MĪMIRŪ:

The application of an endangered indigenous construction practice onto prototype timber portals to assess seismic resilience.

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Cover figure. The whare Mīmirū was a full-scale, proof-of-concept, three-portal, timber structure temporarily erected at Opeke marae during February to April 2023. Snap-back testing of this prototype produced experimental field measurements of mode shapes and damping to acquire an in-field Natural Frequency. Image: Anthony Hōete / Natural Hazards Commission Toka Tū Ake

0.0 Executive Summary

This research project, Mīmirū, aligns with the research investment priorities of the Natural Hazards Commission Toka Tū Ake Biennial Grant. It seeks to "facilitate research and education about matters relevant to natural disaster damage, methods of reducing or preventing natural disaster damage, and insurance provided" in accordance with the Natural Hazards Insurance Act 2023. This research specifically targeted two of the Commission's five future research investment goals, namely 1. Empowering People and 2. Improving Building Resilience.

The ingoa Māori name of this research was coined to reflect seismic resilience through a mātauraunga Māori lens. Mīmirū, a portmanteau of 'mīmiro' and 'rū', breathes new life into the indigenous material knowledge of mīmiro, whilst also referring to Rūaumoko, or Rū, the god of earthquakes. Mīmirū is thus the recontextualisation of a traditional Māori construction technique within a contemporary seismic setting.

This research project, Mīmirū, empowers people by increasing community participation in disaster risk perception and management. This was principally undertaken through the active participation a local Māori community within the 'foreign field' of experimental seismic research, brokering an understanding the high seismicity of their land and improving the resilience of their structures, particularly Marae buildings. Occurring beyond the confines and conventions of the laboratory and the library, this kaupapa māori research (KMR) was exercised at Ōpeke Marae, located 10km south of Ōpōtiki, in the eastern Bay of Plenty, New Zealand (NZ). The project partnered with the hapū of that marae, Ngāti Ira o Waioweka. This meant that the research was led and co-created by Māori who were guided by the tikanga (protocols) specific to that hapū. Marae are the only place in NZ where Māori can truly be Māori: "They are the most central of all Māori institutions"[1]. Playing a particularly significant role in post-disaster contexts, and typically being first responders, the marae enables the provision of shelter, resources and support for its own people and wider community. Therefore, improving the resilience of marae buildings, such as the wharenui, is paramount in sustaining and enhancing Māori wellbeing.

While Māori are the principal people the research seeks to empower, the research also speaks to people who do not specifically belong to seismic research yet hold an interest in the built environment and who the research could impact. This community includes architects, developers and non-seismic engineers, and so this report has been prepared to increase the accessibility of earthquake engineering. To this end, an extensive glossary is included. The research seeks benefits not just for Māori but for all who live in NZ. To build an Aotearoa more resilient to its natural hazardscape.

The geometry of our proof-of-concept, full-scale prototypical timber portal (14m-width, 7m-high) was determined by a previous field activity conducted in 2022. This was the QuakeCoRE-funded temporary re-standing of the existing historic carvings of Tānewhirinaki, the hapū's ancestral House, where evidence of mīmiro had been previously recognised (Treadwell, 2019). The hapū undertook the installation of the portals as builders, as the process of making and constructing would further disseminate knowledge transfer.

This strategy of people participation as a means to improve building resilience was driven by a desire for the research to impact the future-proofing of marae. As first responders, marae structures need to transform from a position of 'response and recovery' to one of 'reduction and readiness'. Or as Dave Gawn, CEO of the National Emergency Management Agency (NEMA), succinctly puts it: 'to move marae to the 'left of bang''. [2] A

[1] Tapsell, (2002) Marae and tribal identity in urban Aotearoa/New Zealand. Pacific Studies, 25, 141-171.

[2] Gawn, D. (2002) QuakeCore Annual Meeting Plenary Community Portfolio Session: 31st August 2022, Napier

Marine Corps phrase, 'left of bang' in the context of this research, means taking a proactive approach to natural hazards through advanced decision-making based on observation, design and strategic planning. Being to the ‘right of bang’ is synonymous with a reactive after-the-event response.

Beyond retrofitting existing marae structures and deployment in newly built wharenui, this research could advance the structural development of Māori housing, such as pāpakāinga.

The research designed, fabricated, installed and tested post-tensioned, lightweight, laminated timber portals for proof-of-concept seismic and structural resilience within a linear range. The seismic and structural testing comprised four key steps involving both desktop and field-based methods.

Step one: desktop research via digital prototype. A Preliminary Finite Element Model (FEM) of a three-portal (two-bay) section was created using the analytical structural engineering software SAP2000. The FEM was based on four parameters: geometry, material properties, boundary conditions and connections. While the geometry and material properties were known, the boundary condition (foundations) and connections were assumed to be fixed supports and rigid connections, respectively. From these parameters, distinct dynamic characteristics were attained from the FEM, including the portals' natural frequency, mode shapes, and damping.

Step two: field-based research at Ōpeke Marae via analogue prototype. Field testing entailed the application of loads comparable to seismic forces onto a full-scale proof-of-concept prototype consisting of three portals to attain the structure's natural frequency. The applied pull load from a jeep’s winch and the resultant gradual application of horizontal displacements was measured using load cells. Meanwhile the free vibration responses of the prototype, induced upon a 'snap-back' release, was measured by wire-draw gauges that recorded the impulsive excitation of the oscillating structure.

Step three: validation of the FEM. Through the 'overlaying' of comparative data, the configuration of the boundary conditions could be manipulated until the natural frequencies of the digital FEM and analogue field prototypes matched.

Step four: development of a full-size FEM of 20 portals based on the validated Preliminary FEM. The FEM of the complete structure of the future design proposal for the wharenui was used to assess structural performance under various applied loads, including dead loads (self-weight), live loads, wind loads, earthquake loads, and their combinations, in accordance with NZS1170 Structural Design Actions (New Zealand Standard Seismic Performance of Engineering Systems in Buildings).

The results of these tests outlined the portals' drift displacement, stress capacity and ductility within a linear range, validating their seismic and structural resilience. The structural performance of the portals, under various possible load combinations was evaluated by examining deformation levels, induced forces and stresses. After being compared to maximum allowable values, the results of these tests revealed that the structure's drift value was small and within the elastic range of the timber material used for the portals. The minimal displacement was due to the portals' stiffness, attributed to its relatively smaller spacing between adjacent portals as compared to standard western portal systems. Subsequently, the portals' ductility proved to be of no concern since the linear displacement was nowhere near yield. These results indicate that the structure successfully exhibits a high degree of resilience to both wind and seismic forces.

1.0 Technical Abstract

This research project, Mīmirū, applies an Indigenous construction practice mīmiro onto prototype, lightweight timber portals to assess seismic resilience and structural performance. Within the context of improving the building resilience of marae structures, the research was undertaken at Ōpeke Marae, 10km south of Ōpōtiki, in the eastern Bay of Plenty, NZ. As defined in the Building Act 2004, this is an area of high seismicity. Active participation and dissemination of Māori construction knowledge was enabled through a KMR approach, which means embracing and empowering the established partnership between the hapū of Ōpeke Marae, Ngāti Ira o Waioweka and the University of Auckland. Co-designing, installing and testing the seismic and structural resilience of the portals increases community involvement in disaster risk perception and management. This research project, Mīmirū, is located within a broader aim and impact: to restand Tānewhirinaki, the hapū's ancestral home University of Auckland and that was subject to fatal structural damage by the 1931 Napier earthquake (magnitude 7.8). The cultural importance of marae buildings means that the development of seismic and structural resilience will, in turn, empower and enhance Māori wellbeing.

The research methodology operated around a sequence of both in-field testing (analogue) and Finite Element Modelling (digital, FEM) to experiment and prove Mīmirū's response to a variety of induced loads, both lateral and vertical. The purpose of undertaking both in-field testing at Ōpeke Marae and FEM aimed to ensure the accuracy and validation of the developed FEM element through comparison with the physical prototype's response. The four-step research method allows for the FEM analysis of a more developed, full-size structure to evaluate Mīmirū's seismic and structural resilience, thereby enhancing its role in disaster risk management.

Step 1. A Preliminary FEM was created of three portals based on four key parameters: geometry, material properties, boundary conditions and connections. The geometry was previously determined by re-standing the historic carvings of the original whare tīpuna Tānewhirinaki (Te Whare Rangitupu project, Hōete, 2022) and used a shorter 3.4m three-portal section from the longer 24.8m twenty-portal proposed wharenui. The material properties were determined by the specification of the newly engineered pinus radiata components. The boundary conditions and connections were, however, presumed to be fixed and rigid. Step 2. A full-scale analogue prototype was constructed on-site using post-tensioned glulam members. These were installed and erected by hapū participants to perform an analogue 'snap-back' release of real-world loads. Step 3. For both the Preliminary FEM and analogue prototype, the four key parameters produce three distinct dynamic characteristics which can be measured. Natural frequency, mode shape, and damping ratio can be calculated from the measured free vibration data obtained after releasing the applied pull load. To validate the Preliminary FEM's natural frequency against the measured natural frequency of the analogue prototype, the presumed-fixed boundary condition was now replaced with springs to reduce rigidity and stiffness and allow for gradual adjustment of the resultant natural frequency until it matches that of the prototype. Frequency matching was achieved by adjusting the spring stiffness of the foundations without altering the assumed fixed connections between the various elements of the portals. Step 4. The validated FEM (3 portals) was subsequently used to develop a FEM for the full-size structure (20 portals). This full-size FEM was used for further assessment of seismic resilience and structural performance of the portals under various loading cases and combinations in accordance with up-to-date NZS 1170 Structural Design Actions. These load combinations primarily considered the self-weight of the portal and roof system, live loads, and wind and earthquake loads. The success of the full-Size FEM testing lies in its drift displacement, stress capacity and ductility within a linear range. The peak responses of the structure, considering all load cases and combinations, were minimal due to its substantial stiffness, resulting from reduced spacing between the portal frames. The results successfully indicated seismic and structural resilience of Mīmirū.

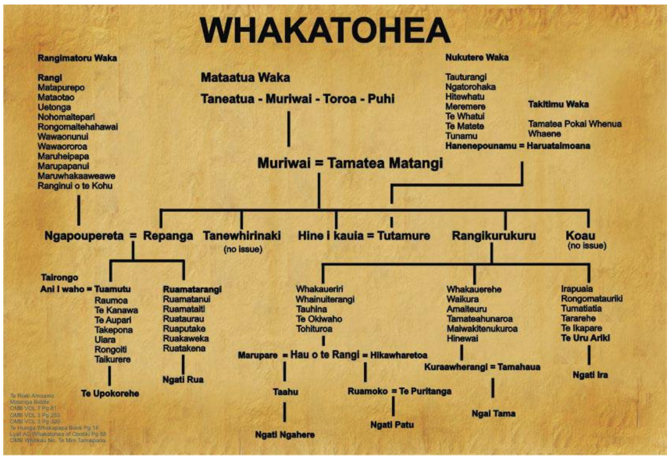
2.0 Introduction

The innovation within this 'Mīmirū' research lies in the application of traditional māori architectonics to a contemporary seismic setting. In doing so, the endangered, indigenous construction technique of 'mīmiro' has been successfully proven to be able to sustain 'rū', or earthquakes.

First Evidence. Before the arrival of European colonists in Aotearoa NZ, there was evidence of Māori using a traditional construction technique to build their whare. This technique called mīmiro has its origins in boat building. The late-1970s excavation of the 17th century Māori lake village Kohika provided the first physical evidence of mīmiro being used to stabilise whare structures. Meaning 'to lash or bind with a cord', the cross-sectional stability of mīmiro is achieved through the combined application of tensile and compressive forces on various timber components, such as a poupou (wall post), heke (rafters) and a triangular tāhuhu (ridge pole), that have been interlocked and post-tensioned. Tauwhenua was the traditional plaited natural rope made from muka flax, which slightly deflected and flattened the precambered heke, increasing their length when tensioned. This holistic structure allows the whare to achieve the cross-sectional stability necessary to resist seismic and lateral wind loads. The subsequent introduction of colonial fixing methods in NZ, particularly nails, rendered the use of mīmiro as an architectural construction technique endangered.[3] Of the hundreds of whare in Aotearoa today, there is only known example that still uses mīmiro, and that is Whakaata, carved by John Rua (Ngāi Tūhoe) in 1976.

The māori construction legacy that can be traced from 17th-century Kohika to Whakaata establishes mīmiro as a critical techno-cultural bridge between peoples and places. Other evidence of the application of mimiro was identified in the historical carvings of Tānewhirinaki (Treadwell, 2019), a wharenui that has not stood since the 1931 Hawke's Bay earthquake. This whare tīpuna of the hapū Ngāti Ira o Waioweka was once lauded by the scholar James Cowan as "the best extant example of a native decorated building"[4]

Ngāti Ira o Waioweka Whakapapa[5]



Waioweka pā (Ōpeke Marae Pepeha)[6]

Ko Mātiti te maunga

Ko Waioweka te awa

Ko Ōpeke te marae

Ko Irapuaia te whare tipuna

Ko Te Kurapare te whare kai

Ko Ngāti Ira te hapū

Ko Whakatōhea te iwi

Figure 1. Te Whakatōhea iwi take their name from the tohetohe *(stubbornness) of their tīpuna, Muriwai. The hapū Ngāti Ira takes their name from Muriwai's grandson, Irapuaia, after whom the wharenui at Ōpeke marae in Waioweka is named.*

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[3] Treadwell, J. (2019) "Tuia Te Whare: The culture of Māori architectural technology.", University of Auckland
[4] Cowan, J. (1930) The Māori Yesterday and Today, Whitcombe and Tombs (Christchurch), p123
[5] Te Whakatōhea Whakapapa. https://tewehioterangi.com/whakatohea.html. Accessed 22 November 2024.
[6] Hōete, A., Hemi, J. *Tānewhirinaki 2022 Conservation Statement* (2022), 9.

In 2022, an aligned QuakeCoRE research, Te Whare Rangitupu (Hōete, 2022), took place on the Ōpeke Marae of Ngāti Ira. This earlier research is important as it led to the co-design of a new wharenui that could contain the existing carvings of Tānewhirinaki and, as importantly, could incorporate the traditional Māori construction technique should future research deem it feasible. That 'future research' is today this research project, Mīmirū. And so one immediate research impact this research will be the revitalisation of an endangered indigenous construction practice onto a proposed new seismically resilient wharenui. This design proposal has informed the geometry of the portals tested within this research project: in the geometry of the Preliminary FEM (Step 1), the fabrication of the analogue prototype (Step 2) and the design of a full-size twenty-portal structure (Step 4).

Te Whare Rangitupu established the geometry of the Mīmirū portals for seismic and structural testing. The dimensions set a 14m-span and a 7m-height from the ground to the portals' apex. The removal of any pou tokomanawa is innovative as within the whare mīmirū, the tāhuhu is supported not by central posts but by the lateral forces of post-tensioned heke. Tā Moko Mead has commented that being 'pou free' was not uncommon with pre-colonial whare[7] , so the whare Mīmirū also reinstates the traditional column-free whare.

The structural design was advanced in consultation with Alistair Cattanach, a timber specialist and Chartered Engineer from Dunning Thornton, and Andrew Hewlitt from Red Stag Timber Lab. The research was not conducted on the original carvings, which today have deteriorated and are in need of protection. Recognising that Māori were fast adoptors / adaptors of technology, this research, Mīmirū, instead was conducted on newly engineered timbers that embrace the traditional tectonics of cambering and mortise-and-tenon jointing. In this way, the architectural application of mīmiro was tested and validated while allowing Ngāti Ira to retain guardianship of the mātauranga that lies within their carvings.

The structural performance and testing of mīmiro in a seismic setting hasn't previously been documented. This Mimirū research is indigenous innovation that has arisen through the 'transdisciplinary triangulation' of Māori architectonics, construction and structural engineering. In examining this indigenous, post-tensioning technology, Mīmirū challenges the subconscious bias that considers Māori whare to be architectonically simplistic. Instead, it re-brands the whare whakairo (carved meeting house) as a house of technology. In doing so, it demonstrates that Māori living in traditional times (te ao tāwhito) were not only gifted in toi arts and crafts but, moreover, had a sophisticated understanding of architectural technology. The research deployed Mātauranga Māori (mīmiro) to deliver building resilience to rūaumoko (Mīmirū).

[7] Email from Tā Hirini Moko Mead to Anthony Hōete, dated 15 February 2024

3.0 Discussion

3.1 Methodology

Objective: To demonstrate the Structural Resilience of a Lightweight Timber Portal within a Linear Range through Code Compliance to NZS 1170.2 Structural design actions, Part 2: Wind actions.

Research Project Methodology steps:

Step 1: Built a Preliminary Finite Element Model (FEM) (three portals) based on the two known parameters of Geometries and Material Properties, and two presumed parameters of Boundary Conditions (Foundations) and uncertain Connections to acquire a calculated Natural Frequency.

Step 2: Undertook in-field (analogue) snap-back testing on a full-scale proof-of-concept prototype (three portals) to produce experimental field measurements of mode shapes and damping to acquire an in-field Natural Frequency.

Step 3: Validated the Preliminary FEM (Step 1) with the In-Field Tested Prototype (Step 2)

Step 4: Develop and test a full-size FEM (twenty portals) under various NZS1170-compliant load combinations and Dead Loads

The seismic and structural resilience of the Mīmirū portals is contingent on its drift displacement, stress load capacity and ductility within a linear range. These three characteristics are governed by the design of the portal, its inherent properties, and thus, its ability to resist a variety of externally applied forces, which are trialled through this research's methodology.

The response of a portal to applied loads is known as the drift displacement and this can result in two types of structural deformation: elastic and plastic. The elastic potential of the structure determines how much displacement the portal can undergo and yet still revert to its original state if the applied load is removed. Therefore, by definition, elastic systems are lineal. The linear range of the portal is thus defined by the relationship between the portal's range of displacement in the direction of an applied force.

Plastic deformation occurs when there is residual displacement outside of the structure's elastic range, causing the structure to deform permanently. This happens when the material is subjected to tensile, compressive, torsional or bending stresses that exceed its yield strength. This yield capacity acts as a reference point for measuring the ductility of the system, manifesting its structural response to induced loads on it. Ductility is often quantified by a ratio, which compares the deformation at ultimate failure and the deformation at yield capacity. The stress load capacity of a system determines how much force per unit area it can take before succumbing to elastic, plastic or fluid behaviour. If, due to excess stress, the system's drift displacement exceeds the linear elastic range of the timber used to fabricate the portals, then the system enters a ductile phase, transitioning from elastic to plastic behaviour.

Imposed loading systems on the portal are critical to consider when determining what type of resilience Mīmirū is capable of. In addition to the portals' self-weight (dead load), some natural live loads, namely snow, rain, earthquake and wind loads, are commonly found acting on a building's structure. In addition, the occupancy (live load) of the building in question (i.e. how many people it can accommodate) can also speak to resilience, as its yield is determined by the portals' stress load capacity. Since the climate of the Bay of Plenty testing site isn't prone to snow, this project focuses on improving resilience to earthquake and wind loads.

3.1.1 Preliminary FEM

A Preliminary Finite Element Model (FEM) was created using SAP2000 based on modal-domain data, rooted in known and assumed conditions of 4 key parameters; geometry, material properties, boundary conditions (i.e. foundations) and connections. These parameters dictated the digital (and later physical) construction of the Mīmirū portals:

1. Geometry (known from the architect's drawings)
2. Material Properties (known from material specification knowledge)

- RedStag TimberLab: Structural Grade GL8, Modulus of Elasticity parallel to End Grain (8,000MPa), Pinus Radiata GL8 Density (550kg/m^3) (from NZS 1328.2)
- Short Duration of Modulus of Rigidity for Beams (530MPa)
- Tensile Strength/Parallel (10MPa)
- Compressive Strength/Parallel to Grain (24MPa)
- Bending Strength (19MPa)
- Shear in Beam (3.7MPa)

3. Boundary Conditions (i.e. foundations): how the structure is fixed to the ground
4. Connections (between components): Assumed fixed for the first mode shape

While not typically used for simple structures, such as portals, undertaking FEM analysis ensures accurate reflection of measured data (when compared to a physical prototype) to then validate the structural capacities of the Mīmirū portals. This methodology devises a numerical simulation of the portals' snap-test behaviour and relates it to the portals' functionality, performance and lifecycle. A development of this FEM can then be used for further analysis, such as non-linear time history or plastic-behavioural analysis.

3.1.2 In-Field 'Snap-back' Prototype Test

The 'snap-back' technique refers to the gradual application of horizontal displacements onto a full-scale prototype to measure its response to an impulsive excitation. Enabling reliable on-site modelling helped validate the portals' real-world capabilities, as well as refine the theoretical parameters. Both the Preliminary FEM and full-scale prototype produced three distinct, dynamic characteristics that were monitored and measured; mode shapes, damping and natural frequency.

The installation was set to happen in two stages; (1) installation of the poupou (wall posts) set into concrete footings in week 7, 2023, and (2) installation of other elements, testing and dismantling in week 11, 2023. The four-week gap allowed for the curing of the concrete footings to full Strength, however, this became a 10-week gap due to a fabrication problem by suppliers RedStag TimberLab after a spindle from their main CNC machine (WMP240 5-Axis Gantry Bridge) broke in week 8.

Figure 2. Stage 01 showing the two sets of poupou hung from scaffolding and awaiting the concrete to be poured into the footings. Note: the field trailer to the right. Image: Anthony Hōete.

With the mid-summer weather predicted as fine to overcast, Stage 01 of the installation occurred from 9th – 11th February 2023. Off-site manufacture and digital fabrication of all timber components, as well as the use of various surveying equipment, including a Leica Total Station TS06, ensured the accuracy of the poupou set out. The installation of the six poupou was simplified through the use of a short aluminium truss, which enabled erection as two sets of poupou, one for each side of the portal.

Figure 3. Locations of hand augered holes. Image: Sonny Vercoe.

Whilst the first stage of installation progressed, the testing site's ground conditions were determined using desktop investigation, hand shear vane (HSV) testing, and results from existing geotechnical tests. The desktop investigation involved assessing the interactive Geological Map of New Zealand (GNS Science, 2020), which showcased geological units of surface distribution at scales 1:250,000 and 1:1,000,000. This indicated a ground composition of gravel, sand, silt, mud and clay with local occurrences of peat. The Verification Method B1/VM4 Foundations (MBIE, 2017) was used to determine the site's ground condition ultimate bearing capacity (q_u) and confirmed NZS3604 compliance for *good ground* (SNZ, 2011). The HSV testing determined peak undrained shear strengths (s_u). Earlier geological tests on a neighbouring marae (within 100m range of test site) that used shallow, intrusive hand-augering at 9 exploratory locations confirmed that, it too, was founded on *good ground*.

With the autumnal weather for the period being a mix of fine and heavy rain, Stage 02 of the installation belatedly occurred between the 20th and 23rd of April 2023 due to supplier issues with the portal fabrication (the Weinmann WMP240 5-axis CNC machine experienced a major failure and became inoperable for six-weeks). The RedStag TimberLab engineered wood products were delivered by Robert Monk Transport articulated lorry to a yard in Ōpōtiki and then on to the marae by hapū associated vehicles. The installation process followed the PI's methodology and involved a HiAB truck crane, operated by scaffolder John Hunia (of Rāwhiti East Coast Scaffolding) raising the tāhuhu section onto a central scaffolded tower. Once the height was confirmed by the PI, the heke were lowered into place, followed by the application of tensile components to the structure to post-tension it.

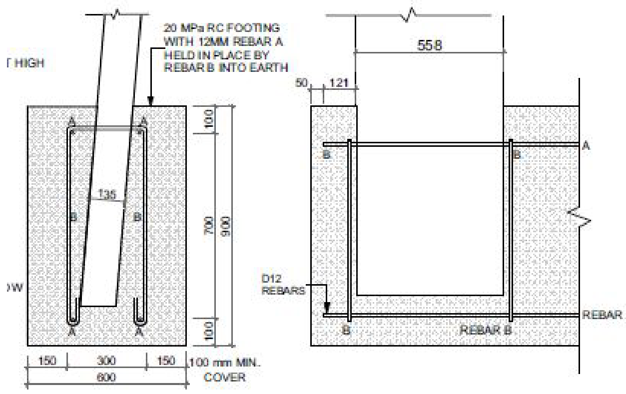


Figure 4. The 900mm deep reinforced concrete footings were dug by hand. Image: Anthony Hōete.

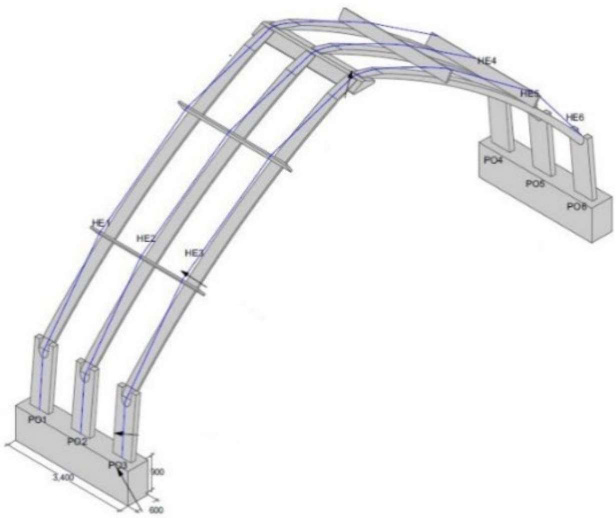


Figure 5. The full-scale prototype consisted of three portals (tāhuhu ridge beam section, six curved heke rafters, 4 kaho purlins and six poupou (inclined posts). Image: Anthony Hōete.

The scaffolding served two purposes: (1) to support, temporarily, the installation of the portals, and (2) to hold all measuring load-gauges and motion sensors independent of the portals themselves. The tensile elements were procured from the sailing industry with input from Harken / Fosters Ship Chandlery (*refer to Drawing 3-051B*) and included:

- Ronstan Series 50 High Load Exit boxes
- Harken 6230 black 45mm Aluminium Element Block Swivel

- Spinlock XAS Rope Clutch
- Harken B8A single-speed, ratcheting, plain-top winch and aluminium lock-in handle
- 98mm S/S Diamond Padeye
- 200mm Nylon Horn Cleats
- Fineline Classic 10mm double-braid Black Rope (7.75kg weight per 100m) which had a constant 2kN pre-stressing force

Instrumentation was independently fixed to the scaffolding and included draw-wire sensors placed along the portals in nine locations (Figure 6) and several load cell gauges to measure the post-tensioned load across the three timber portals.

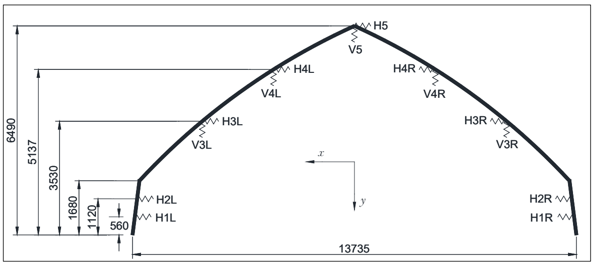
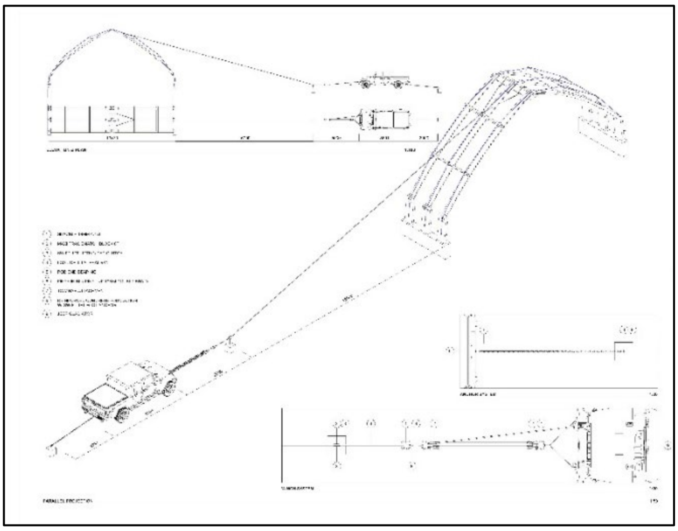


Figure 6 (above). Draw Wire Sensor placements to detect vertical and horizontal displacement. Image: Anthony Hōete.

Figure 7 (right). Preview of Drawing 3-053 Full Test System, demonstrating Horizontal Loading System Methodology. Image: Anthony Hōete.



The vertical loads include the dead load of all object components that would comprise the proposed future wharenui plus the self-weight of the structure itself. 14kN of vertical loads were exerted via suspension of 1m^3, 1,000L (2 tonnes) intermediate bulk containers (IBCs), from the portals' tāhuhu (ridge beam) to simulate these roof build-up and historic carving dead loads. The following Table 1 details the specification:

Roof Build-Up *(refer to Drawing 3.032C)* **<u>Sub-total roof weight (excl. timber portal) 10,694 kg = 104.8kN</u>**	• TRS SuperSeamTM Metal Roof Cladding w/ 250-450mm Tray Pan (double swage to avoid oil canning) • Thermakraft Anti-abrasive Self-supporting Breathable Synthetic Underlay (407mm) • WPB Plywood (18mm) w/ Stainless Steel screw-fixed @300crs • 125mm treated battens @400crs w/ 100mm thick R3.2 ceiling insulation min. 25mm ventilation on • Tyvek Supro Plus breather membrane roof underlay on • 18mm thick ceiling sarking S/S screw fixed to • 70mm thick x 50mm wide purlin on edge at 600crs with pre-drilled central holes to take 5mm diameter S/S tensioning cable
Existing Carvings of Tānewhirinaki **<u>Sub-total suspended carving weight: 4,571 kg = 44.8kN.</u>**	• Average Heke length (5.5m), Width (0.35m) • Total no. of Heke (36) • Original Tāhuhu was destroyed • Poupou Carvings self-supported on the ground
Self-weight of Proposed Portal (Using the profiles of	• Cambered Heke, GL8 (415mm ,330mm x 165mm half-round), 2.4m long (6,880kg) notched into;

the 3 main components)*(Refer to Drawing 3-050G)* **Sub-total timber portal weight 11,251kg = 110.3kN**	• Top end: 650mm wide x 200mm high triangular GL8 Tāhuhu (1,011 kg) and; • Bottom end: 540mm x 135mm Poupou, GL8 Piers @ 1250mm crs (3,360kg)
Total dead load: 26,516 kg = 259.9kN *(Roof Plan Area = 264m^2, Roof Dead Load (including carvings, excluding timber portals) = 100kg/m^2*)	

Horizontal loads were applied via a winch-and-pulley system (*Figure 7*) with a load twice the Gross Vehicle Weight Rating (GVWR) of the Jeep Gladiator attached to it (5.2 tonnes). Concrete blocks anchored the pulley system. A winch rope was attached up to a 'triple pulley', and back again to an anchor onto the Jeep. This allowed for a 6x multiplied horizontal load. There was also a main pull cable (wire rope) that ran from the Jeep's anchor to the Mīmirū portals and back, doubling the already 6x multiplied load. Overall, the horizontal loading system created an embedded 12x load multiplier.

Wire draw gauge displacement sensors were used to measure both horizontal and vertical displacement during the snap-back test. Load cell displacement Sensors were also attached to the post-tensioned cables along the portals' arch to ensure that all three portals were experiencing the same tensile force of 2kN. This post-tension force was applied by a rope that was cleated onto a poupou at one end and tensioned by a winch at the other. Wire draw gauge sensors accurately measured the portals' oscillations (vertical and horizontal), caused by the snap-back release. Whilst the portal did not fail, the testing ultimately stopped out of concern for damaging the chassis of the attached five vehicles.

Seeking to empower the source community, the field testing occurred on Ōpeke Marae on Saturday 23rd April 2023. The test operations occupied a site area of approximately 1,400 m^2 (accounting for the test unit, field-testing trailer, and loading equipment). With a slight fall of 1:70 (South to North), the site was clear and quasi-flat. It was surrounded by the neighbouring marae (complex of Māori buildings), papakāinga (community housing) and the urupa (cemetery).

Figure 8. Prototype portal strucutre showing independent scaffolding holding measuring gauges. In the bottom centre, IBCs carry the simulated vertical load. Image: Anthony Hōete.

3.1.3 Validating Preliminary FEM with In-Field Prototype

Validation of the Preliminary FEM can be undertaken through two approaches: direct and indirect. A direct FEM approach involves adjusting the material properties (mass and stiffness) of the structure to reconfigure natural frequencies. In light of this research's aim to improve seismic resilience in buildings, an indirect FEM approach was taken. Rather than change the geometry or material properties, iteration of boundary condition behaviour (i.e. the foundations) was manipulated against the natural frequency of the in-field prototype and proceeded until there was a good match. Comparison and adjustment of both numerical (FEM) and experimental (prototype) modal parameters minimise the occurrences of 'residuals' in the validation process. Once validation of the Preliminary FEM is attained, it's possible to investigate:

1. Seismic Resilience: the ability of the Mīmirū portal to:

    (a) resist an earthquake of a certain magnitude/code case loading, and

    (b) behave at failure (demonstrating ductility or brittleness), and whether any 'limited damage' enables future reuse

2. Future Potential: the possibility of the Mīmirū portal to span 40m+, beyond the current economic span of Glulam, and therefore have commercial viability. (*refer to 5.0 Future Works*)

3.1.4 Load Case Scenarios on Full-Size FEM

The seismic and structural resilience of the Mīmirū portals was tested using a SAP2000, Full-Size FEM of 20 portals. The testing was computed under three main combination loads (compliant with up-to-date NZS1170 codes) concerning self-weight, live loads, wind and seismic loads to determine where peak values arose in relation to the portals' drift displacement and stress demands. These load combinations were referred to as Wind 01, Wind 02 and Seismic. An 'Envelope' load combination (wind + seismic) took into consideration the dead loads of the proposed, restorative Tānewhirinaki structure using the Mīmirū portals. The caseload test results were then compared to the maximum allowable values to discern where any critical inefficiencies lay when the portals' geometry, material properties, foundations and connections experienced these loads. Monitoring the structure's response to variations of lateral wind, gravity and seismic loads proved a quantitative extent on how resilient the Mīmirū structure can be, both seismically and structurally.

3.2 Analysis

Throughout the testing process, analysing the behavioural qualities of various timber and tensile components revealed the Mīmirū portals' structural capabilities. In particular, the chosen loading systems applied tensile forces, and the overall derived elasticity of the portals demonstrated the influence of the four key parameters' on its response to the snap-back test and caseload scenarios. These produced three dynamic characteristics that ultimately validated Mīmirū's resilience: mode shapes, damping and natural frequency.

Natural frequency (f) refers to the frequency at which a system (i.e. the portals) oscillates when not subjected to a continuous or repeated external force. It is dependent on the system's stiffness and mass and, therefore, is sustained as long as the system is able to vibrate freely. Natural frequency is inversely proportional to the Natural Period (T) (the time it takes for one full cycle of oscillation to occur) and can be described as $f = 1/T$. This means that a higher natural frequency, due to a stiffer structure, will have a shorter natural period (take longer to complete one full cycle).

Damping refers to the rate at which the free vibration of the system decays. This energy dissipation occurs because several mechanisms are simultaneously acting on the system. These mechanisms can be friction from steel connections, cracks in foundations or concrete elements, or friction between structural and non-structural elements (e.g. partition walls and portals). The Mode Shapes visually represent the initial displacements, or changes in a system's movement, that cause it to vibrate at its natural frequency. This movement is influenced by damping and showcases how the system dynamically responds to the forces and mechanisms acting on it.

(01) The Preliminary FEM assisted in translating the design-driven digital model of the proposed Tānewhirinaki Mīmirū structure (*Figure 11*) into an analytical model catered to experimentation and testing. With the geometry and material properties known through fabrication, the connections were assumed to be moment-resisting, and the foundation was assumed to be fixed, as it would be optimal to have minimal sliding of the concrete footings. The attained dynamic characteristics of the Preliminary FEM were a good indication of whether, at its core, the Mīmirū portals had elastic potential, and thus, were seismically resilient.

The vertical 14kN supplementary load was modelled as a line mass, as it was decided that the IBCs would influenced the experimental period testing. The line mass was applied across the length of the tāhuhu, mimicking the constant dead load (roof build-up, suspended carvings and portal itself), with 1.25m interspacing between each pair of heke. This minimal interspacing contributed to the overall stiffness of the portals. The post-tensioned cable was modelled as a tendon element, with a constant 2kN pre-stressing force. It's yield characteristics were determined through a tensile test performed in a laboratory on a 20m length of rope. In this test, the rope failed at 4.6kN and stretched 1m. Attaining the yield (4.6kN) and ultimate stress capacity (0.06GPa) of the rope aided in finding it's elasticity (1.17GPa) (i.e. the rope's ability to withstand changes in length when under lengthwise tension or compression). The coefficient of thermal expansion was assumed as 50 × 10-6 /°C. Knowing the maximum allowable values provided validated parameters within which to test for seismic and structural resilience. Factoring in the constant force ensured that the pre-stressing of each portal was consistent, enabling the portals to move as a holistic system.

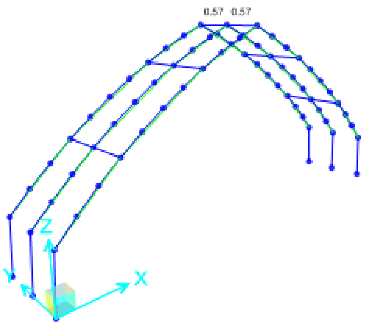


Figure 9. Preliminary FEM SAP2000 Isometric showing Line Mass and Tendon Elements. Image: Sonny Vercoe

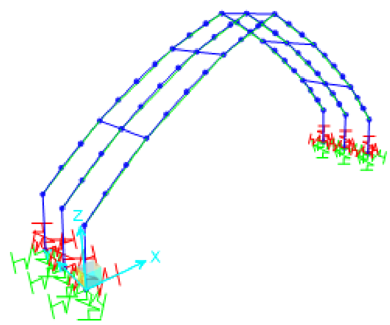


Figure 10. Preliminary FEM SAP2000 Isometric showing inclusion of Rotational Springs at Foundation. Image: Sonny Vercoe

The applied pull load was measured using load cells, while the free vibration responses of the prototype, induced upon release of the applied load, were recorded using accelerometers. The forces of the portals, line mass (across tāhuhu) and tendon element (post-tension cable) were applied to a 0.38s experimental period to test for it's dynamic characteristics. *(Figure 9).*

(02) The snap-back release test on the 3-portal prototype enabled real-world horizontal and vertical displacements onto the portals to test the initial assumptions made for the Preliminary FEM. The first dynamic characteristics (mode shapes, damping and natural frequency) were defined by these assumptions.

(03) Validation of the Preliminary FEM was exercised through adjustment of the portals' boundary condition (i.e. foundations) and tested the portals as an elastic system. The fixed foundation used for the first mode shape was changed to **rotational** spring connections to reduce foundational stiffness and validate against the experimental period of 0.38s. Its displacement was modelled as a 'lineal spring in x and z' and rotational in y (*Figure 10*), with a stiffness of 2566kNm.

(04) Lastly, NZS1170 load combination scenarios tested on a Full-Size FEM allowed for validation of the Mīmirū portals' seismic resilience at its proposed scale (19 portals). Three main case load scenarios (Wind 01, Wind 02 and Seismic) tested on the Full-Size FEM produced the system's drift displacement, stress capacity and ductility. These characteristics demonstrated where peak values occurred, thus which loads (i.e. wind, seismic) would be considered the worst-case scenario. The 0.57 kNs^2/m^2 line mass, which mimicked roof and historic carving loads, was remodelled separately from the 19 portals, unlike the Preliminary FEM. The walls and roof have the same properties (non-structural) and hence were modelled as 'shells'. Because of this, the wall's boundary conditions were roller supports. *(Refer to Appendices Page 26)*

4.0 Conclusions

The Finite element modelling and subsequent in-field testing at Ōpeke Marae demonstrated that the application of the endangered, indigenous Māori construction technique, mīmiro, was effective in providing cross-sectional stability to a prototype timber portal structure. All components of the structure, both timber and tensile, sustained tension without failure, surpassing the code loadings for seismic strength by 2.5x. This means the portal can achieve a level of seismic resilience such that the original Tānewhirinaki wharenui would not have succumbed to the 1931 earthquake. Resultant drift displacement, stress capacity and ductility validated this resilience.

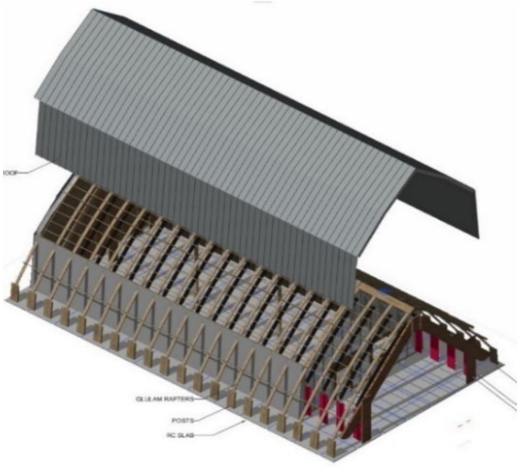


Figure 11. a digital model of the proposed Tānewhirinaki wharenui using mīmirū portals. The geometry of this proposal established the geometry of the portals used in this research:

- 14m span, 6.5m height, 24.8m length
- 390m^2 Roof Area
- 264m^2 Roof Plan Area

Image: Anthony Hōete

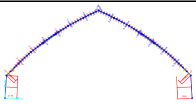
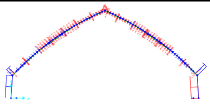
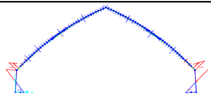
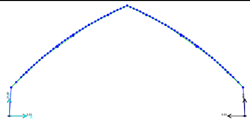
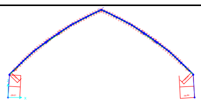
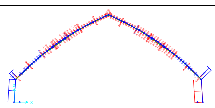
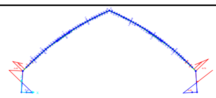
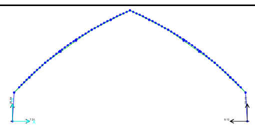
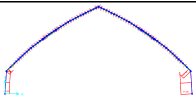
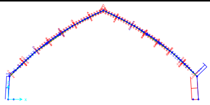
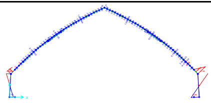
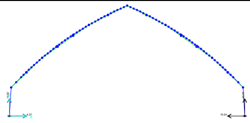
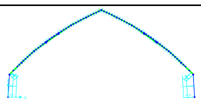
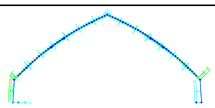
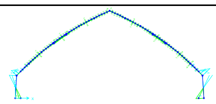
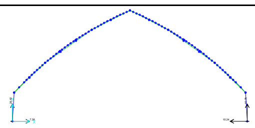
Lateral wind loads were applied in all combination case load scenarios since this is an ever-present force exerted on structures, though it can vary in speed, direction and magnitude. The gravity loads applied to the portals were the variable component which determined whether the overall portal experienced tensile or compressive stresses.

Wind Case Load Scenario 01 parameters involved a standard gravitational force (0.9N) x (the portals self-weight) + auto-loaded NZS 1170.5 lateral wind loads across the portals' span (14m). This created tension forces on the leeward sides of the portals, acting upwards. Tensile forces occur when an object is stretched while experiencing an applied force. This tension acts in the opposite direction to the applied force (i.e. wind).

Wind Case Load Scenario 02 had a 20% safety factor increase (i.e. the load-carrying capacity of a system beyond what it actually supports). It involved a factored gravitational force (1.2N) x (the portals self-weight) + NZS code lateral wind loads. The increase in gravity created compressive forces on the windward sides of the portals, acting downwards. Compressive forces occur when power or pressure is exerted on an object, causing it to be compacted or compressed.

The Seismic Case Scenario involved both horizontal and vertical loads. The horizontal loads were defined by automated loadings generated by SAP2000 in accordance with NZS 1170.5. The vertical loads included the self-weight of the portals, + (live loads) x the NZS 1170.5 earthquake load combination factor of (0.3). This combination factor accounts for uncertainty or variability in experienced earthquake loads (Ψ_E).

An overall 'Envelope' caseload scenario involved both lateral wind loads and seismic loads in determining the extent of each load type's influence on certain parts of the portals.

Load combinations	Axial force (kN)	Shear force (kN)	Bending moment (kNm)	Reactions (kN)
$0.9G + \Psi_C Q + W$ (Wind 01)				
$1.2G + \Psi_C Q + W$ (Wind 02)				
$G + \Psi_E Q + E_u$ (Seismic)				
Envelope (Wind + Seismic)				

The Table 2 above illustrates the comparative summary of the portals' structural responses under various load combination scenarios (deformed shape and displacement taken from the apex). The application of three caseload scenarios established that the relatively smaller dimensions and spacings of the Mīmirū portals, as compared to Western industrial portals, allow for stiffness that keeps the portal's drift value small and within the elastic range of the timber material used for the portals. This stiffness is evident through the natural period (T) of the Full-Size FEM being 0.14s (with a natural frequency of 7.72Hz), as compared to the Preliminary FEM's experimental period of 0.38s (2.63Hz). Therefore, since the drift displacement was nowhere near yield, ductility doesn't pose a concern.

The results of the caseload investigation indicated that the Wind 02 loadings produced higher values than Wind 01 overall, but the Seismic caseload produced a larger horizontal displacement (1.76mm versus Wind 02's 0.55mm). The shear force range of the Seismic Case Load was -7.95 kN to 16.61 kN, as compared to Wind 02's -7.28 kN to 12.6 kN shear force range. Therefore, horizontal displacement is governed by seismic loads, while wind loads govern vertical displacement. With the 'Envelope' test, seismic loads seem to mainly influence the portals' right-hand side, while wind loads influence the left. Additionally, the arched form of the roof generates suction on its leeward side, demonstrating the criticality of the wind loads acting on the portal, as compared to seismic.

Considering the lightweight nature of the Mīmirū structure and the small mass (weight) of the lightweight timber roof, this concludes that overall, at the foundations, the lateral seismic forces are less critical than the wind-induced lateral forces. However, these results indicate that the structure exhibits a high degree of resilience to both wind and seismic forces.

5.0 Future Research

Following the successful application of an endangered indigenous construction practice (mīmiro) onto prototype timber portals to assess seismic resilience, Mīmirū has proven to be both structurally and seismically resilient, within a linear range for wharenui-sized structures. Through improving building resilience of wharenui structures and, thus, empowering the people of the source community, Ngāti Ira o Waioweka, there is future potential for the Mīmirū portals system to be utilized at a larger scale. This would make it a commercially viable structure, rooted in Mātauranga Māori technology. The possibility for Mīmirū to span 40m+ would exceed the current economic span of glulam components (circa 35m) and enable new investigations into the use of post-tensioning at scales comparable to industrial warehouses and plane hangars.

The 2025 WhareWaka project, led by Professor Anthony Hōete, is the first opportunity to investigate the application of Mīmirū as a large 40m clear-span hangar for Unmanned Aerial Vehicles (UAVs). This proposed research will be sited at the Tāwhaki National Aerospace Centre, in Ferrymead, Ōtautahi, whose Kaupapa (purpose) is it "to advance Aotearoa's aerospace industry and rejuvenate the unique whenua (land) at Kaitorete… by weaving together mātauranga Māori, and the very best research, science and cutting-edge innovation in aerospace and environmental rejuvenation to ensure our people and planet flourish for generations to come"[8] This investigation is to be developed with Associate Professor Sherif Beskhyroun and other specialist timber engineers in the endeavour to broaden the scope of Mīmirū within the construction industry.

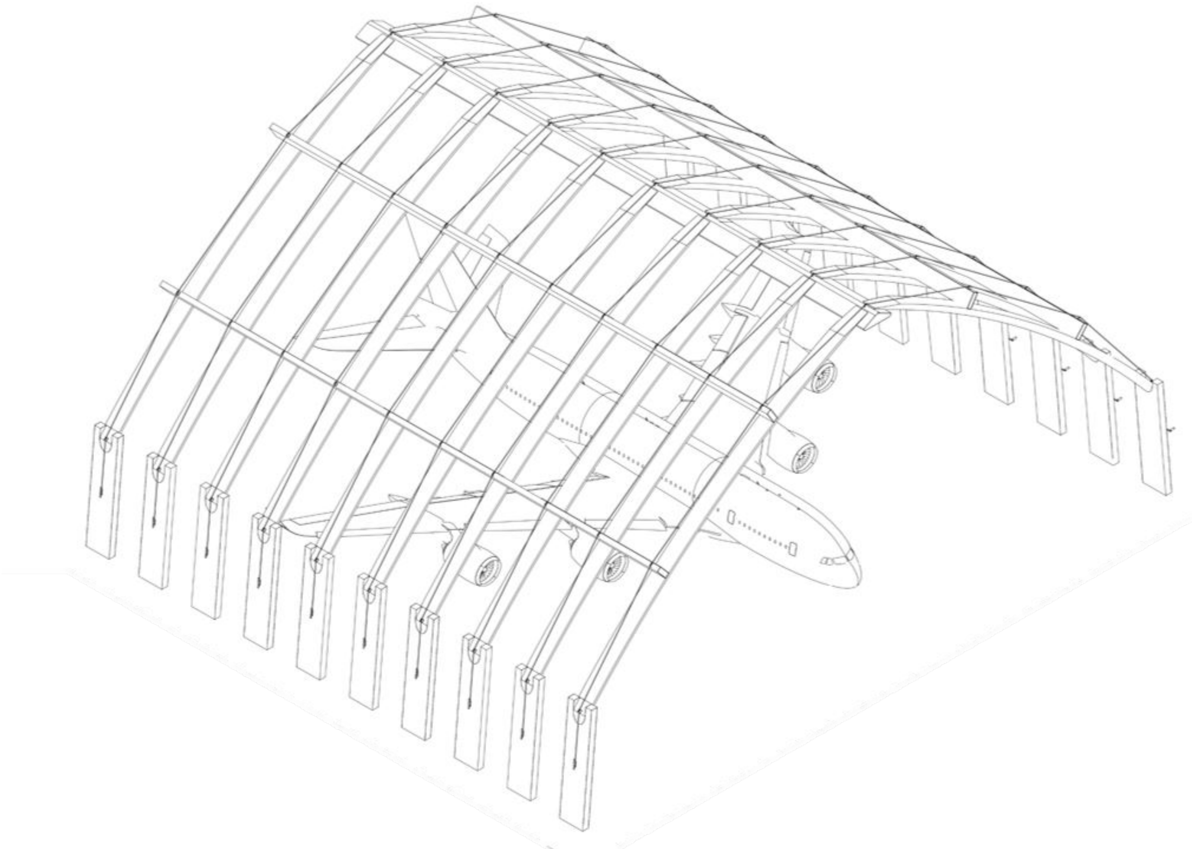


Figure 12. Proposed Mīmirū Portals used to create a UAV hangar spanning 40m+. Image: Anthony Hōete

[8] Tāwhaki National Aerospace Centre, "Kaupapa," Tawhaki, https://tawhaki.co.nz/kaupapa/

6.0 Glossary

In order to empower people in their understanding of seismic resilience and improving the structural capabilities of our cultural and socially significant architecture, this glossary enables one to fully understand, and thus, actively participate in spreading knowledge. The ability to understand the knowledge that has transversed centuries allows us, today, to appreciate the skills and techniques of those gone before us; and adapt it to contemporary ideas.

6.1 Te Reo Terminology (Te Aka Māori Dictionary)

Hapū	Kinship group, clan, tribe, subtribe - section of a large kinship group and the primary political unit in traditional Māori society. It consisted of a number of *whānau* sharing descent from a common ancestor, usually being named after the ancestor, but sometimes from an important event in the group's history. A number of related *hapū* usually shared adjacent territories forming a looser tribal federation (*iwi*).
Heke	Rafter (part of roof-build up)
Ingoa Māori	Māori name
Iwi	extended kinship group, tribe, nation, people, nationality, race - often refers to a large group of people descended from a common ancestor and associated with a distinct territory.
Kaupapa	Topic, policy, matter for discussion, plan, purpose, scheme, proposal, agenda, subject, programme, theme, issue, initiative.
Kohika	A preserved 17th century Māori lake-village near Whakatāne, in the Bay of Plenty. Located on the banks of a lake in the extensive swamp lands of the Rangitāiki Plains.
Marae	Courtyard - the open area in front of the *wharenui*, where formal greetings and discussions take place. Often also used to include the complex of buildings around the *marae*.
Mātauranga	Knowledge, wisdom, understanding, skill - sometimes used in the plural.
Mīmiro	The indigenous Māori construction technique involving the post-tensioning of a structure.
Mīmirū	A portmanteau of 'mīmiro' and 'rū', the architectural application of the indigenous Māori, post-tensioning construction technique (mīmiro) within a seismic context (rū).
Ngāti Awa	A tribal group (iwi) of the Whakatāne and Te Teko areas.
Ngāti Ira o Waioweka	Ngāti Īrapuaia, the hapū of Opeke Marae whose whare tīpuna is Tanēwhirinaki
Ōpeke Marae	A complex of buildings located south of Ōpōtiki at the entrance to the Waioeka Gorge. It belongs to the hapū Ngāti Īrapuaia (also known as Ngāti Ira) of Whakatōhea iwi.

Pāpakāinga	Original home, home base, village, communal Māori land - sometimes written as one word, *papakāinga*.
Poupou	Wall pillars, posts, poles, upright slabs forming the framework of the walls of a house, carved wall figures, pegs, and stakes.
Pou tokomanawa	centre ridge pole of a meeting house
Rohe	boundary, district, region, territory, area, border (of land).
Rū	Earthquake or seismic activity
Rua Whetu Joint	Refers to the traditional Māori construction joint where the cross-sectional connection between the heke (rafters) and poupou (wall posts) is semi-circular.
Rūamoko (noun)	The Māori god of earthquakes and volcanoes.
Tāhuhu	ridge pole (of a house), subject of a sentence, main theme, direct line of ancestry.
Tānewhirinaki	The wharenui (or meeting house) of the iwi Ngāti Ira o Waioweka destroyed by the 1931 Napier Earthquake.
Taonga	treasure, anything prized - applied to anything considered to be of value, including socially or culturally valuable objects, resources, phenomena, ideas and techniques.
Tauwhenua	Rope which passes over rafters and ridgepole to tension a meeting house
Te Ao tāwhito	Refers to the traditional world, pre-colonisation, pre-European contact
Te Whare Rangitupu	2022 research project led by Professor Anthony Hōete involving the re-standing of the original Tānewhirinaki carvings on a scaffolded structure, protected by a marque. Translates to Scaffolding (for raising a ridge pole) House.
Tikanga	correct procedure, custom, habit, lore, method, manner, rule, way, code, meaning, plan, practice, convention, protocol
Toi	native, indigenous, aborigine, indigene.
Urupa	burial ground, cemetery, graveyard.
Wānanga	(noun) seminar, conference, forum, educational seminar. (verb) to meet and discuss, deliberate, consider.
Whakapapa	genealogy, lineage, descent - reciting *whakapapa* was, and is, an important skill and reflected the importance of genealogies in Māori society in terms of leadership, land and fishing rights, kinship and status. It is central to all Māori institutions.
Whare	house, building, residence, dwelling, shed, hut, habitation.
Whare Whakaata	Treadwell, in Tuīa te Whare, considers whare Whakaata, at the Okains Bay Museum, to be potentially the only extant example of a whare potentially deploying mimiro.
Whare Whakairo	A carved meeting house.
Wharenui	Large meeting house - main building of a marae where guests are accommodated.

6.2 English Terminology (https://www.eq-assess.org.nz/ and Britannica Dictionary)

Amplitude	The maximum displacement or distance moved by a point on a vibrating body or wave, measured from its equilibrium position. It's equivalent to half the length of the vibration path.
Base Shear	An estimate of the maximum expected lateral force on the base of a structure due to seismic activity
Brittle	Refers to a material or structure that fractures or breaks suddenly once its probable strength capacity has been reached; has little tendency to deform before it fractures
Civil Defence	The system of protective measures and emergency relief activities conducted by civilians in case of a hostile attack, sabotage or natural disaster.
Colonial	Refer to the political-economic phenomenon whereby various European nations explored, conquered, settled, and exploited large areas of the world.
Compression	The decrease in volume of any object or substance resulting from applied stress. Can happen to solids, liquids, gases, and living systems.
Connections	The entire assemblage of connection components and connectors where two members intersect
Damping	The value of equivalent viscous damping corresponding to the energy dissipated by the structure, or its systems and elements, during an earthquake. For elastic procedures, a constant 5% damping as per NZS 1170.5:2004 is used.
Density	density, mass of a unit volume of a material substance. The formula for density is d = M/V, where d is density, M is mass, and V is volume.
Disaster Risk Prevention	Refers to the broad development and application of policies, strategies, and practices to minimize vulnerabilities and disaster risks throughout society.
Displacement	The distance moved by a particle or body in a specific direction. The distance travelled by the particle or body depends on the path it follows; it will be equal to the magnitude of the displacement only if the path is straight.
Ductility	Describes the ability of a structure to sustain its load carrying capacity and dissipate energy when it is subjected to cyclic inelastic displacements during an earthquake.
Dynamic Characteristics	Characteristics concerned with the motion of material objects in relation to the physical factors that affect them: force, mass, momentum, and energy.
Elasticity	The ability of a deformed material body to return to its original shape and size when forces causing the deformation are removed.
Empowerment	The act or action of gaining freedom, power or authority over something.
Experimental Research	Research that undertakes the process of observing, asking questions, and seeking answers through tests and experiments.
Finite Element Modelling (FEM)	FEM refers to an approximation method that subdivides a complex problem space, or domain, into numerous smaller, simpler pieces (finite elements) whose behaviour

	can be described with comparatively simple equations. Often used for simulating the effects of ground-induced actions on a structure (e.g. seismic activity)
Fixed Connections	Refers to a rigid joint between two or more structural members that doesn't rotate or translate, providing extra stability in at least one direction.
Fluid Behaviour	Behaviour pertaining to any material that cannot sustain a tangential, or shearing, force when at rest and that undergoes a continuous change in shape when subjected to such a stress.
Foundations	A part of a structural system that supports and anchors the superstructure of a building, transmitting its loads directly to the earth.
Genealogy	The study of family origins and history, tracing one's ancestry.
Geometry	Concerning the shape of individual objects, spatial relationships among various objects and the properties of the surrounding space.
Glulam	Glued Laminated Timber. An engineered timber product made from layers of timber bonded with structural adhesives
Hand Shear Vane Testing	Refers to a method of measuring undrained shear strength of a cohesive soil and is carried out with a rod with vanes mounted on it that are inserted into the ground and rotated.
Inertia	The property of a body by virtue of which it opposes any agency that attempts to put it in motion or, if it is moving, to change the magnitude or direction of its velocity. It's determined by the mass of the body and its moment of movement about a specific axis.
Lateral Stability	The ability of a building to remain horizontally stable when an external lateral force is applied.
Leeward	Refers to the side away from the wind, or in the direction toward which the wind is blowing.
Ley Line	Refers to a supposed straight line connecting 3 or more prehistoric or ancient sites, sometimes regarded as the line of a former track, and associated by some with lines of energy and other paranormal phenomena.
LIDAR	Light Detection and Ranging — is a remote sensing method used to examine the surface of an object.
Line Mass	Refers to when a mass is determined by the sum of additional masses on a system. The translational mass per unit length on a specific element.
Linear Behaviour	Linear behaviour refers to the proportional displacement of a system or body due to an applied force, and that displacement being in the direction of that force.
Loads	
1. Dead vs self-weight loads	Dead load is a type of permanent load case coming from all a building’s components and materials (including its structure). Dead load includes structure self-weight and

	loads from other non-structural objects (floor covering, insulation, etc). The dead load is supported by the structure (walls, floors and roof).
2. Gravity loads	The load applied in a vertical direction, including the weight of building materials (dead load), environmental loads such as snow, and building contents (live load)
3. Lateral loads	Load acting in the horizontal direction, which can be due to wind or earthquake effects
4. Live loads	Represents variable loads, such as the weight of people, furniture, vehicles, office equipment, etc., that can change over time.
Mass	Refers to the amount of matter in a solid, liquid or gas element.
Material Properties	Refers to a material's physical, mechanical or optical properties that define how it behaves.
Methodology	A system of approaches of doing, teaching or studying
Mode Shapes	Refers to the special initial displacements of a system that cause it to vibrate in relation to the system's natural frequencies.
Moment Connections	Refers to a joint that allows for the transfer of bending moment forces between two or more structural members (e.g. between a column and a beam). The lateral loads are resisted by shear and flexure in members and joints of a frame.
Mortice and tenon	A mortise and tenon joint connects two pieces of wood or other material together using gluing or friction fitting. The rua whetu joint is considered by this research to belong to the latter.
Natural Frequency	The frequency at which a system oscillates when not subjected to a continuous or repeated external force. Described as $f = 1/T$ where T = Natural Period
Natural Period	Refers to the period or time it takes for a body or system to complete one full cycle of free vibration/oscillation.
Oscillations	Refers to the repetitive or periodic variation of some measure (typically time), about a central value or between two or more different states.
Pinned connection	A proper pinned connection stops structural members from translating or slipping but does allow them to rotate, meaning there is no transmittal of bending moments between the portal elements.
Plastic Deformation	The ability of certain solids to flow or change shape permanently when subjected to stresses of intermediate magnitude between those producing temporary deformation, or elastic behaviour, and those causing failure of the material, or rupture.
Post Tensioning	Refers to the strengthening of a structural element through the application of a tension force.
Proof-of-Concept	A realization of a certain idea, method or principle in order to demonstrate its feasibility,[1] or viability,[2] or a demonstration in principle with the aim of

	verifying that some concept or theory has practical potential. A proof of concept is usually small and may or may not be complete.
Prototype	The first or preliminary version of a device or vehicle from which other forms are developed.
Residual Displacement	Refers to the permanent displacements attained by a structure following seismic activity.
Rigid Connections	A non-flexible connection between two components, elements that does not admit the relative rotation between the elements and, consequently, transfers bending moments.
Rotational	Relating to a circular movement about an axis or central point.
Safety Factor Increase	Refers to the load-carrying capacity of a system beyond what the system actually supports (i.e. how much stronger a system is than it needs to be for an intended load).
SAP2000	A tool used for creating and analysing structural models which offers many features across a single, customizable user interface to generate complex models and run comprehensive tests.
Seismic Resilience	The ability of a system to absorb an external shock and quickly return to its initial state. This could apply at the scale of a building or a community.
Seismicity	The worldwide or local distribution of earthquakes in space, time and magnitude. More specifically, it refers to the measure of the frequency of earthquakes in a region.
Self-Weight vs Dead load	Self-weight is load coming from all structural elements defined in the model calculated with respect to the used section material and slab or wall thickness. Dead load is a type of load (load case) coming from all object components (not only structural), loading object structure in a permanent way.
Shear	The ability to resist lateral loads along it's primary axis
Snap-back Testing	A testing process to quantify the variation in the stiffness and damping behaviour over a range of lateral load levels. It gives the response of the system to one impulsive excitation, to evaluate the influence of loading history on the dynamic response of the system.
Stiffness	An objects incapability or high resistance to bending
Stress (Capacity)	The force per unit area within materials that arises from externally applied forces, uneven heating, or permanent deformation that permits an accurate description and prediction of elastic, plastic and fluid behaviour.
Structural System	Combinations of structural elements that form a recognisable means of lateral or gravity load support, e.g. moment resisting frame, frame/wall. Also used to describe the way in which support/restraint is provided by the foundation soils.
Suction	The production of a partial vacuum by the removal of air, in order to force fluid into a vacant space or procure adhesion.

Tendon Element	In structural engineering, refers to objects that can be embedded into other structural objects (i.e. frames and shells) to represent prestressing. Can be discretized into segments for analysis. Can be modelled as loads on a structure or independent elements.
Tension	The application of a force along a length of the medium causes it to stretch.
Transitional	The alteration of a physical system from one state, or condition to another.
Validation Testing	Testing that quantifies the credibility of a model.
Windward	Refers to the side facing the wind, or in the direction from which the wind is coming.
Yield Point/Strength	Refers to the point on a stress-strain curve where elastic behaviour ends and plastic behaviour begins. This region is anticipated to be subjected to nonlinear deformations under earthquake-induced forces.
Young's Modulus	Aka Modulus of Elasticity refers to a measure of a material's ability to withstand changes in length when under lengthwise tension or compression. (longitudinal stress/strain).

7.0 Outputs and Dissemination

7.1 Publications and Communications

- Hōete, A. & Treadwell, J. (2024) Mīmirū https://www.nzia.co.nz/awards/local/award-detail/11667
- Hōete, A & Treadwell, J. (2024) Architecture NZ, Winners announced: 2024 New Zealand Architecture Awards, https://architecturenow.co.nz/articles/winners-announced-2024-new-zealand-architecture-awards/
- Hōete, A. (2024) Museum of NZ Te Papa Tongarewa Ruaumoko Travelling Exhibition featuring Mīmirū: a seismic engagement model for children.
- Hōete, A. (2024) 'From the Māori to the Transcolonised City' in Batchelor, D., McKay, B., eds., Urban Aotearoa (Wellington, BWB Books)
- Hōete, A; Treadwell, J (2024). NZ Institute of Architects' National Award shortlist; Waikato – BoP Regional Award winner
- Hōete, Anthony (2024). Sunday Documentary: Anthony Hoete, FROM THE GROUND UP. The University of Auckland. Media. https://doi.org/10.17608/k6.auckland.25712865.v1
- Hōete, A & Jorgensen A. (2023) The revitalisation of the Māori meeting house, ICOMOS General Assembly 2023, Sydney Conference & Convention Centre, Darling Harbour, Sydney, September 29 https://icomosga2023.org/wpcontent/ uploads/ICOMOS-GA2023-ScientificSymposiumSchedule-v9.pdf.
- Hōete, A & Jorgensen A. (2023) An Archaeology of Seismic Resilience, NZ Archaeological Association Conference, Hamilton, NZ, 3-7 July, Winner Best Overall Conference paper: https://nzarchaeology.org/membership/previousaward-Winners
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- Triponel, Te Rina. (2023). University of Auckland News and Opinion: https://www.auckland.ac.nz/en/news/2023/04/26/endangered-maori-construction-methods-passesseismic-testing.html

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7.3 Appendices

Refer to Ngārchitecture package "241106_Toka Tū Ake EQC_erez.pdf" which includes the following drawings:

- P1: 3-05 Location Plan in relation to Whakaari
- P2: 3-010D: Site Plan
- P3: Gantt Chart of Installation and Testing
- P4: 3-001 Tānewhirinaki rebuild using Mīmirū - 3D Views
- P5: 3.012 Tānewhirinaki rebuild using Mīmirū - Ground Plan
- P6: 3.020 Tānewhirinaki rebuild using Mīmirū – Front and rear Elevation
- P7: 3.030 Tānewhirinaki rebuild using Mīmirū -Long Section
- P8: 3.031B Tānewhirinaki rebuild using Mīmirū – Cross Section
- P9: 3.032C Tānewhirinaki rebuild using Mīmirū – Shell-Structure Details
- P10: 3-011A Footing and Poupou set out
- P11: 3-10: Temporary Works: Scaffolding
- P12: 3-050G Portal Fabrication
- P13: 3-051B: Portal Winch
- P14: 3-052: Poupou engraving
- P15: 3-053: Full Test System
- P16: 3-006 Footings and Poupou Installation photos
- P17: 3.032B Tānewhirinaki rebuild using Mīmirū – Details Cross-Sectional
- P18: 2.010 Front Elevation Carvings
- P19: 2.011 Mahau Elevation carvings
- P20: 2.012 Front Interior Elevation Carvings
- P21: 2.013 Rear Interior Elevation Carvings
- P22: 2.014 East Interior Elevation Carvings
- P23: 2.015 West Interior Elevation Carvings
- P24: 2.016 Uninstalled Carvings
- P25: Preliminary FEM Natural Frequency
- P26: Full-Size FEM SAP2000 Isometric showing roof, walls and roller supports, carvings, line mass and tendons
- P27: Fundamental Mode Shapes
- P28: Table showcasing Deformed Shape and Displacement
- P29: Location Maps of Ōpeke Marae (Immediate & Within the North Island, NZ)
- P30: Testing Date Photos (Date) Draw Wire Sensors & Displacement Sensors

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