

SUPPLEMENTARY TO SUBMISSION FROM COLIN J MORRIS

Introducing supporting evidence from Jocelyn Campbell

Qualifications and Experience

1. Full name: Jocelyn Karen Campbell
2. M.Sc. (First Class Honours) in Geology from the University of Canterbury graduating in 1964
3. From 1968 I was on the academic staff of the Department of Geological Sciences at the University of Canterbury retiring at the end of March of this year. I still retain research and graduate student supervision roles with the Department. My primary teaching area has been in Structural Geology, but I have taught undergraduate and post graduate courses not only in this field, but in Engineering Rock Mechanics, Quaternary Stratigraphy, Petrology, Tectonics, Tectonic Geomorphology, Field Mapping and related fields. I have been principal, or co-supervisor, for 30 or more thesis projects.
4. In 1989 Dr Jarg Pettinga and I established the Canterbury Active Tectonics Research Programme to address the whole area of active deformation and seismic hazard extending through Canterbury, Marlborough, into parts of Nelson and the West Coast by a systematic programme of regional structural mapping, tectonic geomorphic analysis and site specific characterisation of active faults. The database of active faults held by Ecan and to a large extent by Geological and Nuclear Sciences (GNS) for these areas are drawn from this programme.
5. In the last few years I have been closely involved in the investigation of active deformation occurring close to, and beneath the Canterbury Plains which includes all the theses from which data have been drawn for the Stirling et al. (2007) report from which the Seismic Hazard Assessment upgraded data are derived, quoted by Mc Morran in his submission on the URS site investigation, together with others which were not referenced but contain pertinent data. I am currently involved in research and thesis supervision on active faulting and folding in close proximity to the area of interest. I am also involved

in collaboration with a geophysics programme of graduate students who visit New Zealand each summer from ETH Zurich and have now completed seismic reflection lines down both sides of the Waimakariri River from the Kowai River junction to southeast of the Hororata Fault. This includes the areas of the proposed tunnel and headrace canal. These lines are still being processed as a PhD project and are not yet in the public domain.

**NOTES TO ACCOMPANY SUBMISSION BY COLIN MORRIS
IN RELATION TO PROBABALISTIC SEISMIC HAZARD ASSESSMENT
AND DAM SAFETY ASSURANCE**

INTRODUCTION

1. I have been asked by Colin Morris to comment on the validity of points relating to his submission that include some that draw on his conclusions from reading technical resource materials outside his professional area of expertise. These concern aspects of geology and seismology as they relate to the CPW scheme. In particular he has questions on the reliability of seismic hazard assessment and geotechnical aspects of safety concerning the dam and related canals. Before preparing his submission, he discussed with me the degree to which methods of estimating the likely magnitude and frequency of damaging earthquakes on active faults are inexact. He also has legitimate concerns about the risks to population centres such as Coalgate, downstream of the dam, given historical statistics on dam failures.

2. METHODOLOGY OF CHARACTERISING ACTIVE FAULTS

- a. He is quite correct in his conclusion that assigning figures to the likely return periods and magnitudes to active faults are approximations and provide only a broad guide to the relative level of activity on different faults for two reasons.
3. Faults do not normally rupture at regularly spaced intervals with consistent

magnitudes, so that quoted figures for recurrence intervals are based on average return periods where the paleoseismic record is sufficiently long, or by statistical and indirect methods. Magnitudes are quoted as being the expected maximum energy release for a fault of a given character and rupture surface dimensions and is related to the size of the coseismic displacement. At times more frequent, but smaller, displacements may be interspersed with long intervals often accompanied by a larger break.

4. Few active faults have a complete and comprehensive historic and prehistoric record from which a base of accurate quantitative data can be drawn up to determine the full set of parameters needed to characterise them reliably. This is particularly the case in New Zealand with a short historic record and, until recently, inadequate instrument coverage so that most major faults are documented only by paleoseismic interpretation of past ground displacements, or by methods where empirical relationships are used to derive the parameters indirectly as outlined below.
5. These limitations are understood by those working in this field and with the application of the data, but frequently the estimated figures become simplified and often presented in tabulated form without discussion or quoted error estimates by the time they enter the general public domain, as in the URS presentation of McMorran. Here they may be accepted at face value.
6. McMorran will have been aware of these points, but legitimately could use data in the only form available, that is, quoted from Geological and Nuclear Sciences' (GNS) tabulated database of active faults. This currently comprises a listing of 133 faults (by no means complete) used as seismic sources for their nationwide Probabilistic Seismic Hazard Assessment model, referring specifically to the 2007 update on the Canterbury Region prepared for Environment Canterbury (Stirling et al., 2007). The methodology used has been evolving since the late 1990's (Stirling et al., 1998) but it is worth noting the way in which the parameters in the database tabulation, including estimates of recurrence interval and magnitude, have been calculated from two basic measurements, the length (L) of the fault plane determined from field mapping and down dip crustal thickness width (W). Consequently all derived data depend on the accuracy with which these are identified. Slip-rate is the

only independently determined measure and may be made from field observation or by an indirect method involving the statistical allocation of regional strain rates, which is not explained in either reference. Direct measurement of some properties such as the dates and magnitudes of events from historic or paleoseismic events allow for comparison and modification of the derived data, but the availability of good quality data is commonly limited to a small proportion of the faults listed. These methods have provided a useful general comparison for the probability of experiencing given values of spectral ground accelerations within a given period of time e.g. 50 years at a first order approximation on a national scale. It has limitations where the real uncertainties relating to the detail of complex linkages, mechanisms and stress loadings on local scale fault systems, such as the Canterbury range front network, have to be interpreted from a slender database of direct observations.

7. REVIEW OF LOCAL FAULT ZONES

8. In the revision of the Canterbury Seismic Hazard Assessment, a number of points relating to the treatment of local source models need to be raised. Only those in the immediate vicinity of the CPW scheme are discussed here.
9. There has been a policy of amalgamating faults in a zone together as single long faults e.g. Porters Pass, Springfield, Cust and Springbank-Hororata Fault Zones. In reality these are strongly segmented systems of imbricated, branching and overlapping surface breaks that are complexly linked at depth. For example the Porters Pass Fault (27 km from dam site) was changed from the segmented model used in 1999 to a single source “Porters to Grey” because “our methodology produces recurrence intervals that best match the paleoseismically-derived estimates”. This simplification hides the reality of a complex history of ruptures which appear to affect part or all of this zone at different times, and there are some indications that slip rates have accelerated in the last 2,000 years with a correspondingly shorter recurrence intervals than the 1500 years indicated. In Stirling et al (2007), only the Alpine Fault takes into account the elapsed time since the last rupture in 1717 to be incorporated into the expected probability of damaging ground accelerations within the time brackets specified (50, 150, 475 and 1000 yrs). The elapsed time since the last event on the Porters Pass Fault is between 500 and 600 years ago and

could equally well be taken into account.

10. The Springfield Fault (14 km from dam) is not located where shown in yellow on Fig. 4 in the McMorran report. It is strictly only a strand on the south side of the Waimakariri River passing into the head of the Hawkins River Valley at Dalethorpe and overlapped by another segment around the face of Bell Hill. This is a site where recent research has demonstrated the growth of a substantial scarp where some 6 to 8 uplift events have taken place, probably within the last 18 to 20 thousand years, half the recurrence interval of the 5,200 years allocated in the GNS database and again with a significant, but not accurately dated, elapsed time since the last major displacement. This fault is related to, but cannot connect in simple continuity with, the View Hill fault north of the Waimakariri River where it is marked by 4 m high scarp. This fault system passes through the proposed tunnel alignment, but is not shown on the URS tunnel section line. The recently completed seismic reflection lines on Wrights and Frasers roads by the Swiss geophysical project group from ETH, Zurich, will clarify this as they become available.

11. The Cust Fault is shown in the same map and is highly improbable in terms of its mapped location and extent. However, there is an important fault just upstream of the Waimakariri Gorge Bridge that must extend across to the south side and probably is connected with a significant fault through Pig Saddle into the northern end of the reservoir footprint. This does not have an obvious surface expression, but stratigraphically it has a throw of several hundred metres and offsets late Quaternary Burnham gravel. Old terrace surfaces (probably Hororata and Windwhistle) are tilted up to the projected position of this fault. This fault may also intersect the tunnel and is imaged in the seismic reflection sections.

12. The Springbank Fault certainly does not extend into the Malvern Hills as shown on the same map, but probably terminates at the Eyre River based on the work of Estrada (2003) or just possibly connects with the Hororata Fault with which it shares many characteristics in common. Both are essentially

blind thrusts with no surface expression, but defined by the growth of a major anticline on the hanging wall. In both cases growth of this anticline is defined by warping of late Quaternary surfaces, clearly evident in the rise to be seen on the West Coast Highway 73 adjacent to Racecourse Hill. Slip-rates for these two faults are estimated between 0.22 to 0.5 mm /yr, relatively low values. Conventionally this would be assumed to be taken up by episodic co-seismic displacements with predictably long return periods at these low rates. However, an unpublished analysis by Bal (pers. com) of releveling of bench marks on the highway separated by an interval of 40 years, indicates progressively increasing uplift rising sharply at the Hororata Fault and attaining uplift rates of 0.5 mm/yr by Sheffield where re-leveling ceased. Aseismic tilting and deformation is also associated with a number of other Canterbury Faults and its distribution, nature and significance is currently under investigation. Although the deformation rate is small, it is mentioned because it is in the area of the canals and the dam and because its significance in taking up accumulating strain with respect to seismic hazard considerations is not understood.

13. This discussion of the major local fault systems illustrates the limitations of the available data in making well-informed decisions on the seismic hazard question. They are just sufficient to recognise the complexity of the system, some of the problems that have emerged and the limitations of the existing data. Unfortunately critical information such as the timing of previous seismic events, slip-rates and related data cannot be produced on demand, but are serendipitous and depend on the preservation of datable material and topographic features in fortuitous relationships.

ASPECTS OF DAM FOUNDATIONS

- a. The impact of potential shaking or other causes of dam failure is the primary reason for Colin Morris' concern about the reliability of the available active fault data.
- b. Some questions on the preliminary investigation and projected design of the dam footprint need to be asked in this context. Drilling and regional mapping indicate that the "bedrock" beneath the gravel veneer

under the dam is all in Waipara Greensand. This is a widespread lithology throughout Canterbury and is almost ubiquitously associated with slope instability wherever it crops out. Its properties are clearly affected by water content leading to the common occurrence of earthflows, and as the slip surface for deeper-seated landslides. Locally it may be cemented, but elsewhere is well sorted with high porosity and is friable, so permeabilities may be expected to be very variable (note anomalously low values quoted in the site data). Bulk strength is classified as very weak (UCS values are difficult to measure but are very low in uncemented material, and have low shear wave transmission velocities, currently the subject of field and laboratory testing). The spectral acceleration modelling is based on assumptions of Class C (shallow soil) site conditions (McVerry et al., 2006). The presence of thick units of weak rock materials are known to modify the amplitude and frequency of seismically generated shear waves and are the sites of greatest structural damage in built up environments. Richard Davidson in “The Dam Safety Assurance Report” refers to this unit as simply as “competent Tertiary age sediment”.

- c. All the design features in the dam such as the (Soil Cement Bentonite) SCB cut-off wall, and materials specified in the shoulders target minimising flow through the gravels lying on the greensand and terminate at the greensand contact at depth and at upstream outcrop. Saturation and elevated pore pressures seem to be a probable eventuality with uncertain effects on the performance of this material. The Waipara Greensand has interesting characteristics when sheared, developing slick, brown clay coatings from the breakdown of glauconite that may be expected to have very low residual friction angles.
- d. One other feature of the dam design that has not been referred to is the way in which the old, backfilled channel close to the northern abutment, shown in the cross-section of Fig 6 (McMorran), will be dealt with. This is inferred to extend to 40m below present ground surface, substantially deeper than the specified foundation depth of 3 m and the 5 m SCB wall. Thick Burnham gravel of high permeability,

underlain by silts and older gravels occupy the channel and present an obvious conduit for piping beneath the dam.

- e. One other lithology that has not been referred to is the presence of bentonite clays stratigraphically immediately above the Harper Volcanics, quarried in commercial quantities further to the southwest. The volcanics crop out on the left abutment. The headrace canal will cross the projected strike of this material expressly extracted for its swelling clay properties.
- f. The question of the possible presence of a fault beneath, or near the dam has been raised. There is probably some structural control on the reason why both the Selwyn and Waianiwaniwa Rivers exit the range front strike-ridge formed by the Harper Volcanics at this point. There is a notable discordance in strike in this ridge between the orientation of the ridge extending northeast from the northern dam abutment and the anomalous east-west swing of the ridge between Glentunnel and Coalgate. It is suggested that a relatively quick and cheap magnetometer survey could establish continuity of the volcanics under the floodplain.

14. CONCLUDING STATEMENT

In my opinion the concerns raised by Colin Morris are legitimate. The risk posed by the dam may be low, but is real and difficult to quantify given the approximations that are inherent in the available data. The presence of a settlement immediately downstream is an important factor in acceptable risk. I have outlined the uncertainties relating only to the closest seismic sources and raised queries with regard to ground response, to illustrate the nature of the problem and confirm the opinion he had formed about the difficulties of obtaining and using reliable data. While Canterbury has been fortunate not to have suffered a major damaging event affecting a densely populated area within the present and last century, there is clear evidence of past events that have had a profound impact and at magnitudes frequently reaching above 7.0 on the Richter scale and sometimes approaching the scale of the recent Sichuan event.

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APPENDIX ON DERIVATION OF FAULT PARAMETERS IN GNS DATABASE

The initial step is to derive the moment magnitude (M_w) from a choice of three empirically derived equations depending on the fault type (in the Canterbury case reverse and oblique-slip faults). These equations all use the dimensions L (rupture length) and W (width or distance to seismogenic zone at base of the brittle crust) effectively relating to the surface area of rupture. The seismic moment (M_0) is determined from M_w by a standard relationship. M_0 in turn is a function of the maximum displacement (D) on the rupture area and a rigidity modulus for crustal rocks that is a measure of the elastic strain released during the seismic event. This allows an indirect estimate of D and of the maximum magnitude (Richter scale) of which such a fault is capable. If the long term slip-rate (SR) is known (the cumulative displacements smoothed over a long enough interval) then the average recurrence interval (RI) is determined by dividing the displacement by the slip-rate ie. $RI = D/SR$. Where actual measurements of displacement from offset landscape features and dated historic and prehistoric events allow direct estimates of D , RI and SR to be determined, these derived estimates may be modified to the extent that the quantity and quality of observation allow. Note that the derived data are entirely dependent on the accuracy with which the length of the fault has been defined from surface mapping, the dip angle and depth to the seismogenic base of the crust are known, from which L and W are derived.

Slip-rate is an independent parameter and both of the Stirling et al publications are reticent on the method used to derive this information. For a number of faults this is known from the dating of offset features, but certainly not for many, including several Canterbury faults listed. It seems to be done by a method of statistical distribution of the balance of strain rates left when slip rates on known faults are subtracted from the total relative plate motion. The results are probably a reasonable first order approximation in terms of the listed data and represent a useful starting point when looking at regional patterns of probabilities on a national scale, but is severely limited in reliability when assessing site specific and local variability, when considered in the context of the very incomplete knowledge we do have of faults in the immediate vicinity of the Malvern District.

