INNOVATIVE DESIGN AND CONSTRUCTION OF NEW ZEALAND’S FIRST 3M DIAMETER CONCRETE BORED PILES WITH PLUNGED 16T COLUMN CAGE IN CHALLENGING SEISMIC, GEOTECHNICAL AND URBAN ENVIRONMENT

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SUMMARY

Innovation happens when designers and constructors collaborate to put existing concepts together in a new way. By pushing to find innovative solutions in the design and construction of the piles and piers, the M2PP project team achieved significant construction efficiencies and savings as discussed in this paper.

Multi-span bridge piers on the MacKays to Peka Peka (M2PP) Expressway Project are founded on large 3m diameter bored concrete mono-piles. With depths of up to 38m and 60tonne reinforcing cages, these piles are some of the largest bored piles ever constructed in New Zealand.

Designers and constructors collaborated to develop this innovative and challenging solution resulting in robust bridge supports and significant construction efficiencies.

The design approach included:

- Use of hammer-head piers on mono piles, which eliminated the need for pilecaps
- Non-linear pushover analysis modelling of the piles.
- Pile load testing to optimise geotechnical design.
- Restricting the potential plastic hinges to within the piles only.
- Use of bentonite drilling support fluids instead of steel casings.
- Connection detailing for the pier column on oversized pile shafts, using the AASHTO 2013 design provisions.

The construction of the 3m diameter bored piles has given the following construction advantages:

- Nearly 50% reduction in pile numbers resulting in approximately $3 million dollars material savings and about 80 trimmed from the programme.
- Plunging of fully assembled asymmetric column cage into the piles to eliminate a second stage pile-column pour.
- Elimination of permanent steel casings by the use of bentonite support fluids, saving costs, significantly increasing the available skin friction and avoiding lapping of reinforcement in potential plastic hinge zones.
Elimination of pile group/pile caps which minimises lateral spread soil loads on bridge piles

PROJECT BACKGROUND

The MacKays to Peka Peka Expressway (M2PP) is an 18km 4-lane highway that will take State Highway 1 along the Kāpiti Coast. M2PP is the first of the Wellington Northern Corridor RONS projects. M2PP will separate local and state highway traffic and result in safer and shorter trips within and through the Kāpiti Coast - with local and national benefits. It is being built by an alliance made up of the NZ Transport Agency, Beca, Fletcher Construction and Higgins Group supported by Goodmans Contractors, and Boffa Miskell. The project includes 17 bridges comprising multi-span and single span bridges over local roads and streams, including a new 182m long crossing of the Waikanae River.

CHALLENGING ENVIRONMENTS

Ground Conditions

The Expressway alignment traverses through sand dunes and inter-dune peat deposits. The peat is very soft with a high organic content and may be up to 6m thick. The dune deposits are fine, single sized sand, with a high liquefaction potential where saturated. These conditions present the following challenges to the expressway design:

- Peat deposits can cause significant post construction settlements due to high compressibility which, without treatment would have resulted in poor ride ability, settlement of services and adjacent properties, altered surface drainage patterns and increased maintenance.
- The dune and sandy alluvium presents significant challenges due to liquefaction and associated settlement and lateral spreading, particularly to bridge structures.

Seismicity of the Area

The site is located in a highly seismic area and the following active faults are located near the Project.

- The Ohariu fault is between 1 and 3km from the Expressway and has an estimated MCE (maximum considered earthquake) magnitude of M7.2 at a return period of 2000 years.
- The Wairarapa fault is around 30km further from the Expressway but has an estimated MCE magnitude of 8.2 at a return period of 1200 years.

![Figure 1: Critical active faults around the site](image1.png)  
![Figure 2: A comparison of Spectral Acceleration of different cities with Project site for 1/2500 years seismic events.](image2.png)
To appreciate the high seismicity of the project site the design spectral acceleration curve is compared against other locations in New Zealand and Australia in Figure 2.

**Seismic Design Criteria**

The bridges are to be designed to achieve the requirements of the NZTA Bridge Manual 2nd Edition[7]. The bridges are lifelines post-earthquake and any damage shall be repairable within 12 months.

More specifically the bridges are to be designed to:

- Have no damage under SLS1 (1/25 years) seismic events.
- Have some minor damage under the SLS2 (1/100 years) seismic events. Damage to such components is to be cleared and access restored within 24 hours for full traffic use.
- Have some damage to the structure under Ultimate Limit State design (1/2500 years) earthquake events. The bridge should be useable by emergency traffic within 3 days. Permanent repair to reinstate the design capacity for both vehicle and seismic loading should be feasible and should be economically viable and able to be accomplished within 12 months.
- Prevent total collapse under the maximum credible earthquake (MCE) by ensuring sufficient ductility capacity in the yielding elements or where appropriate providing secondary load paths.

**Urban Environment**

The Expressway is a new feature in the landscape and by its nature is strongly horizontal. The expression of that horizontality is acknowledged whilst also recognising that it hovers over the ground where it crosses local roads. Where bridges interface with local roads the concept is to translate its supporting armature of columns and beams into a single and fluid shape to simplify the appearance of the structure rather than drawing attention to it.

Therefore, the bridges should be:

- Consistent in their form so they register as a ‘family’ and provide some visual continuity within the local environment.
- Expressed as simple forms that sit across the changes in landscape and are not seen as strong statements in their own right.
- Consists of elements like piers, cross heads, decks and barriers, which when united create one sculptural form and ensure services are concealed from view.
- Of a form that the underside is visually appealing, to recognise the primacy of the local road user’s experience in design considerations.
- Designed in such a way that the intersection of the piers with the ground is in concert with the abutment forms and materials.
- Designed to enhance the quality of the space beneath the bridges, including the use of natural light penetration.

**BRIDGE FORM**

The multi-span bridge beams are single hollow core or super tee beams and are simply supported and connected via transverse post-tensioning or a concrete topping slab. In the longitudinal direction the bridge deck will slide over the abutments and in the transverse direction the deck is restrained by shear keys under seismic loads.
Piers are single columns with precast crossheads. Each pier is supported by a single bored, cast in-situ concrete mono-pile, which resists both longitudinal and transverse seismic effects. The abutments are cast-in-situ concrete, supported by steel H-piles, MSE walls and ground improvements, which resist only transverse seismic inertia loads from the deck. Figures 3 and 4 show a typical cross-section of a multi-span bridge.

NEW ZEALAND’S FIRST 3M DIAMETER BORED PILE

The designers and constructors collaborated to develop this innovative and challenging solution to use 3m diameter bored concrete piles, to provide efficient support to the bridge piers and also give significant efficiencies in construction and design. The ability to construct these piles was a result of:

- Innovative design of hammer-head piers on mono plies.
- Non-linear soil-structure interaction using multi-linear soil springs expressed as P-Y curves.
- Pile load testing and analysis to optimise design parameters.
- Restricting the potential plastic hinges to within the piles.
- Detailing pier-pile connection without pilecap following AASHTO guide lines.
- Pushing NZ bentonite drilling technology to a new level, including fluid trials and new tools.
- Developing understanding and innovative systems in the lifting of 60T reinforcing cages “the step change”.
- Development of specialist plunge column cage guide frames and lifting gear.
- Extensive concrete mix trials to ensure workability for long periods to allow plunging.
- Complex large diameter pile cage and column cage fabrication and transport systems.
- Risk management of challenging tremie pour and plunge column operation.
- 2.1dia 40m deep test piles with Osterberg Cells.
- The use of friction pile design principles to provide flexibility in pile design to accommodate changes in structural design loading and the unpredictable presence of silt layers within the founding stratum.

We believe that this is the first use of 3m diameter bored reinforced concrete piles in New Zealand although we are aware of shafts/caissons or non-bored piles of a similar size e.g. Arthurs Pass Viaduct.
DESIGN ASPECTS

Hammerhead Piers on Mono Piles

These bridges sit in an urban environment, where space and aesthetics are very important. The bridges are designed to enhance the quality of the local road space beneath the overpass by maximising natural light penetration. Hammerhead piers have been used because they’re aesthetically appealing, occupy less space and provide more light and room for the traffic underneath the bridges.

The bridge piers were originally designed to be supported by a group of piles and a pilecap, buried in the ground. The Alliance team challenged this concept, instead utilising a large mono pile system for each pier. The decision to plunge the pier cage naturally followed.

Preliminary design indicated that we needed 2.7m~3.0m diameter piles to support each pier using a mono pile system. After detailed investigation a 3m diameter pile was adopted to allow the plunging of the architectural shaped pier cage. As both pier core reinforcement and pile reinforcement are in circular shape, the adopted system has flexibility and construction tolerances.

The bridge piers supported on large mono-piles act as cantilever structures supporting static and seismic inertial loads as well as resisting lateral ground movement loads under extreme seismic loads. The absence of a pilecap reduces the lateral loads applied by laterally spreading ground in the liquefaction design case.

Site Specific Seismic Hazard Assessment

A site specific seismic hazard assessment (SSSHA) was undertaken for the Expressway corridor. The assessment utilised the New Zealand National Seismic Model and appropriate attenuation relationships to estimate the earthquake shaking hazard at the site. The SSSHA recommends that the project adopt the recommended local Z-factor of 0.4 (NZS 1170.5) but utilise modified R factors as set out in Table 1. The values in brackets are NZS1170 recommended values for comparison.

The SSSHA also proposed modified response spectra, specific geotechnical design values and specific MCE events for the site. Figure 6 shows a comparison of the MCE response spectra for Ohariu fault (with Median + 1 standard deviation), Wairarapa fault (with Median + 1.5 standard deviation), 1000 and 2500 year return period response spectra obtained in this investigation and the NZS 1170.5 response spectra for the same return periods for subsoil Class D.

<table>
<thead>
<tr>
<th>Required Annual Probability of Exceedance</th>
<th>Rs for SLS or Ru for ULS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/250</td>
<td>0.80 (0.75)</td>
</tr>
<tr>
<td>1/500</td>
<td>1.00 (1.00)</td>
</tr>
<tr>
<td>1/1000</td>
<td>1.25 (1.30)</td>
</tr>
<tr>
<td>1/2500</td>
<td>1.65 (1.80)</td>
</tr>
</tbody>
</table>

Figure 6: Comparison of Spectra for Site Sub-soil Class D
Soil-structure Interaction

Design of piles for the effect of seismic motions is generally performed by using a soil-pile interaction model in which a vertical element is supported by a series of horizontal linear elastic Winkler spring elements. The element represents the performance of the pile, and soil properties are represented by linear-elastic spring constants. The effect of horizontal seismic motions on piles are allowed for by incorporating a horizontal force at the top of the pile, which is equivalent to the inertia force from the superstructure.

In the past modelling of non-linear soil responses has been undertaken by approximating the non-linear behaviour of soil with linear springs. Multi-linear soil springs are more rarely used due to the limitations of most structural engineering analysis packages. On the M2PP project, the soil response was modelled using p-y-curves derived in the geotechnical software package L-Pile\[5\]. The soil profile at each pile location was simplified into horizontal layers with similar strength/density and the most appropriate p-y response model selected. Response models were selected as follows:

- Sands and silty sands utilised a model published by Reese, Cox and Koop\[13\]
- Plastic silts and clays utilised a model published by Matlock\[14\]
- Liquefied sand utilised a model published by Rollins, Gerber and Ashford\[15\]

A range of soil properties comprising bulk density (overburden stress), friction angle or undrained shear strength were then utilised to factor the soil model and generate appropriate P-Y curves. For each layer ‘nominal’, ‘hard’ and ‘soft’ values were derived to reflect the likely range of soil properties. This approach was taken to consider a ‘most likely’ behaviour alongside a case likely to result in upper bound deflections i.e. the ‘soft’ case and upper bound actions i.e. the ‘hard’ case. The P-Y curves were then utilised in two different ways, either within subsidiary analyses to derive a pile top response matrix or as inputs to a global analysis.

At the pier locations, where reinforced concrete mono piles were employed, the spring characteristics were derived in L-Pile by modelling the stiffness characteristics of the pile (refer to Figure 7) and applying shear and flexure increments to the pile head.

The flexure and shear effects were proportioned to match those expected by the structural system, e.g. as shown in Figure 8 a cantilever moment being proportional to the distance from the pile head to the centroid of the seismic mass and application of the base shear. At each increment shear-displacement and moment-rotation relationships were recorded, until yielding of the pile occurred. The resulting shear-displacement and moment-rotation plots defined the characteristics of the pile head spring.
Pile Axial Capacity

To allow flexibility in pile capacity and to accommodate irregularly occurring silt interbeds within the foundation stratum, the pier piles are designed assuming they derive their capacity in friction. Assuming heavily over-consolidated conditions and a rough interface allowed the adoption of skin friction values in the dense gravels of up to 250kPa. With limited historical precedent for heavily loaded piles in these soils testing was considered prudent, additionally, the increased certainty that results from a load testing program allows the adoption of higher strength reduction factors.

Pile Load Testing

Two, near full scale (2.1 m diameter, 32-35m long) fully instrumented test piles were employed on the project. One installed at the site of the Waikanae River Bridge and another at the Te-Moana Bridge. The test piles were instrumented and tested by Fugro Singapore Pte. Ltd[21]. An assembly consisting of two 510 mm Osterberg cells (O-cells) was installed near the toe of each pile approximately 30 m below ground level; three diameters above the pile toe. The typical instrumentation (refer Figure 9[21]) included:

1. A pair of automated digital survey levels for measuring top of pile displacement,
2. Seven levels of four vibrating wire strain gauges above the O-cell assembly, attached at 90° spacing within the reinforcing cage,
3. Four tell-tale rods at 90° spacing monitored by displacement transducers (attached to the top of the pile) for measuring shaft compression above the O-cell assembly,
4. Four displacement transducers for measuring expansion of the O-cell assembly,
5. Three levels of four vibrating wire strain gauges below the O-cell assembly, attached at 90° spacing, and
6. Four tell-tale rods at 90° spacing monitored by displacement transducers (attached to the top of the pile) for measuring pile toe displacements.

Potential Plastic Hinges Restricted in Piles

Design economy was achieved by allowing the formation of plastic hinges at depth in the piles. This develops an inelastic displacement capacity in the piles which contributes to satisfying the spectral displacement demands in lieu of an increase in flexural section capacity.

In this regard NZTA Bridge Manual[7-8] limits the level of plastic hinging by limiting the level of displacement ductility to less than 3 which defines the upper boundary of limited ductility in NZS3101. The limit on displacement ductility implies that pile hinging is acceptable within the
strain limits and resulting curvature limits as defined in NZS3101[4] when assuming limited ductility.

The strain limits associated with the curvature limits appear significantly higher than strain limits of $\varepsilon_c=0.008$ and $\varepsilon_s=0.015$ with $\varepsilon_c$ being the limiting concrete strain and $\varepsilon_s$ being the limiting steel strain suggested by Priestley, Calvi and Konalsky[2] for piles hinging at depth.

What compensates for the suggested lower strain limits is the difference in the approach of deriving the plastic hinge length required to calculate the inelastic rotation and displacement capacity: Based on NZS3101[4] the plastic hinge length $L_p$ for a pile is $hc/2$, whereby $hc$ is in this case the pile diameter. Based on Priestley’s recommendations [2], $L_p$ can be calculated as:

$$L_p = D + 0.1(H - H_{cp}) \leq 1.6D$$  \hspace{1cm} (1)

with $H_{cp} = 0$ for cantilever columns.

Refer to Figure 10 for definition of terms.

Hence $L_p$ is up to three times greater than the value derived from the code NZS3101.

During displacement-based seismic design the flexural capacity of sections where plastic hinges were intended to form (“ductile sections”), e.g. in the concrete piles, adopted the probable strengths for concrete and reinforcing steel ($1.3f'_c$, $1.1f_y$). The number and diameter of longitudinal reinforcing bars in the piles and the piers were determined in order to satisfy the seismic demand on the structure across all cases considered. These bars were then detailed, spliced and curtailed in accordance with NZS3101:2006.

Transverse pile and pier reinforcement inside and outside the Potential Plastic Hinge (PPH) regions was designed to NZS3101:2006 for (overstrength) shear, concrete confinement and anti-buckling. The overstrength flexural capacity of the concrete piles and piers for the purposes of determining shear demand was determined in SAP2000 based on the overstrengths for concrete and reinforcing steel, that is, $1.7f'_c$ and $1.3f_y$. The shear capacity of the piers and pile, on the other hand, used the characteristic strengths for concrete and reinforcing steel, (that is, $f'_c$ and $f_y$) and the design and detailing was in accordance with NZS3101:2006.

The hinges in the piers (which cantilever) always occurred at the base of the pier, while plastic hinges were found to occur between 5m and 12m deep in the piles. The locations of the hinges, and thus the PPH regions in the piles, differed due to different soil profiles and soil conditions (whether the soil was upper bound, lower bound, or lower bound liquefied). As a single pile and pier design for the bridge is to be adopted, a PPH region that envelopes all possible plastic hinge positions, and extended approximately 16.0m in the pile, and 2.1m in the pier, has been adopted. The PPH region does not stray into the pier/pile splice zone.

Pier Supported by Oversized Pile Shaft

Two types of column anchorage failure are possible in an enlarged pile shaft. The bar pull-out of the pile, and column pull-out due to concrete damage caused by a ‘plying’ action when the confined core of the column rocks back and forth in its shaft. Both can contribute to the anchorage failure of a column. The plying action introduces horizontal forces that can be relatively large near the top and bottom of the anchorage region. These horizontal forces are resisted by the surrounding concrete and the transverse reinforcement in the shaft.
There is no guidance in New Zealand standards to prevent these types of anchorage failures, but this type of pier-pile shaft connection is discussed with details in the draft appendix to the AASHTO bridge design code, ‘Precast Bent System for High Seismic Regions- Appendix A: Design Provisions’, 2013[22]. This design approach requires additional hoop reinforcement in the top region of the pile.

**Use of DH40 Bar Hoops**

To force the formation of hinges in the piles at a depth below the pier-pile reinforcement splices zone, the top of pile shaft was designed for high over-strength shear and confinement demands. This led the team to use the 40mm diameter deformed bars as hoops for the piles and 40mm bundle bars as longitudinal reinforcement to meet the reinforcement demand without the excessive congestion. We believe that it is the first use of DH40 bars as hoops in New Zealand.

**Tremie Concrete Mix**

The concrete for the piles was designed with high flow and longer setting time than normal. This ensured adequate flow around the heavy reinforcement cages and allowed sufficient time to plunge the column reinforcement cage into the fresh concrete. Consideration was also given to the loss of water from the concrete due to highly permeable soil around the piles.

The concrete mix was originally designed to meet the specified requirements for compressive strength, aggregate size, water-binder-ratio and slump. Unusually, the target slump was 220mm, instead of the more common value of 170mm, in order to ensure adequate flow around the heavy reinforcement cages. The concrete supplier Firth Concrete in consultation with the Alliance team developed a mix for these requirements, the performance of which was verified through a series of in-house trials and then a full-scale test pile.

Following this, the Alliance team specified two additional requirements in the plastic properties of the pile mix– slump retention of up to 3 hours as a safety margin in the event of any delays on site, or any difficulties in plunging the cage into the fresh concrete; and an extra-high level of cohesion. The additional cohesion was needed to resist the ingress of groundwater into the fresh concrete under hydrostatic pressure at depth – a risk specific to this project because of the highly permeable nature of the soil around these piles. The successful test pile mix was then progressively modified through further in-house trials until it could be proven to have levels...
of slump retention and cohesion that satisfied the Alliance requirements, after which it was put into action in supplying the bridge piles.

**PILE CONSTRUCTION**

**Drilling Technology**

Trials were undertaken to find the best drilling support fluid. This involved trial bores left open for several days with different types of bentonite and/or polymer fluids. For the soil conditions at the Expressway, pure sodium bentonite was the clear winner.

A drilling bucket was specifically designed and built to drill a 3m diameter hole through the underlying local sand, silt and gravels under bentonite. Consideration was made to size and volume of bucket, along with under fluid systems. Some of the “gravels” got up to 600mm diameter.

The mass of the bucket plus the telescoping kelly bar increased the drilling loads up to 28T for a single line pull. This resulted in the use of a Soilmec RT3 setup on 120T Leibherr 885 Crawler Crane. No other crane in New Zealand was suitable for this job as the 885 had 30t line pull on single winch.

Figure 13; Installation of 3m Diameter Bored Piles
Due to the high drilling loads an extensive inspection and maintenance programme was set in place to mitigate risks of high wear on heavily loaded elements including kelly bar, swivels and drive gear.

Cage Fabrication and Lifting

3m diameter pile cages are labour and plant intensive to build, difficult to transport on tight local roads and complex to lift and install. Key features of the cage fabrication and installation included:

- Substantial temporary strengthening of pile cage to avoid cage deformation.
- Extensive welding and testing of each 95kg HD40 hoop and other welds.
- 3D designed and load tested cage clamps for connection of lifting equipment.
- Modified trailers for transportation of over-length and over-wide loads.
- Fabrication of a jig for asymmetrical architectural curved column reinforcing cage.

In addition to the above, complex lift planning and temporary works was required to:

- Lift 35T cage sections from horizontal to vertical with two winch lift for 200T crawler crane
- Temporarily support cage sections on the pile casing with clamps
- Connect additional cage sections over pile hole using cherry pickers
- Lower total 60T cage to height hanging off stress bar bridle system
- Withdraw and laydown 16T pile casing with a modified extra wide vibrohammer.
- Lift and install 16T pre-assembled column cage to stringent tolerances.

Concrete Testing and Development

A series of concrete tests were conducted to evaluate the duration of the concrete mix workability. Field trials included plunging a reinforcing cage into a 1200Ø concrete pile. This helped to determine what time could reasonably be allowed to plunge the column cage.
Figure 15: A dummy cage plunging trial in concrete to measure concrete’s initial set and cage plunging ability with the time

Figure 16: Lifting frame and column cage plunging trial to measure the total time of plunging operation

One trial mix used fly ash and the other used a concrete fluidifier. The mix design using fly ash with a number of admixtures was chosen and developed. There was also a concern that the temperature of a straight cement mix in a 3m diameter pile would reach 80°C over 76hrs, whereas the fly ash mix was estimated to reach 65°C over 90hrs.

Table 2: Cage Plunge Test Results

<table>
<thead>
<tr>
<th>Slump at the Plant</th>
<th>1145</th>
<th>1245</th>
<th>1345</th>
<th>1445</th>
<th>1545</th>
<th>1645</th>
<th>1745</th>
<th>1845</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>220</td>
<td>200</td>
<td>180</td>
<td>150</td>
<td>125</td>
<td>120</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Cage Reached bottom of pile</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Plunge Column Cage

Plunging the fully assembled column reinforcement cage into the pile concrete reduced the programme and saved 210 days in preparation and forming column pour connections and 175 days in fixing steel at height across the project. It also made things safer by eliminating confined space work and reducing work at heights. The primary risks associated with this opportunity were:

- Maintaining concrete workability for around 5hours.
- Achieving design tolerances (Horizontal 20mm, Vertical 20 mm).
- High bleed water from a high slump concrete.
Time and motion trials were done on setting up temporary works and plunging the column cage into a dummy hole. Regular reviews of the trials and throughout piling led to refinement and continuous improvement on reducing time and increasing safety and quality assurance.

Figure 19: Plunging the fully assembled 16T column cage

Construction Risks and Mitigation

Constructing 3m diameter piles to tight tolerances (Pile = Horizontal 75mm, Vertical 25mm, Verticality 1:75, Column = Horizontal/Vertical 20mm) without any defects has a number of challenges.

After the pile is tremmie poured, it is critical to dismantle the pile access platform, extract the 3m diameter temporary casing, clean away waste slurry and install the guide frame to accept the column cage.

To enable these operations to be efficient and accurate a guide frame was developed. The frame has three parts.

1. A precast concrete base placed around the installed casing and its position surveyed for accuracy.
2. A guide frame on the precast base, which is installed after the casing is withdrawn.
3. A lifting frame connected to the column cage that engages the guide frame ensuring orientation and vertical position.

When the column cage is plunged it is critical that the concrete has good workability. Bleed water from concrete with a high slump is not uncommon and is easily detected by cross-hole sonic log testing. Each pile has four sonic log tubes attached to the reinforcing cage and to date 24 piles have been constructed and all piles have satisfactory sonic log results.

Another key risk included supplying 270m³ of consistent quality concrete within a 2-3hr period. Workshops were held with the concrete supplier and mitigation developed in the form of:

- Three concrete batching plants available in case of breakdown.
- 20 No concrete trucks on turn around.
- Starting concrete pour early in the morning (5am) to avoid traffic delays.
- 2 No boom pumps pumping concrete.
- Every truck is slump tested by a trained concrete technician.
• Controlling the tremie embedment depth and remove pipes regularly to keep fresh concrete on top.

**USER'S SATISFACTION**

The piles and piers proved to be a success both in their design and construction. The client, New Zealand Transport Agency, is satisfied with the final outcomes for the project. In the following text we include the statements from Principal Project Manager Tony Coulman of New Zealand Transport Agency, Local Member of Parliament, Nathan Guy MP for Otaki and few local community members.

**New Zealand Transport Agency**

A statement from Tony Coulman, NZ Transport Agency Principal Project Manager

“The collaborative design-construct approach and attention to safety in design by the M2PP Team has delivered exceptional innovation by ensuring that the design was optimised not only for the high seismic forces but for the team’s ability to construct these large scale piles and pier columns in a manner that yielded significant savings.

The development of a guide frame and plunging of prefabricated column cages into the bridge foundation piles not only reduced costs and steps in the construction process, but provided significant time savings in delivery, and contributed to improved safety outcomes.

These achievements will contribute greatly towards one of the Transport Agency’s core objectives of delivering a cost optimised expressway.”[23]

**Local Member of Parliament**

The Member of Parliament for Otaki, Nathan Guy posted on his website on 25 march 2015

“It's about 18 months since the Kapiti Expressway got underway and the progress how been absolutely amazing. Last week I had the privilege of visiting many of the sites along the route that ended the tour at Ōtaki Pre-Cast Yard. The project is on target to complete the 18km route that includes 18 bridges and end-to-end cycleway, walkway and bridleway by mid-2017.

This year there is a real focus on bridges with the foundation team having so far pioneered some of the country's largest and deepest bored piles (3m diameter 60 tonne reinforcing cages) in difficult local soil conditions.

Soon the country's biggest crosshead beam will be poured at Otaki weighing 170 tonnes and "Super T” beams will be made at the new facility at Otaihanga to support the Waikanae River bridge decks. This will be an exciting development to see them installed and then for all of us to drive on it.”[24]

**Local Community**

Sue Gibbons; “Would be interested in knowing how the Bentonite works in the piling operation and how it is extracted for re use, thanks”.

Merrell Greenwood “Simply love these newsletters and then I can see more intelligently as I drive around what is happening. I think you are amazing with all the care you are taking and the explanations you give about everything. Thank you so much for taking the time to tell us so much, we truly appreciate it, and read all with interest.”
Brian Sherborne       "Awesome effort. As a technology teacher at the Raumati Technology Centre I appreciate the technical aspects. As a resident of Rata Rd and close to the construction area I appreciate being informed about aspects of the project that may impact on us. Well done. "

CONCLUSIONS

Innovation happens when designers and constructors collaborate to put existing concepts together in a new way. By pushing to find innovative solutions in the design and construction of the piles and piers, we had achieved significant construction efficiencies and savings.

Collaboration between designers and constructors enabled the use of 3m diameter piles with plunged columns cages for the multi-span bridge piers.

This approach allowed the M2PP Alliance Team to construct 24 No piles safely and efficiently saving the project over $6,300,000 and 120 days. Innovative design, early planning and thorough trials have facilitated a highly effective construction method and produced high quality piles and pile-column interface connections.

Figure 20: Completed columns for hammered-head piers of Waikanae River Bridge

ACKNOWLEDGEMENTS

The authors would like to acknowledge the numerous and continuing contributions of the NZTA, other Alliance partners and suppliers in the development and implementation of the innovative approach taken on this project.
REFERENCES

[19] Priestley M. N: Advice to NZTA via Email Correspondence, 20th February 2014