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Opus International Consultants Ltd

P +64 3 471 5500

Dunedin Office
Opus House, 197 Rattray Street
Private Bag 1913, Dunedin 9054
New Zealand

Russell McGuigan
Programme Delivery Manager
Tasman District Council
Private Bag 4,
Richmond 7050,

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Lee River Dam - Seismic Risk Considerations

Dear Russell

Your query regarding briefing Councillors on the seismic risk aspects of this develop refers.

Firstly in dam engineering terms, I can say that concrete faced rockfill dams of the type proposed for the Lee River site provide very high levels of resilience to seismic loading.

> Relative to other dam types, the reservoir water pressure acting on the upstream sloping membrane pushes perpendicular to the dam face in a direction that intersects the dam foundation within the rockfill footprint. This water pressure force adds to the weight of the rockfill embankment, increasing the frictional resistance of the dam to any tendency to slide. In this way, the dam is intrinsically very stable.
>
> Another favourable aspect of this dam type is the drained nature of the rockfill, due to the waterproof membrane separating it from the reservoir. Earth core / granular shoulder embankment dams do not have this fully drained condition, as the upstream shoulder and core are exposed to saturation from the impounded water body. This absence of water within the embankment enables the full strength of the rockfill to be utilised, without any reduction associated with the presence of saturation and water pressure within the aggregate. A simple analogy might be to think of the performance of a road basecourse aggregate in dry versus saturated conditions.
>
> A final favourable characteristic of this dam type is its free draining characteristics. Even in situations where the upstream membrane joints might become damaged and result in extensive leakage, the compacted rockfill can convey this leakage safely without the risk of significant erosion or deterioration that might apply to other embankment dam types. Furthermore, the concrete faced rockfill embankment is constructed with several internal zones that have differing specified particle sizes, such that finer zones are located upstream of coarser zones. This arrangement still provides effective relief of leakage where it is needed, but it also leads to control of the maximum possible rate of leakage in the event of membrane damage.

Behaviour of embankment dams under seismic loading is a function of the ground motion that can occur at the site, along with the associated dynamic response of the embankment to that ground motion.

> The design process looks at the behaviour under smaller more frequent earthquake events, as well as the very large extreme events that might plausibly occur. The smaller scale events relate to earthquakes with a probability of occurrence of 1 in 150 years or 0.67% per annum. Under this

level of shaking the dam is required to remain essentially in serviceable condition. The extreme design event relates to much larger earthquakes with a probability of up to 1 in 10,000 years or 0.01% per annum. Under this level of shaking the dam is required to prevent the sudden uncontrolled release of the impounded reservoir, but it may require extensive repair or even lead to demolition. By way of comparison, conventional dwellings are designed to not collapse in earthquakes with a probability of occurrence of 1 in 500 years or 0.2% per annum. The degree of ground motion is not linearly related to the earthquake probability; i.e. the 10,000 year event does not generate 20 times greater acceleration than the 500 year event. Determination of the actual expected ground motions for the respective design events is the field of seismology. Seismologists use probability methods as introduced above, as well as deterministic methods related to the predicted motion on specific faults. They also use wave propagation and attenuation models to assess the actual site effects caused by faulting some distance from the dam.

A key aspect of design is the determination of the expected degree of deformation that might be experienced in the embankment. That is the resultant displacement of portions of the dam that would be evident immediately after the earthquake. Often the crest deformation is a key consideration. Rockfill embankments can experience crest settlement associated with densification of the rockfill during the earthquake. Slope instability of the embankment shoulder may also be experienced in cases where the shear strength of the rockfill is exceeded. If the embankment deforms beyond a given limit, the membrane joints will rupture and leakage will occur. Significant settlement and/or instability might result in loss of reservoir freeboard and possibly overtopping. These adverse effects are addressed through careful control of rockfill quality and attention to effective compaction, as well as selection of appropriate batter slopes and freeboard allowance.

The recent seismicity review undertaken by GNS has updated the ground motion expectations for the site in light of the current state of knowledge. I will not seek to reproduce these findings, as their draft report and has already been provided. However, I have included the Tonkin and Taylor summary below along with some general observations.

"Changes in site seismicity

The design of the dam to date was based on a site specific hazard assessment prepared by GNS in early 2011 based on the requirements of NZSOLD 2000. New NZSOLD Dam Safety Guidelines (2015) have since been introduced requir[ing] consideration of different scenarios in the evaluation of seismic hazard spectra for the dam design. The understanding of fault mechanisms in New Zealand has also developed due to the recent Canterbury Earthquake Sequence, [and] the Seddon and the Kaikoura earthquakes in the intervening years. T+T on behalf of the Principal has therefore commissioned GNS to review and update the site specific seismic study to be consistent with the requirements of DSG (2015). A final draft report has been completed and will be finalised shortly. The final draft report suggests an increase in the Peak Ground Acceleration (PGA) of the Maximum Design Earthquake for the dam site from 0.48g to between approximately 0.6 to 0.7g. The PGA for the Operating Basis Earthquake (OBE) has also increased, although only slightly.

Implications for design and construction due to the change in seismicity

Quantification (analysis and design) of the seismic changes has not yet been undertaken. The analysis and redesign by T+T is intended to be undertaken at an early stage of the ECI phase with a view to gaining benefit on constructability of and components (e.g. to refine reinforcing arrangements). Whilst the analysis and design has not been undertaken the following changes to the dam may be required to address the increased seismicity:

- *Changes in the structural steel and concrete dam components such as:*
    - *The parapet wall dimensions and reinforcing;*
    - *The spillway walls dimensions and reinforcing*
    - *The spillway flip bucket dimensions and reinforcing*
    - *The spillway bridges dimensions and reinforcing*
    - *Culvert concrete dimensions and reinforcing*
    - *Concrete starter dam dimensions and reinforcing*
    - *Spillway cut slope stabilisation and support*

Other components that will be investigated but may not require physical amendments include depending on the analysis:

- *Requirements for additional drainage zones within the dam embankment to accommodate post-earthquake drainage*
- *Increased seismic induced dam embankment settlements requiring increased freeboard (either by increasing the dam height or the parapet wall)*
- *Geogrid reinforcing of the dam crest to reduce seismic deformation"*

I have no further comments on the above thoughts, other than to highlight the focus on the secondary structural elements rather than the key embankment form. This is not unexpected as the increased peak ground acceleration value does not translate directly into embankment deformation outcomes. The energy distribution in the seismic motion as described in the "spectral distribution" is also important, as is the magnitude of the events that represent the duration of shaking or the number of load cycles. Embankment deformation occurs typically at the peak acceleration point of each cycle in the weakest movement direction (i.e. downslope) at the crest, so the adverse effect is sensitive to the dynamic response of the embankment rather than simply the peak ground acceleration, and to the number of significant cycles.

Overall, completion of detailed design will be required to quantify the net effect of this new knowledge, but the result is unlikely to significantly change the seismic resilience or risk exposure associated with this development. There may be some commercial cost implications of course, but relative to the overall development investment involved, the adjustment of such factors as reinforcement content or added local geogrid is not expected be such as to change the commitment to the development.

Yours sincerely

Ian G Walsh CPEng(46343), FIPENZ
Independent Peer Reviewer