SEISMIC STRENGTHENING AND UPLIFT OF THE 1904 WELLINGTON TOWN HALL

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Abstract

The Wellington Town Hall is a large unreinforced masonry building constructed circa 1904 in Wellington, New Zealand. The building features a large auditorium and forms part of the Wellington City municipal complex. Heritage New Zealand has designated the building a Category I rating, the highest possible rating in New Zealand, recognising the building's outstanding historical and cultural significance. Wellington is located in the region of highest seismicity in New Zealand. The Town Hall predates modern seismic design and has been assessed as vulnerable to even moderate shaking.

Wellington City Council has engaged a team to strengthen and uplift the Town Hall as part of a greater Civic Music Hub initiative. The Town Hall strengthening design is intended to maintain the historic fabric of the building and the outstanding acoustics of the auditorium, while simultaneously preserving the building for another 100 years. This is being accomplished through a series of engineering interventions, including base isolating the building on lead-rubber bearings, re-founding the building on 400+ new piles and adding new reinforced concrete overlay walls. In addition to strengthening efforts, other interventions for uplift purposes were also included in the project scope, such as constructing a new glass atrium, strengthening floors to allow future soundproof "floating" rooms to be built by tenants, and building a watertight basement to accommodate expensive recording equipment.

The paper will describe the various interventions, both strengthening and uplift, from the perspective of using seismic engineering as a way to promote resilience in our historic and urban structures.

Keywords: heritage, unreinforced masonry, retrofit, base isolation

1. Introduction

The Wellington Town Hall is a large unreinforced masonry building constructed circa 1904 in Wellington, New Zealand. Figure 1 illustrates the northern (Civic Square) façade of building. The building features a large auditorium as well as the offices of the Mayor and a Debating Chamber for the City Council, and forms part of the Wellington City municipal complex. Heritage New Zealand has designated the building a Category I rating, the highest possible rating in New Zealand, recognising the building's outstanding historical and cultural significance. The main auditorium has been described as having world-class acoustics and was the home of the New Zealand Symphony Orchestra (NZSO) until the Town Hall was closed in 2013 (refer Figure 1). In addition, the Town Hall has been used to record several soundtracks for major films as part of Wellington's burgeoning film industry.

The Town Hall is located on Civic Square in central Wellington, on reclaimed land and less than 2 km from the Wellington Fault. In addition to the proximity of the Wellington Fault, which is capable of producing earthquakes up to M8.2, Wellington is located near the Hikurangi Subduction Zone off the east coast of the North Island of New Zealand. This subduction zone is believed to be capable of producing megathrust earthquakes greater than M9. The Town Hall predates modern seismic design and has been assessed as vulnerable to even moderate shaking.

Fig. 1 – Photograph illustrating the Wellington Town Hall northern façade as it currently stands (left) and auditorium - courtesy Wellington City Council (right)

2. History of the Wellington Town Hall

The Town Hall was originally constructed circa 1904. While no structural or detailed architectural plans are available, watercolour renderings produced at the time show general floor plans, elevations, and building cross-sections. Figure 2 shows the eastern façade of the building, which was once the primary entrance. A large clock tower dominated this façade, as well as a prominent portico entrance and intricate parapet ornamentation.

However, after the 1931 Napier earthquake, which destroyed significant areas of the cities of Napier and Hastings, New Zealanders realised the seismic threat posed by unreinforced masonry (URM). New measures were subsequently adopted prohibiting the use of URM in new buildings and addressing existing URM buildings [1]. As a result, the Town Hall's clock tower, high parapets, and other ornamentation were dismantled, although the URM walls of the Town Hall were not modified at this time.

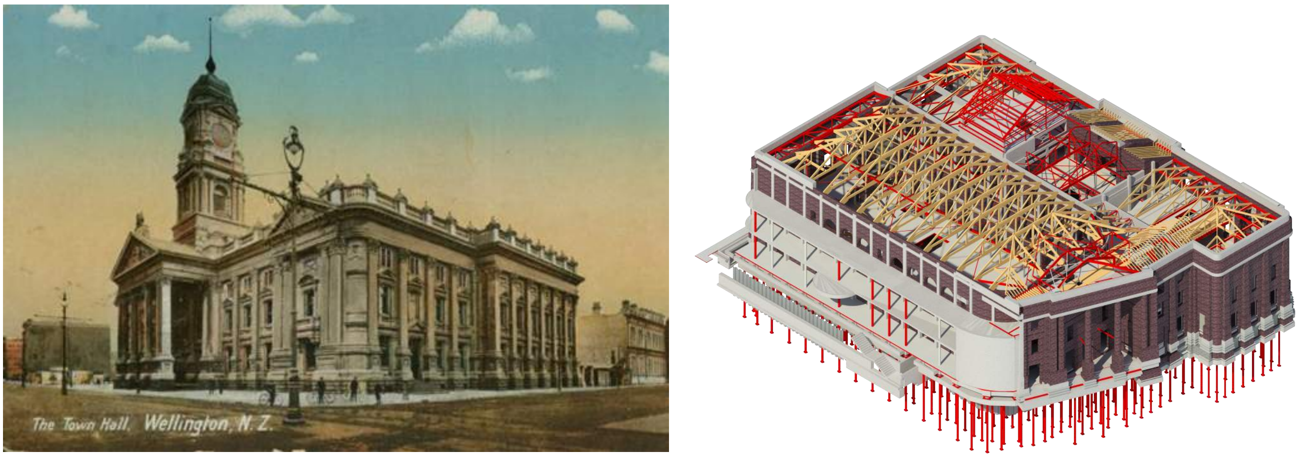

Fig. 2 – Original northern and eastern facades with clock tower and parapets (left) and 3D Revit model of the proposed strengthened building illustrating the primary structure and new foundations (right)

In 1942 two large earthquakes struck the nearby Wairarapa region, damaging the Town Hall. Repairs were undertaken to cracks in the URM walls, buttressing was added to support the western wall of the auditorium (which heretofore spanned from ground to roof level), and recessed vertical concrete banding was introduced in all of the auditorium and exterior walls. The remaining parapets were, in some places, replaced with significantly shorter reinforced concrete parapets which were doweled into the top of the URM walls.

In the late 1940s and early 1950s, a neighbouring building, the Municipal Office Building (MOB), was built to house various city departments (refer Figure 3). As part of this construction, a three-storey annex to the MOB was appended to the southwest corner of the Town Hall and made to look like a symmetrical portion of the MOB, although structurally it belonged to the Town Hall. The floor levels of this annex did not correspond to the existing floor levels of Town Hall. A 4 inch (100 mm) seismic gap was left between the MOB Annex and the rest of the MOB.

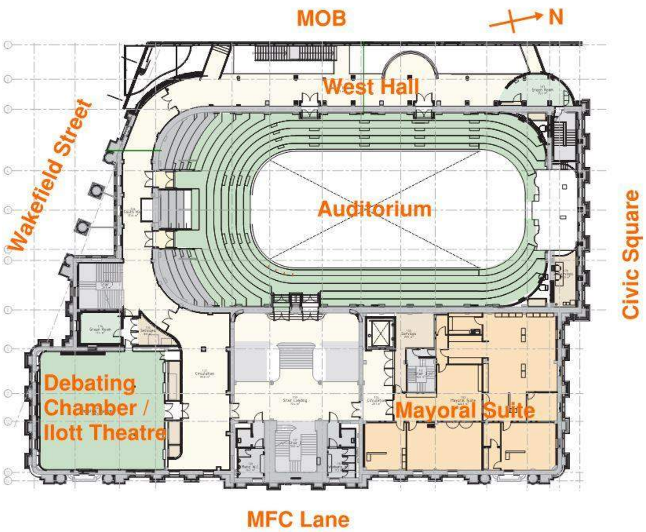

Fig. 3 – Schematic layout of the Town Hall

The most comprehensive intervention to date came in the early 1990s. The project entailed seismic strengthening and significant alterations to the structure, such as the demolition of a double-storey high recital hall and replacement with office space, construction of a small theatre in the southeast corner, creation of a glass-enclosed West Hall between the Town Hall and the MOB, and addition of a mechanical penthouse.

3. Case for Intervention

Detailed seismic assessments carried out between 2009 and 2013 determined that the Town Hall was legally considered "earthquake prone," meaning that it had less than one third of the capacity of a structure built to new building standards (as they stood at the time of assessment). This was primarily due to unreinforced concrete pile foundations and brittle URM walls. Wellington City Council (WCC) closed the Town Hall in 2013 and began investigating options to retrofit the building. Councillors voted overwhelmingly in favour of investing in the project in order to preserve the heritage building and superb acoustics of the auditorium.

The project went through a full design cycle all the way to building consent in 2013 but stalled at that point. In late 2016, a new vision of the Town Hall as a keystone of a new Civic Music Hub was proposed. With buy-in from the New Zealand Symphony Orchestra (NZSO) and Victoria University of Wellington's New Zealand School of Music (NZSM) as major tenants, a revamped version of the project restarted. This version of the project had three tiers:

- base building (strengthening to increase the seismic capacity to 100% of that required for an equivalent new building),
- uplift (work required to facilitate the creation of the new Civic Music Hub), and
- tenant fit-out (work to meet the performance requirements of the individual tenants).

Currently, the base build and uplift design are complete. Construction of this portion of the work is underway with an expected completion date in 2023. The design of the tenant fit-out works is partially complete and will continue during the base build construction period.

4. Seismic Loads

Seismic loads for the project were determined using NZS 1170.5 [2] in accordance with the project performance objectives (refer Table 1). The Wellington Town Hall site was categorized as subsoil class D with a site period of 0.7s. Interpolated subsoil Class C-D spectra were determined in accordance with the procedure detailed in NZS 1170.5 for the 1,000 and 3,000 year return period earthquakes (refer Figure 4).

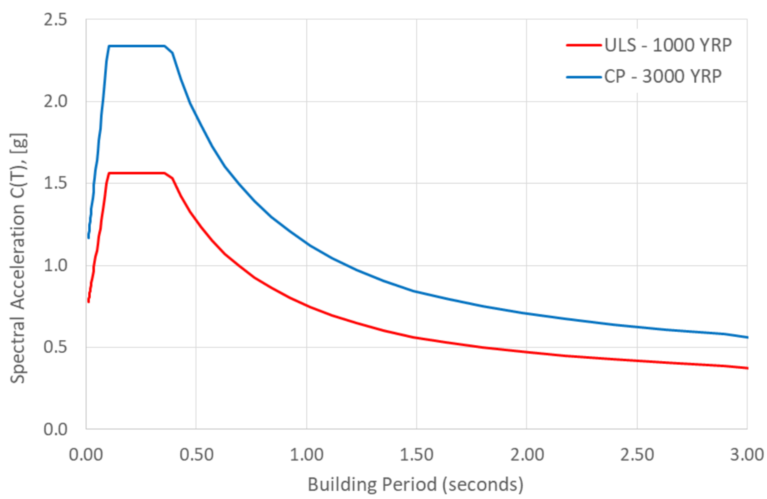

Fig. 4 – NZS1170.5 hazard spectra for Wellington Town Hall site

Table 1 – Seismic hazard and building performance limit state parameters

Performance Objective	Return Period	Building Performance Limit State
Life safety of building occupants	1,000 years	Ultimate Limit State (ULS)
Collapse avoidance	3,000 years	Collapse Prevention Limit State (CP)

5. Methods of Intervention: Base Build

5.1 Foundations

The Town Hall is founded on reclamation fill over beach deposits over alluvium. Bedrock is believed to be at least 45 metres below grade and is not realistically reachable. The reclamation fill and beach deposits are particularly susceptible to liquefaction, although the upper alluvium also has liquefiable lenses. The lower alluvium is considered competent. The existing foundation system is a series of unreinforced concrete piles (founded at varying depths) and a grillage of foundation beams. The existing piles date back to the original 1904 construction and are considered non-ductile. During previous strengthening work undertaken in the 1990's, local disturbances to the soil resulted in the formation of a shear failure in one of these piles at the underside of the foundation beams, necessitating emergency remedial work to stabilise the structure. This highlights the vulnerability of the existing foundations to even modest ground movement.

Thus, one of the primary interventions to strengthen the Town Hall is refounding the building, vertically and laterally. This is being achieved through the introduction of approximately 450 new screw piles, which are to be installed into the lower alluvium. The screw piles are approximately 300 mm diameter grout-filled steel tubes with a steel helix welded to the base, allowing them to be screwed into the ground with minimal ground disturbance, protecting the vulnerable existing foundations. Due to head-height constraints of working within an existing building, the piles will be installed in sections and spliced in the field. The piles support a heavily reinforced concrete raft slab, typically 850 mm thick.

5.2 Base Isolation

The other major intervention is the introduction of a base isolation system. Base isolation allows the building to experience far reduced accelerations in a seismic event, significantly decreasing the demands on the brittle superstructure. Without base isolation, any seismic strengthening intervention would have been so intrusive as to destroy any remaining heritage aspects of the building, rendering the project unworkable. By limiting the forces transmitted through to the superstructure, additional superstructure strengthening is generally contained to existing elements, rather than requiring the introduction of new lines of vertical resistance or diaphragms.

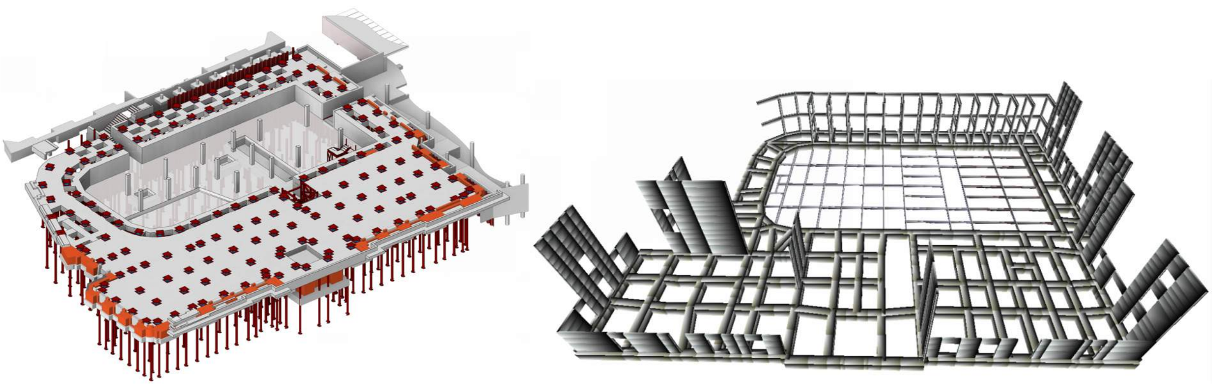

Fig. 5 – Distribution of isolators (left) and new reinforced concrete superstructure elements (right)

The isolation system consists of 148 lead-rubber bearings (LRBs) distributed throughout the building, and 15 flat-plate pot-bearing PTFE sliders where it is impractical to place LRBs (such as the tops of cantilevered columns supporting auditorium floor beams). Figure 5 shows the distribution of the isolators throughout the building. The LRBs are approximately 750 mm diameter and 400 mm high, and are performance-specified to meet specified damping and displacement properties.

Performanced based design using non-linear time history analysis (NLTHA) was adopted for the project to validate the design of the isolation system and superstructure strengthening. While more computationally expensive when compared with conventional linear elastic analysis techniques, this methodology had the following benefits:

- the response of URM to earthquake excitation is characterised by pier rocking and bed-joint-sliding failure modes which by their very nature are highly nonlinear and therefore cannot be satisfactorily represented by linear elastic elements.
- targeting strengthening strategies such as fibre reinforced polymer and/or reinforced concrete overlay walls can be explicitly assessed and their benefits accurately quantified.
- seismic demands on secondary and non-structural elements can be more accurately assessed using floor response spectra generated directly from the NLTHA model.

Nominal effective periods, $T_{eff,}$ of the isolation system for the ULS and CP performance limit states were 1.5 seconds and 1.8 seconds respectively. The effective periods are lower than would commonly be used. Reasons for this included:

- minimise the rattle space required around the perimeter of the building - the building shared a common boundary on the western side to the MOB.
- minimise the physical size of the isolators i.e. larger displacement demands require larger isolators. This has a consequential effect on the size of the structure supporting the isolators, would add cost and reduce the useable area below the isolation plane.

Further information on the design and assessment of the Wellington Town Hall can be found in the paper "Performance-Based Design and Assessment of the Wellington Town Hall" [3].

The introduction of base isolation to the Town Hall resulted in number of other required interventions, such as the creation of a "rattle space" around the perimeter of the building to allow it to move independently from adjacent structure and ground in a seismic event. The minimum rattle space dimension was set to avoid structure-to-structure contact (pounding) under the Collapse Prevention Limit State. Where the Town Hall is adjacent other structures, the assumed movement from those structures was added to the Town Hall's movement taken from the analysis model.

On three sides of the building, the creation of the rattle space required the inclusion of lids to bridge over the rattle space. On the Wakefield Street frontage, the isolation plane daylights over grade level and thus the building can move laterally over the footpath unencumbered. On the Michael Fowler Centre (MFC) side of the building, a trench and retaining structure were designed to create the rattle space. On the Civic Square side of the building, sections of precast concrete hollowcore floor units will be removed from the adjacent parking garage roof (which forms the walking surface of Civic Square at this location) along the length of the building. On the MOB side of the building, the West Hall is bifurcated into a structure belonging to the Town Hall and a structure belonging to the MOB. A gap will be left between these two structures corresponding to the required separation noted above.

5.3 Wall Strengthening

Even after the implementation of the isolation system many of the existing URM walls were still deficient in terms of their in- or out-of-plane capacity. Several different techniques were designed to strengthen the existing walls. The first, and most common, is the introduction of 200 mm thick concrete overlay walls, reinforced and continuously doweled into the existing URM walls (refer Figure 6). Where an overlay wall isn't practical for architectural or constructability reasons, recessed concrete banding is used to improve out-of-plane capacity. The banding could have been orientated in the horizontal or vertical direction, but was chosen to be vertical as cutting a horizontal slot in the wall would have weakened the wall substantially in terms of gravity loading and would have required more temporary works to support it during construction. A vertical slot only weakens the wall laterally, which was deemed to be acceptable for the construction earthquake.

In addition to the overlay walls and vertical banding, one other major intervention is used to support the URM walls out of plane. At the western wall of the auditorium, only a narrow (~4 m) width of diaphragm is available to support the wall (refer Figure 3). The diaphragm alone was deemed to be too flexible to restrain the wall adequately, so six new reinforced concrete moment frames are to be introduced. The out-of-plane loads from the western auditorium wall will be shared between the new diaphragm, which spans back to the perpendicular auditorium walls, and the six moment frames. An elevation of one of these moment frames is shown in Figure 7. For loads in the north-south direction, the new diaphragm is assumed to cantilever back to the western auditorium wall. In order to make a more coherent structure, the existing MOB Annex is be demolished and the West Hall re-clad in a more modern aesthetic.

5.4 Diaphragms

At locations where the existing diaphragms are required to carry transfer or inertial seismic loads, the shear capacity of the slab as well as the capacity of the connections to the walls were checked. The original 1904 floors typically consist of arched unreinforced concrete floors supported on cast-in rolled steel joists. The quality of the concrete was poor. Consequently, this construction type was assumed to have a low shear capacity and will be typically reinforced with recessed steel plates to provide collector elements capable of transferring the required diaphragm loads to the supporting walls. At roof level where there is no slab present, but where some steel work exists from previous interventions, new steel members will be added to form roof diaphragm trusses.

5.5 Other Elements

Although the high parapets and other decorative elements were removed in the 1930s, some URM and lightly reinforced concrete parapets still remain. These will be secured back to the roof diaphragm by new vertical grouted steel dowels, drilled down up to 7 m into the URM walls below. This reinforcement allows the parapets to cantilever from the level of the roof diaphragm. Steel waler members (typically universal column sections web horizontal) with horizontal dowels into the URM walls then transfer the seismic loads into the supporting roof diaphragm trusses.

Along the Wakefield Street facade, two existing 12 m tall, 1.0 m diameter URM pillars will be strengthened with new vertical 50 mm diameter high strength post-tensioned steel bars.

The auditorium is the most prominent and celebrated space in the Town Hall and one of the main reasons for preserving the building. As such, the auditorium was treated with careful consideration to avoid altering its appearance or acoustics. All wall strengthening will be done on the exterior faces (such as the bracing of the western wall with the concrete moment frames noted in Section 4.3 above). A wraparound balcony will be strengthened using a new plywood diaphragm applied to the underside of the existing timber trusses that support the seating tiers.

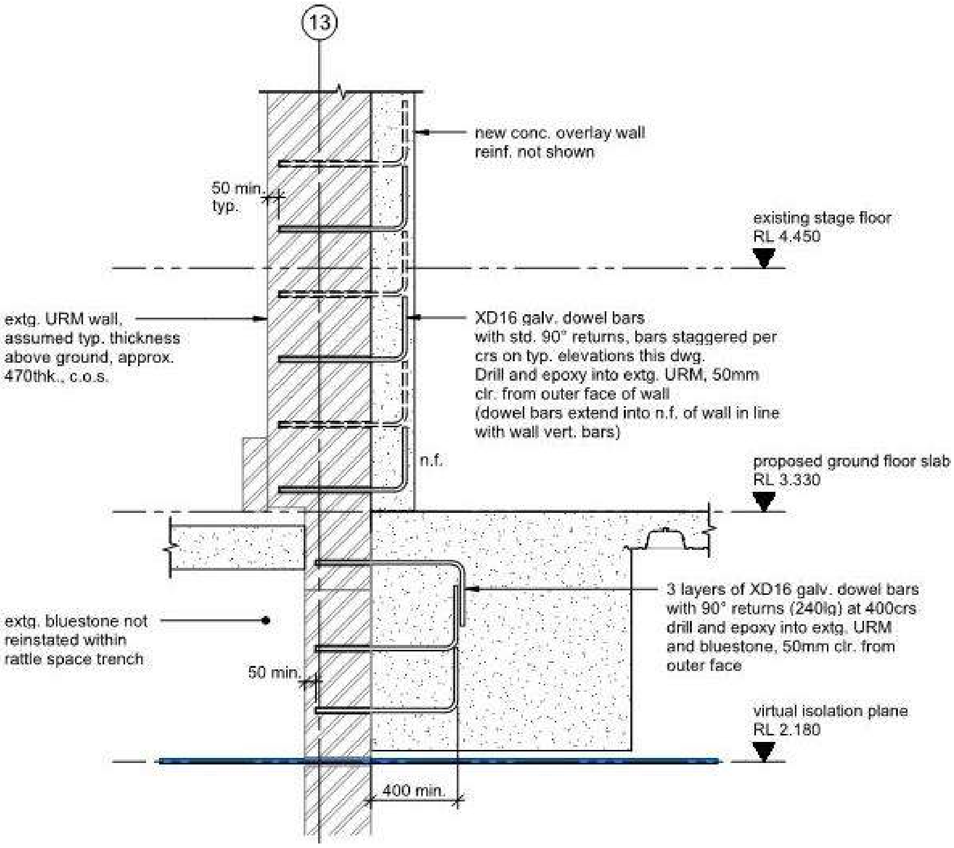

Fig. 6 – Typical overlay wall detail

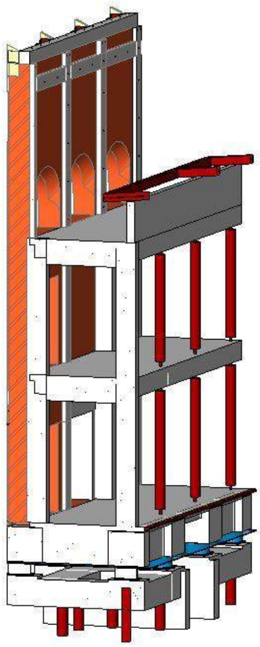

Fig. 7 – Typical West Hall concrete moment frame

At the front of the auditorium tiered choir stalls connect the first floor-level balcony and organ loft with the stage level. These choir stalls were deemed to have high heritage value and thus only minimal alterations were permitted. For ventilation purposes, many small grills are being added to the vertical faces of the tiers, diminishing the capacity of the existing timber structure to transfer its own inertial seismic loads back to the support structure. Furthermore, the addition of backstage dressing rooms underneath the choir stalls requires the installation of new pipework and cable trays suspended from the underside of the choir stall structure. For these reasons, the primary choir stall rakers will be strengthened by sandwiching them with steel channels, and a steel truss diaphragm will be created using flat plates and angles.

The original organ, which is also being refurbished as part of the project, will be braced back to adjacent URM walls to protect occupants in the choir stalls and on the stage below. As the organ is an exceptionally complex piece of equipment with over 4,000 pipes, the bracing was designed in consultation with the organ refurbishment subcontractor to limit impact on the acoustics or maintenance access inside the organ.

6. Methods of Intervention: Uplift

To develop the Town Hall as part of the Civic Music Hub, further work is required beyond the seismic strengthening of the base building. This work includes the addition of new performing and support spaces, refurbishment of existing spaces, and connections with adjacent structures.

At the southeast corner of the building the existing Ilott Theatre sloped down from the ground floor to the basement to achieve a tiered seating area. In the strengthened building the entire structure will be level at the ground floor to accommodate the creation of a consistent isolation plane. As a result the Ilott Theatre's space will become level and much shorter in height, creating more of a studio than a recital hall. For the uplift portion of the works, the floor here was designed to accommodate future tenant works, including the addition of acoustic "boxes-in-boxes" (refer next section).

Above the Ilott Theatre, at the first floor, the double-height Debating Chamber will be left mostly untouched. One major alteration will be the reframing of a second-floor balcony to improve acoustics and sight lines, and the removal of two cast-iron posts supporting this balcony. The posts require removal as the balcony is being raised and the posts are no longer required.

In the northeast corner of the building, the second floor will be strengthened to accommodate a future tenant acoustic box-in-box, although the actual design of this element is part of the tenant fit-out works.

The auditorium, although deemed to already have superior interior acoustics, has problems with ingress of exterior noise such as heavy rain, traffic, and helicopters. To address this problem new acoustic barriers are to be added to the roof. These consist of a new layer of plywood on the top of the existing roof trusses and a new layer of particle board at the bottom chord of the roof trusses. The existing roof trusses and joists were assessed for gravity load carrying capacity. This included testing of the original 1904 joists to determine their strength and stiffness as insufficient documentation could be found to estimate the mechanical properties of the historic timber. Although nominally a trafficable floor, the client was advised the existing roof structure had insufficient capacity to support the required live loads and access to the space would need to be significantly restricted.

Underneath the auditorium floor, a new basement will be dug to accommodate a high-end recording suite, storage facilities, practice rooms, and dressing rooms. Many of these facilities require acoustic isolation, which will be achieved through acoustic "box-in-box" construction (refer next section) as part of the tenant fit-out works. The new basement spaces will be below the water table. The habitable nature, and proposed uses, of the basement spaces are such that the client wanted a dry environment. To that end, a two-tier waterproofing system will be constructed.

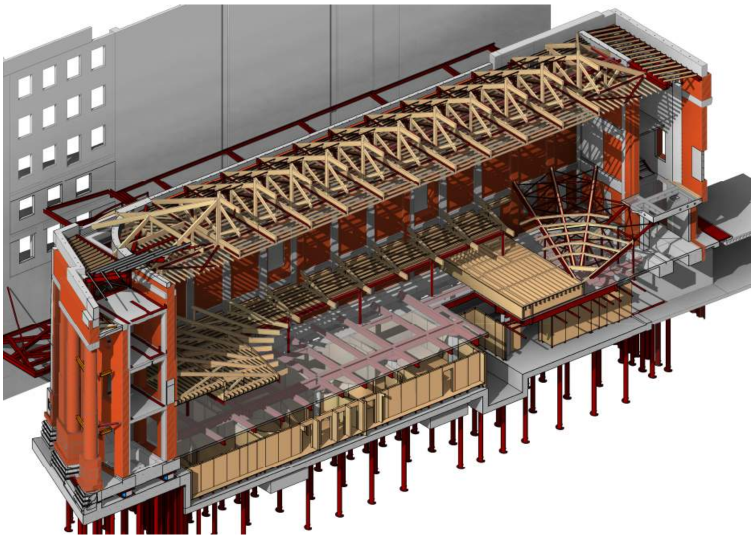

Fig. 8 – Section through the auditorium illustrating the layout of the roof trusses and tiered choir stalls

The reinforced concrete basement walls were designed to minimise water ingress though the use of hydrophilic waterbars and backstops at construction joints, tightly spaced reinforcement, and a concrete mix design specified to reduce shrinkage. Even with these measures, some water ingress is anticipated. Therefore, inside the basement a drained cavity system was specified by the architect, which will allow any water to drain to sumps without intruding into habitable spaces.

The West Hall, located between the Town Hall and the MOB, will be completely rebuilt. The new structure consists of insitu reinforced concrete slabs supported on a reinforced concrete moment frames (the latter provided to brace the auditorium walls). A new glass atrium roof will be provided over the seismic joint formed between Town Hall and the MOB. The new glass roof will be supported on a steel structure that will cantilever laterally from the MOB and be supported vertically on both the MOB and the Town Hall (the latter consists of sliding joint to accommodate anticipated seismic movements). As shown in Fig. 9, a modern glass, brass, and aluminium façade will enclose the West Hall on each end, creating a laneway between Wakefield Street on the south end and the Civic Square on the north end.

7. Methods of Intervention: Tenant Fit-Out Works

The last design stage of the project is the design of the tenant fit-out works. There are three proposed primary tenants: the WCC and Mayor, the NZSO, and the NZSM. Structurally, the fit-out works for the WCC and Mayor require little to no design. The NZSO and NZSM works both involve the creation of acoustically isolated "boxes-in-boxes."

A box-in-box is designed to limit the transfer of structure-borne noise by isolating the room from the rest of the structure as much as possible. The acoustically isolated box-in-box is achieved typically by casting a slab on top of another slab. The upper slab has a cast-in screw-jacking system which is used to raise the upper slab 25-100 mm above the lower slab after the upper slab has achieved sufficient strength to span between jacking points (refer Fig. 10). On top of the upper slab, a set of walls and a ceiling are constructed, creating a "floating" box with minimal contact to the base structure.

Fig. 9 – Proposed West Hall rendering (courtesy Athfield Architects)

The intentional lack of contact with base structure creates significant challenges in terms of restraining the boxes seismically. Any connection with the base structure has the potential to transmit noise, so careful detailing is required to limit this transmission. Some strategies that have been considered include using the jacks as lateral load resisting elements (which works for small loads only), bracing the boxes up to diaphragms above with acoustically resilient buffers at steel-to-steel connections, and employing snubbers designed to only make contact during a seismic event.

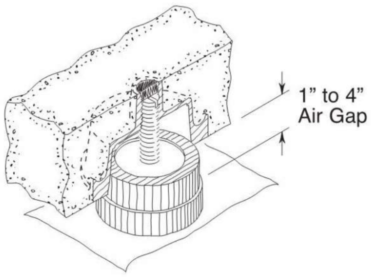

Fig. 10 – Typical acoustic slab jack (courtesy Mason Industries)

8. Challenges

The Town Hall was an extremely challenging project to design and will continue to be challenging to construct. The piecemeal nature of the existing building created difficulties in terms of providing coherent and consistent load paths throughout the building. Furthermore, much of the original structure was undocumented, and even the more recent 1990's work had incomplete structural drawings. This caused significant challenges when completing the design and detailing of the strengthening works, and extensive on-site investigations were required. Despite this, further discoveries are anticipated during the construction phase. These discoveries will likely have an impact on the detailing of strengthening works and this will need to be addressed with input from the Contractor during the construction phase.

Another challenge was the emphasis on preservation of the heritage fabric of the exterior of the building, thereby restricting all the remediation works to the interior only. This inhibited several solutions and required considerable creativity in achieving the desired outcome. For instance, all of the exterior URM walls are supported from the inside only, through the use of dowels into overlay walls which are supported on sizeable concrete grillage beams hugging the inside face of the walls. These grillage beams are supported on the LRBs. At URM pier locations, beam stubs cantilever over the LRBs and extend underneath the URM pier to support tributary gravity and seismic loads.

In the interior of the building, highest importance was placed on the preservation of the auditorium in its current form. One of the big construction challenges there will be the support of the historic balcony and choir stalls during the demolition of the auditorium floor, the excavation of the basement, and the installation of the screw piles.

The site itself imposes many challenges as well. The poor soils required extensive intervention to the existing foundation system. The site's proximity to the Wellington Harbour mean a high water table as well as the consideration of aggressive soils and brackish water. In addition to the already high water table, seasonal inundation and global sea level rise were required to be considered in the design, bringing the design water table up to the top of the basement.

During the construction phase, the constrained nature of the site, with buildings on three sides, will create many challenges for access into the building. As currently conceived, the only access to the building for heavy equipment will be through the south entrance to the West Hall (after the demolition of the MOB Annex). All equipment, including the equipment required for excavation, sheet piling, screw piling, and jet grouting, will need to be brought through this entrance and then driven to various workfaces throughout the building. This will require careful consideration and sequencing from the Contractor.

Temporary works and stabilisation requirements during construction will also be major challenges for the Contractor. While the design was developed to simplify the construction process where possible, sequencing constraints and temporary works requirements are still substantial. Excavation of the basement will be particularly challenging as the installation of temporary retaining structure (typically sheet piling) could create differential settlement in the adjacent auditorium URM walls. This could potentially damage or irreparably destabilise them. Furthermore, the creation of the isolation plane will need to be carefully sequenced and managed to avoid prematurely disconnecting the building from its foundation or excessively weakening the structure. Additionally, where URM walls and columns are disconnected from existing diaphragms, temporary bracing will need to be supplied to maintain the structural integrity of the building.

9. Conclusions

The Wellington Town Hall, having been deemed to be of important heritage and civic value, is being strengthened and uplifted to provide an anchor for a new Civic Music Hub in central Wellington, New Zealand. This is to be achieved through seismic strengthening to increase the capacity of the structure to 100% of that required for an equivalent new building (this included refounding the building and the introduction of a base isolation system) and uplift of the existing facilities to promote its use as a centre for performing arts. The building will also be upgraded to include high end performance and recording spaces. The owners of the Wellington Town Hall have invested considerable resources into the restoration of this historic building, maintaining the heritage fabric of the city while also creating new performance spaces for future generations.

10. References

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