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Thornton
consultants

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Wellington City Council
Private Bag
WELLINGTON

Attention: Peter Brennan

Dear Peter

WELLINGTON CENTRAL LIBRARY – STRUCTURAL ADVISORY ROLE - FEEDBACK

Over the last couple of months, in accordance with our commission, we have participated in various design and buildability reviews with Aurecon, Athfield Architects, the ECI contractor, the quantity surveyors, Ken Elwood and yourselves.

This letter report attempts to summarise structural savings incorporated, list further potential savings and comment on some aspects of design. We have separately provided information on temporary support solutions relating to the base-isolation option. Many of our comments relate to Option C.

1. STRUCTURAL SAVINGS INCORPORATED

The revised preliminary design phase, carried out by Aurecon, appears to have been reasonably robust particularly considering the relatively short available time frame. Aurecon have been receptive to suggestions from ourselves, the ECI contractor and the Architects. The main changes from the earlier drawings, that should result in significant savings in both cost and construction duration, are as follows:

- **Constructing Pilecaps and Foundation Beams in the Basement**
  While this will have some adverse effect on available parking, it will give a major reduction in the amount of excavation, temporary water barriers/sheetpiling, temporary shoring and wet trades generally. It also eliminates the requirement for separate basement column strengthening beneath base-isolators/braced frames. It should give major programme and cost saving for both Options B & C.

- **Reduction in Extent of Ground Floor Demolition**
  Option C (base-isolation), requires a new ground floor structure to cope with the reactions at the tops of the isolator bearings. In the original scheme the entire existing ground floor was to be demolished and replaced with a fully new floor. In the revised scheme, only around 35% of the existing floor is to be fully demolished. In the remaining area the new floor structure (slab and beams) is to be cast on top of the existing floor slab. This will greatly reduce the extent of demolition and also reduce the extent of temporary support and bracing required, saving time and cost. The resulting raised ground floor will give in the order of 100years additional mitigation against sea-level rise for most of the ground floor. We would recommend that in detailed design, structural allowance is made for the remainder of the ground floor to also be raised, once the need arises. We also note that no sea-level rise mitigation would be easily incorporated within Options A/B.

- **Reduction in Extent of Base-Isolation**
  The original Option C design included portions of Civic Square to the east and south of the library superstructure to be included within the base-isolated area. The revised scheme pulls the rattle-space back effectively to the face of the library façade, reducing the extent of ground floor demolition/reconstruction, the numbers of isolators and the extent of rattle space, affording cost savings.

- **Reduction in Temporary Retention & Slider Bearings – Basement Wall**
  The original Option C design included slider bearings along the western and northern basement walls, where they are set in from the building façade line. In the revised scheme these sliders have been removed. In addition, the construction methodology has been clarified to significantly reduce the requirement for temporary strutting.

- **In-line Seismic Frames**
  The original Options B&C had new seismic, braced-frames to be constructed adjacent and parallel to existing frame lines resulting in double-columns and significant demolition and temporary works. The revised preliminary design utilizes the existing frame lines with new braces and strengthened columns and beams to be centered on the existing grid lines. This gives better utilization of the existing structure, less demolition/temp works and better aesthetic/planning outcomes. The extent of ‘drag-beams’, beams that extend from the ends of the bracing frames to tie the floor diaphragm to the frames, has also been greatly reduced.

- **Reduction in Extent of FRP**
  The extent of Fibre Reinforced Polymer (FRP) to improve the diaphragm action of the suspended floor slabs has been reduced for Option C. [Refer also to later comments on FRP vs inlaid reinforcing bars].

- **Main Lifts Not To Serve Basement**
  The original Option C had the existing 4 passenger lifts continuing to serve the basement level. The consequences of this would have been to require major excavation work below the basement excavation, temporary water barriers/sheet-piling, temporary shoring and other wet trades, in order to create rattle-space around the lift pit. The revised preliminary design has the lowest floor served being the ground floor, significantly reducing work and programme.

- **Replacement of Steel Beams with Reinforced Concrete at Ground Level.**
  The original Option C had structural steel beams at the reconstructed ground floor level. This would have had significant buildability issues in relation to tolerances, temporary support and sequencing. The revised preliminary design predominantly utilizes reinforced concrete beams which we believe greatly improves buildability and reduces construction time.

- **Clarification of Construction/Propping Methodology**
  The provision of temporary works/propping methodology and details for Option C will have enabled this work to be costed and programmed with greater confidence and reductions in contingency.

2. POTENTIAL FURTHER STRUCTURAL SAVINGS

The following issues, when investigated in greater depth during developed/detailed design, may result in additional savings.

- **Hollow-Core Support Angles and Alpha-Slab Frames**
  It is fair to say that this is a somewhat contentious issue and that there are varying opinions relating to it. The pertinent factors are as follows:
    - The magnitude of damage and the likelihood of collapse of hollow-core is related primarily to the magnitude of drift (the displacement of a floor level relative to the floors above and below it) and the extent of flexural yielding of beams that align parallel to the hollow-core.
    - Cracking within hollow-core is believed to commence at drifts around 0.5%.
    - Drifts of 0.5% are not considered to constitute a life-safety risk.
    - Hollow-core collapse is typically not expected below around 1.5% drift however engineers will usually place a safety margin on this value.
    - Shelf angles and alpha-slab support frames can prevent collapse but they will not prevent the initiation of cracking.
    - Aurecon have calculated the worst-case drift for Option C as 0.44% for level 1, the other floors are less than 0.4%.

On the basis of the above, the shelf angles and alpha-slab frames are not required for life-safety and do not add resilience for Option C. It is our view that, for Option C, the estimated costs for these items should be a separate line item and say 25% be included as a provisional item to allow for areas where investigation suggests that existing seating may not be adequate for gravity load support.

- **Steel Frame Detailing**
  The detailing of the superstructure bracing frames, as drawn on the revised preliminary design drawings, particularly the steel column jacketing, appears overly complex and potentially difficult to construct. As discussed in the design meetings, it is anticipated that detailed design of these frames is likely to yield some savings. This would apply to both Options B and C.

- **Precast Panel Connection Improvement**
  The small drifts anticipated for Option C means that the extent and details for additional panel restraint should be significantly less for Option C compared to Options A & B. As for the hollow-core support, it is our view that, for Option C, the estimated costs for these items should be a separate line item and say 25% be included as a provisional item to allow for complex areas, corners and the like, where greater robustness is warranted.

3. IMPORTANCE LEVEL

As discussed at a number of meetings, Importance Level 3 [IL3] would be nice-to-have for the Central Library even though it is not a specific requirement of the New Zealand Building Code. We agree that it is appropriate for Options A & B and we understand that for public consultation purposes it was appropriate for all three options to be shown as having a target of IL3. However, if Option C is selected then it is our recommendation that this issue be revisited. The reason for this is that at IL3, the contents and occupants experience slightly higher accelerations and hence more disruption in smaller earthquakes. A base-isolated IL2 structure can give enhanced (compared to a conventional structure) life safety up to ULS and beyond. Equivalent (compared to IL3) CALS life safety can be provided by allowing for a larger rattle space.

4. COMPARISON OF LIFE SAFETY, ROBUSTNESS AND RESILIENCE FOR THE 3 OPTIONS

In discussing these matters it is appropriate to have some definitions of robustness and resilience. In a structural context, robustness implies avoidance of a brittle-type failure once nominal performance levels are exceeded. This is typically regarded as an ability to withstand lateral displacements 50% greater than those expected at ULS. Well detailed, ductile structures will typically inherently have this ability while brittle (e.g. masonry) structures do not.

Resilience, in this context, implies ability to withstand seismic actions and then still be usable/functioning. This is normally related to the extent of damage and so Low-Damage-Design should result in resilience.

We note our view that the use of *%NBS* targets in the naming of the three options is not really appropriate because in fact the percentages used are design targets rather than NBS.

Option A

Option A is referred to as *Low-Level Remediation targeting ~40%NBS(IL3)*. It might be better referred to as a 'Low-Resilience Option'. In terms of life safety, it would present a risk to occupants and passers-by in the order of 5-10 times greater than an equivalent new building. In terms of structural performance, its Ultimate Limit State [ULS] return period is in the order of 100 years and its Collapse Avoidance Limit State [CALS] is in the order of 250-500 years. In terms of its resilience, structural damage is likely to initiate due to seismic shaking with a return period in the order of 75 years and repair durations could be in the order of 18 months. For larger events, repair costs may exceed the residual value.

It is also worth noting that the structure's seismic rating may be affected by future changes to the Wellington hazard. This would be more significant for Option A as an increase in the hazard may push the building close to Earthquake Prone status.

Option B

Option B is referred to as *Mid-Level Remediation targeting ~80%NBS(IL3)*. It might be better referred to as a 'Medium-Resilience Option'. In terms of life safety, it would present a risk to occupants and passers-by in the order of 1-2 times greater than an equivalent new building. In terms of structural performance, its ULS return period is in the order of 500 years and its CALS return period is in the order of 1500 years. In terms of its resilience, structural damage is likely to initiate due to seismic shaking with a return period in the order of 250 years and repair durations could be in the order of 18 months. For larger events, repair costs may exceed the residual value.

In relation to a potential increase in the Wellington hazard a worst-case scenario might see a reduction in seismic performance rating in the order of 20-30%.

Option C

Option C is referred to as *High-Level Remediation targeting ~100%NBS(IL3)*. It might be better referred to as a 'High-Resilience Option'. In terms of life safety, even at IL2 it would present a lower risk to than an equivalent new, conventional building. In terms of structural performance its ULS return period is 1000 years and its CALS return period is in the order of 1800 years. In terms of its resilience, we would expect that significant structural damage is **not** likely to be initiated in seismic shaking with a return period in excess of 1200-1500 years.

In relation to a potential increase in the Wellington hazard, providing that the design is based on a PSHA, we would expect that the effects of potential future increases in the seismic hazard would be largely incorporated within the design.

5. ISSUES RAISED AT PEER REVIEW WORKSHOP 7-10-2020

At the recent peer review feedback workshop, a number of pertinent issues were raised:

Improvement in Diaphragm Action – FRP vs Chased & Grouted Bars

One of the peer reviewers gave an opinion that FRP may not be an appropriate material to use for diaphragm strengthening (required due to the presence of non-ductile, slab-topping, reinforcing mesh) and suggested that mild steel reinforcing bars, chased and grouted into the slab would be preferred. We partially concur with this view for Option A as large cracks may form at beam edges and the FRP may not be able to satisfactorily span the gaps. It is also relevant for Option B if ULS drifts in the order of 1-1.5% occur. The use of chased and grouted bars would require further investigation and unbonded, sub-slab tendons may also be an option. However, for Option C, because of the small expected drifts, it is our view that FRP would be satisfactory. In any event, at the time of detailed design it would be worth costing various options.

Potential Existing Damage to Hollow-core Units

One of the peer reviewers gave an opinion that there may be existing, hidden damage to the hollow-core flooring units. This is a potential issue for each of the options and we concur that investigations to check for cracking should be carried out as part of developed design. The extent and need for remedial or repair work is difficult to estimate at this time however it is our view that the need for repair is likely to be greatest for Option A and least for Option C. For Option C we would suggest that vertical load testing be carried out to check the capacity of the affected units, particularly in high-load/storage areas.

Viscous Dampers Alternative

The peer reviewers suggested that viscous dampers could be incorporated as part of Option B and one reviewer suggested that equivalent performance (in terms of maximum drift) to Option C could potentially be obtained. The use of viscous dampers had been discussed in design meetings and the consensus view was that their use in combination with BRBs would most likely give improved performance but that the cost is unlikely to be significantly different to the current Option B estimate. On that basis, development of a viscous damper option was to be left until developed design (if Option B is selected).

A number of buildings around New Zealand, both new and strengthened, have incorporated the use of viscous dampers and they typically have predicted drifts of around 1.2-1.5% drift at ULS. On that basis the Alternative Option B would not provide the same level of resilience as Option C. This is because at 1.2-1.5% drift there will still be structural damage to the concrete frames, the hollow-core units and the precast panels plus potential damage to non-structural elements such as glazing, partitions and the like. To use viscous dampers to reduce drifts to the order of 0.5% may be possible in theory but is in our view unlikely to be practical. For very small drifts, the movement of the damper rams is also very small and so the damping achieved is likely to be insufficient.

We trust this provides helpful feedback and would be happy provide further review as required.

Yours faithfully,

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