault rupture can vary considerably along the length of fault rupture. Three Fault Complexity Classifications are provided in the Guidelines, as indicated in Table 1, and defined based on complexity of fault rupture and/or the (un)certainty of fault location. Different planning controls are suggested for each complexity class (see Table 4). The controls have generally been agreed on regarding the case of a 'well defined' definitive surface trace. However, at the time of writing, there is still debate as to the appropriate controls to be placed, if any, on potentially large areas of land where fault location can be implied (often from adjacent features), but location is uncertain and cannot 'readily' be established at the specific site.

Table 1 Fault Complexity Classification

A Well Defined	- A well defined fault trace of limited geographic width - Typically metres to tens of metres wide	
B Distributed	- Deformation is distributed over a relatively broad geographic width - Typically tens to hundreds of metres wide - Usually comprises multiple fault traces and/or folds	
C *Uncertain*	- Location of fault trace(s)is uncertain as it either has not been mapped in detail or it cannot be identified, typically as a result of gaps in the trace(s) or erosion or coverage of the trace(s)	

5.4 *Control Zones*

Fault rupture typically comprises a zone of ground damage, with the severity of ground damage diminishing either side of the zone. As with overseas practices, the creation of a control zone which extends 20 m either side of the 'fault zone' was considered appropriate (refer Figure 1). The implications of such a zone on what is often an already uncertain region which is sometimes quite wide in breadth may be difficult to accommodate as a realistic control measure. However, the converse of identifying the actual fault trace and building located immediately along side the feature also appears indefensible, with the 20 m wide control zone being the agreed compromise.

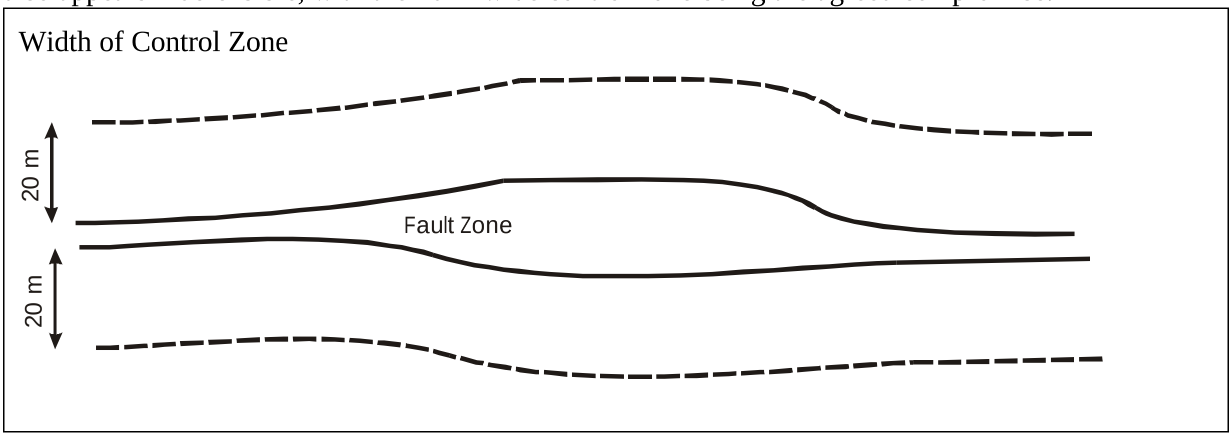


Figure 1 Fault Adjacent Planning Control Zone

6 BUILDING CLASSIFICATION PROCEDURES

6.1 *Principles which apply to actions on buildings*

As indicated in the introduction, the Guidelines have been developed to ensure consistent levels of safety against building collapse are maintained for fault rupture effects and the effect of other actions. The Guidelines follow principles established in building control legislation.

The recently published joint Australian/NZ standard AS/NZS 1170 (Standards Australia and New Zealand 2002) outlined a uniform risk approach used to reflect acceptable levels of safety and was used as the basis for the Guidelines. This revision is expected to be cited within the New Zealand regulatory framework in 2003. The risk-based approach recognizes public expectations that important and critical post-disaster buildings will have a lower probability of collapse than ordinary buildings. This expectation is expressed as annual probability of exceedence of design actions. For ultimate limit state (i.e. collapse avoidance) these annual probabilities range from 1/500 years (for ordinary buildings) to 1/2500 years (for critical post-disaster buildings).

6.2 *Near Fault Building Importance Categories*

The Near Fault Building Importance Categories are presented in Table 2. They were developed to be consistent with those published in the joint Australia/NZ loading standard, AS 1170. However, Category 2 (Buildings of normal occupancy) has been expanded to separate timber framed single storey residential Category 2a buildings (which represent the vast majority of New Zealand houses) from other Category 2b buildings. This was in recognition that this subclass of building has traditionally performed very well during earthquakes to the extent that even severe ground dislocation is not expected to result in overall building collapse. Buildings of greater importance to the community, being Category 3 buildings, are typically those which are places of assembly, schools, etc. and Category 4 buildings being critical facilities such as hospitals, civil defense operational headquarters, ambulance stations, etc.

Table 2 Near Fault Building Importance Categories

Near Fault Building Importance Category	Description	Examples
1	Structures presenting a low degree of hazard to life and other property	- Structures with a total floor area of <30m^2 - Farm buildings, isolated structures, towers in rural situations - Fences, masts, walls, in-ground swimming pools
2a	Residential timber-framed construction	- Timber framed single-story dwellings
2b	Normal structures and structures not in other categories	- Timber framed houses of plan area >300 m2 - Houses outside the scope of NZS 3604 "Timber Framed Buildings" - Multi-occupancy residential, commercial (including shops), industrial, office and retailing buildings designed to accommodate less than 5000 people and also those less than 10,000 m2 gross area. - Public assembly buildings, theatres and cinemas of less than 1000 m2 - Car parking buildings
3	Structures that, as a whole, may contain people in crowds or contents of high value to the community or pose risks to people in crowds	- Emergency medical and other emergency facilities not designated as post disaster facilities - Airport terminals, principal railway stations, correctional institutions, schools, colleges, universities - Structures designed to accommodate more than 5000 people - Public assembly buildings of more than 1000 m^2 - Shopping centres with covered malls with over 10,000 m^2 gross area excluding parking - Public museums and art galleries of more than 1000 m^2 - Municipal buildings, community record stores - Grandstands for more than 10 000 people - Service stations - Chemical storage facilities 500m^2
4	Structures with special post disaster functions	- Major infrastructure facilities, - Air traffic control installations - Designated civilian emergency centres, medical emergency facilities, emergency vehicle garages, fire and police stations, etc.

7 PROPOSED PLANNING CONTROLS IN NEAR FAULT ZONES

The Guidelines adopt a risk management approach as the basis of planning controls associated with development proposals or subdivision consent when active faults are within or adjacent to a prospective building site. Broadly, such an approach is encouraged to follow the following procedure:

- Ascertain whether it is reasonable to anticipate that a fault is present within the development
- If the site is not currently 'zoned' for residential, industrial or commercial development, then any future re-zoning application should accommodate the fault and control zone (upon further investigation) within road or other reserve areas (i.e 'no build' areas).
- If the site is currently zoned for such development (ie. there is an expectation to build), and such a fault can be reasonably anticipated, ascertain the Recurrence Interval Class of the fault by considering:
    - The recurrence interval of movement on this specific fault
    - The Near Fault Building Importance Category of the proposed use of the development
- If current information of the site and its environs indicate the fault be classified as Active, then a field investigation may be necessary to
    - Verify the location of the fault
    - Ratify the recurrence interval
    - Confirm the complexity of the surface expression.

Determine, by reference to a set of tables such as Table 4 Example of Possible Planning Controls 5000 to 10000 yr recurrence event

- the planning controls and possible engineering measures which could be adopted to mitigate the additional risk posed by the presence of the fault.

Table 3 Importance Category against Active Fault Recurrence Interval Classes

Building Importance Category	Recurrence Interval Classes (Average Recurrence Interval (Years))	
	Previously Subdivided and/or developed sites	"Greenfield" Sites
Category 1 – Temporary Buildings	RIC Ia (< 2000 yrs)	RIC Ia & Ib (< 3500 yrs)
Category 2a – Single storey wood framed residential buildings	RIC Ia & Ib (< 3500 yrs)	RIC Ia Ib & IIa (< 5000 yrs)
Category 2b – Normal buildings	RIC Ia Ib & IIa (< 5000 yrs)	RIC Ia Ib IIa IIb & III (< 10,000 yrs)
Category 3 – Important buildings	RIC Ia Ib IIa IIb III & IV (< 20,000 yrs)	RIC Ia Ib IIa IIb III & IV (< 20,000 yrs)
Category 4 – Critical buildings	RIC Ia Ib IIa IIb III IV & V (< 100,000 yrs)	RIC Ia Ib IIa IIb III IV & V (< 100,000 yrs)

Within Table 4 several categories of 'Permitted Use' are marked with an asterisk to indicate that in circumstances where the fault is well defined many control authorities may feel inclined to impose a 'Controlled Use' classification even though the risk-based approach would strictly exempt higher Recurrence Interval Class faults from requiring such controls. The well recognised presence of such features and the relatively control zone width would, in many cases be considered a reasonable compromise.

Table 4 Example of Possible Planning Controls 5000 to 10000 yr recurrence event

Possible Planning Constraints for RIC IIb (5000 to 10000 yrs)											
		Developed Site					Greenfields Site				
	Importance Category	1	2a	2b	3	4	1	2a	2b	3	4
A Well defined		P	P*	P*	N	N	P	P*	D	N	N
B Distributed		P	P	P	N	N	P	P	C	N	N
C Uncertain		P	P	P	N	N	P	P	C	N	N

P = Permitted Use C = Controlled Use D = Discretionary Use N = Non Complying

8 CONCLUSIONS

The Guideline, although still in draft form and likely to be subjected to minor change, successfully encapsulates a risk-based approach to the application of planning controls for rare events with potentially serious consequences. It is expected that planning controls of the future which adopt the procedures outlined will provide a level of control which is consistent with the potential hazard present, with some regard to other loading conditions and hazards considered acceptable by the community.

The development of the Guideline has brought the earth science, engineering advisors and planners together and lead to an appreciation of their respective approaches and the degrees of accuracy and reliability implicit within their respective decision making processes. As a result of the publication of the Guidelines, the planning community can feel confident that future changes in planning control regimes have a defensible position with regards the levels of controls engaged without being unduly draconian.

REFERENCES:

Parliamentary Commissioner for the Environment, 2001, Building on the edge: the use and development of land on or close to fault lines. *Office of the Parliamentary Commissioner for the Environment (New Zealand*), 30 pp. (ISBN: 0-908804-96-2).

Kerr, J., Nathan, S., Brunsdon, D., King, A., Van Dissen, R. 2002. Interim guidelines: Planning for development of land on or close to active faults. *Institute of Geological & Nuclear Sciences Client Report* 2002/124 (prepared for Ministry for the Environment, New Zealand).

New Zealand Government (NZBC), 1992. Regulations to the Building Act. *New Zealand Government Printer*, Wellington

Standards New Zealand, 1992. NZS 4203 Loadings Standard, Standards New Zealand, Wellington.

Smith W.D. 1995. A development in the modelling of far-field intensities for New Zealand earthquakes. *Bulletin of the New Zealand Society for Earthquake Engineering.* 28 (3). 196-217.

Van Dissen R.J., Berryman K., Webb T., Stirling M., Villamor P., Wood P.R., Nathan S., Nicol A., Begg, J. Barrell D., McVerry G., Langridge R., Litchfield N. & Pace B. 2003. An interim classification of New Zealand's active faults for the mitigation of surface rupture hazards. *Proc. Pacific Conference on Earthquake Engineering, Christchurch.* Paper 155.

Standards Australia/Standards New Zealand 2002, AS/NZS 1170.0 Structural Design Actions Part 0 General Principles. Standards New Zealand, Wellington.