PREVALENCE AND DISTRIBUTION OF PRE-TENSIONED PRESTRESSING STEEL CORROSION RISK IN THE NEW ZEALAND CONCRETE BRIDGE STOCK

Rhys A. Rogers¹
Moustafa A. Al-Ani¹
Jason M. Ingham²

SUMMARY

The aim of this research was to use the New Zealand Transport Agency's bridge database to assess the risk of prestressing corrosion to State Highway bridges. Bridge age categories were developed that aligned with events in the concrete industry which resulted in changes to design and construction procedures for pre-tensioned bridge beams. Typical bridge designs from each of the different eras are identified and a field investigation was designed to assess their susceptibility to pre-tensioning steel corrosion. This study has led to a better understanding of the severity of prestressing corrosion in New Zealand's bridges and allowed an estimate of the total cost of the problem to be made.

1 INTRODUCTION

Recent deterioration of several pre-tensioned prestressed concrete bridge beams in New Zealand and Australia (Pape and Melchers, 2007; Bruce et al., 2008) have highlighted a problem that is becoming increasingly prevalent. Prestressed concrete bridge construction became common in New Zealand in the 1950s and a large number of bridges of this type were constructed between 1953 and the mid 1970s. The design requirements for these early bridges specified insufficient cover concrete when compared with modern requirements, and consequently the prestressed reinforcement is now at risk of corrosion.

The Hamanatua Bridge near Gisborne, the Tiwai Point Bridge in Invercargill and the Sorrell Causeway Bridge in Tasmania are three examples where bridges have experienced severe prestressing corrosion damage after short service periods. It is expected that many other bridges of similar age and design are nearing the stage where prestressing corrosion will be identified by routine inspections. When prestressing steel corrosion progresses to the point that it can be detected by a visual inspection it is often too late for remediation to be performed effectively because a small loss of steel section can severely weaken the structure. Therefore it is critical to identify at risk bridges early so that prevention and remediation works can be performed to extend their service lives.

The aim of this research was to use the New Zealand Transport Agency’s (NZTA) Bridge Database System (BDS) to assess the risk of prestressing corrosion to State Highway bridges. Typical bridge designs from different eras were assessed for their resistance to prestressing corrosion and a range of categories were developed to rank the bridges. Prestressed pre-tensioned bridges were assessed according to their design, age and exposure category.

This study leads to a better understanding of the severity of prestressing corrosion in New Zealand's concrete bridges and allows an estimate of the total cost of the problem to be made. The data gained can be used by asset managers to identify at risk bridges throughout the country and allow them to rank bridges so that inspections and maintenance can be performed in the most effective order.

2 PRE-TENSIONED CONCRETE BRIDGE STOCK

The NZTA’s BDS contains data on bridges on the New Zealand State Highway network. Bridges on local roads are managed by their respective councils and are not included in the database. However regional councils have usually followed the NZTA (and its predecessors) regarding design and construction methods for use in their own local bridges. For this reason it is thought that the outcomes of this research can be applied to local council bridges as well as those on the state highway network.

Seven hundred and seventy two bridge entries were extracted from the BDS in October 2008. The data set consists of all of the concrete bridges that are listed as being "precast and pre-
tensioned”, and all those listed as being “pre-tensioned and post-tensioned”. These two categories encompass all concrete bridges in the database that contain pre-tensioned reinforcement.

The data set contains ten different beam types and the number of bridges of each beam type is displayed in Figure 1. The “Misc” category contains four beam types which are each used in six or fewer bridges. The “Other” category contains bridges with beam type listed as other, and those with no beam type listed.

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double Hollow-core</td>
<td>251</td>
</tr>
<tr>
<td>Single Hollow-core</td>
<td>28</td>
</tr>
<tr>
<td>I-Beams</td>
<td>232</td>
</tr>
<tr>
<td>U-Beams</td>
<td>58</td>
</tr>
<tr>
<td>T-Beams</td>
<td>32</td>
</tr>
<tr>
<td>Misc, Other</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure 1: Pre-tensioned concrete bridge stock beam types**

The pre-tensioned concrete bridges listed in the BDS have construction dates ranging from 1934 to 2007. A summary of the number of bridges constructed each year is given in Figure 2 showing that pre-tensioned bridge construction was most common in the decade between 1960 and 1970, with a gradually declining popularity since that time.

**Figure 2: Pre-tensioned concrete bridges constructed per year**

### 3 BEAM TYPES

This section briefly describes some of the characteristics of each of the pre-tensioned beam types listed in the NZTA’s BDS. Their popularity over time is also mentioned, and is summarised in Figure 3.

**Figure 3: Summary of bridge age by beam type**

#### 3.1 Double hollowcore

Double hollowcore (DH) units have been regularly used for standard bridge designs, with spans of up to 18 m. The prevalence of DH units in New Zealand bridges can be traced back to the release of a set of “Standard Plans for Highway Bridges” by the Ministry of Works (MOW) in the mid-1960s (MOW, 1966 - 1970). Figure 4 shows a standard section from this document, labelled “Standard precast pre-tensioned hollow bridge units”. While this section is similar to current designs for U-beams, it is believed to be an early double hollowcore unit. Bridges from this period listed in the BDS as double hollowcore are expected to be of this design.

**Figure 4: Early standard design for bridge double hollowcore units (MOW, 1966 - 1970)**

Double hollowcore units have consistently been used since their introduction into New Zealand. However the design of the units has evolved considerably over time. The age of most DH bridges falls within the range of new to 40 years.
old as shown in Figure 3. Figure 5 shows the typical design of a modern double hollowcore bridge unit.

![Figure 5: Current standard bridge double hollowcore unit (MWD, 1981)](image)

**3.2 Single hollowcore**

Single hollowcore (SH) units are similar to double hollowcore units in design but are narrower and contain only one void per unit. Previous single hollowcore units have been used for spans of up to about 14 m. Figure 6 shows the basic design of a single hollowcore unit.

![Figure 6: Typical bridge single hollowcore unit (Gray et al., 2003)](image)

Single hollowcore units were first used in 1954, which is approximately the same time as double hollowcore units were first used, but single hollowcore units never reached the same level of popularity. Double hollowcore units are usually preferred because they can have a longer span and a greater number of single hollowcore units are required for the same bridge width. However single hollowcore units are more suited to bridges with a large angle of skew because of the smaller width of each unit.

A recent study commissioned by Transfund New Zealand (Now NZTA) recommended that single circular hollowcore units, as shown in Figure 6, not be retained as a standard section (Gray et al., 2003). The latest NZTA standard plans include drawings for 650 mm and 900 mm deep single hollowcore units with spans of up to 25 m (Beca and Opus, 2008), which have one large rectangular void and are closer in design and function to the double hollowcore unit shown in Figure 5 than to the single hollowcore unit shown in Figure 6.

**3.3 I-beams**

I-beams are a well-known form of construction, both in steel and concrete, and consist of a narrow web connecting two wide flanges, in which most of the longitudinal reinforcement is placed. I-beams have recently been used for spans up to 32 m (Gray et al., 2003) but the 2008 NZTA standard plans contain drawings for I-beams with spans up to 24 m, with the super-T section being preferred for the longer spans. Figure 7 shows a typical I-beam.

![Figure 7: Typical bridge I-beam (Bruce et al., 2008)](image)

I-beams have been used in prestressed concrete bridge beams in New Zealand since the introduction of prestressed concrete construction, and were the dominant type of bridge beams constructed until the mid-1970s, but I-beam use in NZ has been in steady decline since the mid-1970s due to the preference of designers shifting to other beam types. There are a number of reasons for this diminishing popularity including the inefficiency of I-beams for shorter spans, the large depth requirement, and construction safety concerns associated with the erection of permanent formwork on widely spaced I-beams (Gray et al., 2003). The age of the majority of I-beam bridges ranges from 30-50 years, although there are also a significant number of I-beam bridges which are younger.

**3.4 T-beams**

Figure 8 shows an example of a bridge T-beam which was constructed in 1969. T-beams are a common form of concrete construction, and are often used as flooring units for multi-storey buildings. However, the popular use of T-beams never extended into bridge design in New Zealand and they represent only 4.1% of the existing NZTA bridge stock. Most of the 32 bridges in the BDS using prestressed T-beams have an age ranging from 40-50 years old.
Super-T (sometimes referred to as ‘Tee-Roff’) beams are significantly larger than traditional T-beams, and contain one large void. It is likely that some of the more recent bridges listed as T-beam bridges in the NZTA bridge stock actually contain super-T beams. The use of super-T beams has been steadily increasing, and the most recent standard bridge designs issued by the NZTA contain drawings for super-T sections which span up to 30 m (Beca and Opus, 2008).

3.5 U-beams

Figure 9 shows a typical U-beam. U-beams have been in use in New Zealand since the mid-1970s, but were infrequently used as they were deemed uneconomic for most situations. U-beams have spans of up to 26 m and are well suited for use in urban situations where a low section depth is required. A recent report has recommended excluding U-beams from new standard sections (Gray et al., 2003), and it is expected that fewer U-beams will be used in future bridge construction. The vast majority of U-beam bridges in NZ, which represent 7.5% of NZTA’s bridge stock, are 30 years old or younger.

3.6 Log beams

Figure 10 shows a typical example of a bridge log beam. The drawing is dated 1957, but the standard plans were not published until the mid-1960s (MOW, 1966 - 1970). The date of the drawing coincides with the construction of a large number of log-beam bridges as shown in Figure 3.

Figure 10: Typical log beam (MOW, 1966 - 1970)

This form of bridge construction was soon found to be inefficient and uneconomical, and only two bridges of this type constructed after 1975 can be found in NZTA’s bridge stock. Therefore, the majority of log-beam bridges, which represent almost 12% of NZTA’s total bridge stock, are aged between 40 and 50 years.

3.7 Miscellaneous

There are a total of fifteen bridges in the NZTA bridge stock listed with a variety of infrequently used beam types, including triple hollowcore, inverted-T and box girder beams. These beam designs are most likely adapted from international designs, with triple hollowcore units and box girder beams more regularly used in North America, and inverted-T beams used in the United Kingdom (Gray et al., 2003).

When assessing the corrosion risk of these miscellaneous bridges, each structure has to be considered on a case-by-case basis.

3.8 Other

There are sixty four bridges in the NZTA concrete pre-tensioned bridge stock with beam types listed as either ‘Other’ or blank, and they represent 8.3% of the total inventory. It is likely that the majority of these bridges consist of either some of the infrequently-used beam types listed in the ‘Miscellaneous’ section, or various combinations of beam types. As such, corrosion risk assessment for these bridges will begin with an identification of the actual beam types used in each bridge, allowing most of them to be inserted into the categories discussed above.

4 AGE CATEGORIES

The earliest concrete bridges containing pre-tensioned reinforcement and listed in the BDS were constructed in 1934; however only nine are listed before the mid 1950s, when pre-tensioned bridge beams started to gain popularity. This can be seen in Figure 2.
tensioned bridges constructed in eight age categories.

4.1 Development of categories

The pre-tensioned concrete bridges in the BDS were separated into categories in order to divide the bridges into groups which have similar corrosion resistance characteristics. Standard plans for bridge sections have been widely used in New Zealand for many years, so the age categories were developed predominantly based on points in time when changes to standard section geometries and concrete design codes have occurred. The standard section geometries have been commonly used throughout the country, so these standard details provide a fair estimate of a bridge’s design characteristics based on its age and beam type. Concrete mix parameters influencing durability were much less uniform nationwide, so generalisation of in-situ concrete characteristics is less accurate because the resistance to chloride ingress is also expected to vary considerably between regions.

Several of the age categories were based on information gathered for only one beam type, with the general design features assumed to be similar for all beam types constructed at approximately the same point in time. This is because most pre-stressed concrete bridge beams produced at one point in time had similar requirements for durability and were designed using the same criteria, although the requirements and criteria changed over time.

Eight construction eras were identified to categorise the bridges based on construction practices that evolved over time, with the era categories separated by milestones which have caused a change in the way that bridge beams were constructed. These milestones include, but are not limited to: the release of new standard bridge sections, the release of concrete design standards, and changes to the type of prestressing steel used.

The categories are intended to provide an indication of the construction practices used at a given point in time. However the year of construction of a bridge alone is insufficient to definitively assign it to a category, and other evidence must be considered also.

The categories are defined by events which influenced the design of concrete bridge beams from that time onwards but often these changes were not uniformly adopted at one point in time and instead were gradually implemented. For this reason the boundaries are not definite and in the years surrounding a boundary some of the bridges constructed will have characteristics more similar to the previous era while others will be representative of the new design.

4.2 Concrete durability

The aim of the categories is to identify differences in the corrosion resistance of concrete bridge beams constructed in each era. Recent research conducted in Australia (Chirgwin et al., 2009) has suggested that an important factor when determining the corrosion resistance of a bridge beam is the criteria used to specify the concrete mix. Over time, the criteria used to specify concrete for precast bridge beams has varied considerably. The Ministry of Works and Development (or its equivalent) at certain points in time imposed various rules to govern mix designs, such as specifying the maximum cement content and banning the use of calcium chloride as an admixture. These restrictions were implemented
through the MWD Specifications for Materials and Workmanship, which are referenced in the standard drawings. However these rules still allowed large variability for mix designers, and concrete durability properties can therefore vary significantly between regions and even between precasting yards in the same region.

There has not been a strict standard governing mix designs for precasters producing bridge beams, and as such regional variations in durability properties are expected to be considerable. For this reason, mix design was neglected as a parameter used to define age categories, although several major changes are noted in section 4.3. Concrete durability properties will be assessed as part of the bridge inspection phase of this project which is outlined in section 6.

4.3 Description of categories

4.3.1 Pre 1953
This category includes nine bridges, which are the earliest pre-tensioned concrete bridges listed in the BDS. All of these bridges are listed with construction dates in the mid-1930s, followed by a fifteen year absence of new pre-tensioned bridges. Some or all of the bridges in this category are expected to not originally have been pre-tensioned, but have been subsequently upgraded with pre-tensioned beams and therefore merit having their recorded age modified to a more recent date.

A breakdown of the beam types listed in this category is given in . These bridges will be amended to their appropriate age categories should further information become available.

4.3.2 1953-1961
The first pre-tensioned concrete bridge listed in the BDS after the 1930s was constructed in 1953 and pre-tensioned concrete bridge construction increased rapidly in the following years. The first pre-tensioned concrete I-beam bridge that is listed in the BDS was constructed in 1956. Previous research into the corrosion resistance of pre-tensioned I-beams (Bruce et al., 2008) identified two ‘generations’ of I-beam bridges, and this 1953-1961 category encompasses the first of the two generations. The general design features of the first generation I-beams are expected to be similar to those evident in other beam types from this category for the reasons given in Section 4.1.

Seventy nine pre-tensioned concrete bridges were constructed in this category with the majority being log beams. I-beams were also beginning to gain popularity. A breakdown of the beam types constructed between 1953 and 1961 is given in . Bridges constructed in this category will most likely be pre-tensioned with 0.2" High Tensile (HT) wire rather than strand. The concrete may contain calcium chloride, used as a set accelerating admixture.

Exposure categories did not exist at this time, so cover depths will be similar regardless of the location of the bridge. In coastal regions specified cover is likely to be well below current requirements, with the first generation I-beams described by Bruce et al. (2008) as having specified cover of 0.9" (23 mm) to the wire, whilst standard log beam plans dated 1957 specify 1.25" (32 mm) cover to the wire centreline (MOW, 1966 - 1970).

I-beam bridges produced in this period have a pre-tensioned strand arrangement which has the prestressing strands not fully confined by the stirrups. This detailing presents a corrosion weakness because the wire or strand in certain parts of the beam is exposed to high levels of chloride ingress before the mild steel stirrups, and can therefore begin corroding before the less critical stirrups. Corrosion of the pre-tensioned reinforcement before the stirrups presents a problem because the small cross section of the prestressed reinforcement can allow corrosion damage to advance considerably before enough expansion due to corrosion product has occurred to crack the concrete. It has been shown that pre-tensioned strand corrosion can lead to beams with severely reduced capacity before corrosion is externally visible (Pape and Melchers, 2007). This design feature does not appear to affect log beams, but is likely to affect T-beams and double hollowcores of this era.

4.3.3 1962-1966
The 1961 category boundary is based on release of the AASHTO H20-S16-T16 loading standard (Bruce et al., 2008). An important ramification of this release is that it resulted in a gradual shift in the industry from the use of HT wire to the use of strand. Beams cast in this time period are likely to contain 3/8" (9.5 mm) strand, although some may still contain HT wire. An amendment to the Ministry of Works standard plan for log beams dated 1964 states that 3/8" strands are to be used in preference to 0.2" HT wire (MOW, 1966 - 1970).

One hundred and thirty four bridges were constructed in this period. The popularity of I-beams increased markedly, while only a few more log beams were constructed than in the previous period. The number of bridges of each beam type is given in . I-beams from this period will be from the second generation as described in by Bruce et al. (2008).
Minimum cover to the strand in these beams is 11/8" (29 mm).

Similar to the previous category, beams constructed in this period are likely to have stirrups which do not fully confine the prestressing strand. This design feature does not apply to log beams, but does apply to I-beams, T-beams, double hollowcore units, and may apply to other types also. Concrete from this era may also contain calcium chloride as an admixture.

4.3.4 1967-1975
The category boundary in 1967 is based on the development of standard plans for pre-tensioned highway bridges, published by the Ministry of Works between 1966 and 1970 (MOW, 1966 - 1970), which later became known as the “blue book”. The plans include standard sections for I-beams, pre-tensioned bridge units (log beams) and pre-tensioned hollow bridge units (early double hollowcore units). While these plans were developed between the late 1950s and 1970 they were not published formally until 1975. A large proportion of the bridges produced in this period are expected to be individually designed, and so the beams from this period will have a greater variation than those produced after 1975. However as the standard sections were designed at about this time, bridges which are not constructed from the standard plans will have general features similar to those in the blue book designs.

One hundred and ninety pre-tensioned concrete bridges were constructed in this period, with the distribution of beam types shown in . The majority of bridges were constructed using I-beams, while the popularity of double hollowcore units increased over previous periods and the proportion of log beams constructed fell considerably when compared to previous periods. There are also a large number of bridges in this category with beam types not listed or listed as “Other”.

Beams constructed in this period are most likely to contain 3/8” strand, but it is possible that some log beams still used HT wire. Some I-beams may contain 1/2” strand.

Cover depths taken from the MOW standard plans from this era are measured in the soffit to the centreline of the bottom strand, with the specified cover ranging from 5/4” (31.75 mm) for log beams to 2” (50.8 mm) for I-beams. I-beams have lower cover in the webs (39.7 mm). Double hollowcores have 7/4” (44.45 mm) cover in both the web and soffit.

Similarly to the previous categories, beams constructed in this period are likely to have stirrups which do not fully confine the prestressing strand. This design feature does not apply to log beams, but does apply to I-beams, T-beams, double hollowcore units, and may apply to the other beam types. Calcium chloride was banned as an admixture by the MOW in the late sixties, so bridges constructed early in this period may still contain cast in chlorides.

4.3.5 1976-1981
This category boundary is based on the formal publication of the standard plans for highway bridges or “blue book”, in 1975. Bridges constructed with standard beam types are expected to match the standard plans in almost all cases.

Ninety one pre-tensioned concrete bridges were constructed in this period, with the distribution of beam types displayed in . Double hollowcore units were the most popular beam type, followed by I-beams. U-beams and single hollowcore units also increased in usage over previous periods.

The design features of beams from this category were described in the previous section. High tensile wire is not expected in beams from this era, and 3/8” strand is expected to be the most common prestressing reinforcement, although the use of 1/2” strand became more common through this period, especially in I-beams.

In the late seventies the Ministry of Works imposed a maximum limit on cement content in concrete, so a considerable change to concrete properties can be expected at that time.

4.3.6 1982-1995
The 1981 boundary is based on the release of new standard bridge plans and the release of NZS 3101:1982. The new standard bridge plans were the first iteration of the “Red Book” or Rural bridges standard bridge plans (MWD, 1981). The Red Book included drawings for single, double and triple hollowcore units, I-beams, and U-beams (Gray et al., 2003). The Red Book also contained a section with bridge designs for low traffic rural roads and farm roads, for bridge spans of 6 m to 16 m.

One hundred and seventy five pre-tensioned concrete bridges were constructed in this time period, with the vast majority being double hollowcore units. I-beams and U-beams were also used commonly. The distribution of beam types constructed in this period is shown in .

Most beams from this period will contain 12.5 mm strand with a characteristic strength of 165 kN per strand. Mild steel for other reinforcing including stirrups is most likely grade 275.

The red book specified cover to outside of all prestressing components as 40 mm plus or minus
3 mm tolerance, and cover to stirrups was specified as 30 mm, with the 28 day compressive strength of concrete specified as 40 MPa.

NZS 3101:1982 required that stirrups must enclose all longitudinal reinforcement, with the required cover depth varying according to bar size, type of member and exposure environment, with lower cover depths permitted for precast construction. It was stated that: “in aggressive environments particular attention must be given to providing a resistant dense concrete” (Blakeley et al., 1983).

4.3.7 1996-2006
The category boundary in 1996 is based on the release of NZS 3101:1995. The majority of beams constructed in this period are based on the standard plans from the red book, updated to the new requirements of NZS 3101:1995.

The Transit New Zealand (TNZ) Bridge Manual was released in 2003. For durability criteria this document refers to the appropriate materials standard (TNZ, 2003), which for pre-tensioned concrete bridges was NZS 3101. The factors influencing the durability of bridges designed to the TNZ Bridge Manual during this period should be similar to those designed to NZS 3101:1995 before the release of the Bridge Manual.

Eighty nine pre-tensioned concrete bridges listed in the BDS were constructed during this age category, with more than half utilising double hollowcore units. All of the other beam types were also used, but to a much lesser degree. The beams in the miscellaneous category for this period are box girders and bridges made up of both I-beams and double hollowcores.

NZS 3101:1995 contained an entire chapter on durability. This chapter is similar in design to the durability chapter which appears in NZS 3101:2006, but with a few key differences. For example, the durability chapter in NZS 3101:1995 only contains criteria for a 50 year design life, and it does not account for the addition of supplementary cementitious materials (SNZ, 1995).

The definitions of exposure categories in the 1995 version of NZS 3101 are the same as for the 2006 version of the standard. Specified cover depths are higher for a 50 year design life than they are in the 2006 version, but requirements for a 100 year design life are not specified.

For a 40 MPa Ordinary Portland Cement (OPC) concrete in the B2 exposure zone, 40 mm cover to the stirrups is required. The standard also stipulates that the concrete must have a minimum OPC content of 350 kg/m³ and maximum water/cement ratio of 0.4, with OPC concrete defined as having no more than 5% mineral admixture.

In the late nineties supplementary cementitious materials became mandatory in concrete mixes, so a change in concrete mix design is expected to have occurred early in this category.

4.3.8 2007-2008
The 2007-2008 category boundary is based on the release of NZS 3101:2006. This standard extended the durability chapter included in the previous iteration of NZS 3101 to include design requirements for a 100 year design life. The 2006 standard also refined some of the durability requirements existing in NZS 3101:1995.

The BDS only lists two U-beam bridges and one double hollowcore bridge as having been constructed after 2006, but it is expected that this low number is partly because data on new bridges has not yet been entered into the database.

The cover depth charts in NZS 3101:2006 allow for the use of supplementary cementitious materials. An example of a 40 MPa beam in the B2 exposure zone constructed from a GP (Portland), GB (blended) or HE (High Early strength) concrete would require 35 mm cover for a 50 year design life and 50 mm cover for a 100 year design life (SNZ, 2006). Beams in the tidal/splash/spray exposure zone (C) must contain fly ash, ground blast furnace slag or amorphous silica and are also subject to other, more stringent requirements. In the C and B2 exposure zones the standard allows for the use of durability models in place of its own requirements.

4.3.9 2008 onwards
In 2008 the NZTA released a new set of standard bridge plans (Beca and Opus, 2008) designed to NZS 3101:2006 and the 2003 Transit New Zealand Bridge Manual. These standard plans include designs for single hollowcore units, double hollowcore units, I-beams and super T beams, covering a span range of 12 m to 30 m.

5 DISTRIBUTION ANALYSIS
Using the information found in NZTA’s BDS, the location of every pre-tensioned concrete bridge listed was input into the ‘Google Earth’ program (Google, 2009). The software allows a visual representation of the location of pre-tensioned concrete bridges throughout New Zealand, which enabled an analysis of the geographic distribution of bridges by various criteria, including beam type and bridge age. The software allows the bridge icons to be assigned a colour based on their age category or other criteria.

The Google Earth software also allows for remote measurement of large distances, as shown by the
screen-capture in Figure 12. This screen shows the Mangahauini Bridge No. 1 near Gisborne on the east coast of the North Island. The waterline and the high tide mark can be approximately identified in the image, and the distance from the bridge to the high tide mark is being measured by the dialogue box. In this case the distance to the high tide mark is approximately 120 m. This information is used in conjunction with NZS 3101:2006 to obtain the exposure category, indicating that the Mangahauini Bridge No. 1 is in the B1 exposure category but is very close to the limit between the B1 and B2 exposure categories.

![Image of Mangahauini Bridge No. 1](image)

**Figure 12: Remote distance measurement in Google Earth**

Using the facilities described, several analyses can be conducted to quantify the corrosion risk of the pre-tensioned concrete bridge stock. For example, by using Google Earth to determine the exposure classification of a bridge and combining this with the concrete strength of the beams, the minimum reinforcement cover required by NZS 3101:2006 can be evaluated for each bridge. The required cover can then be compared either with the measured concrete cover in each bridge, or by referring to the bridge drawings which are referenced in the BDS, or with the expected concrete cover which is determined by referring to the standard drawings from the bridge’s construction period. The comparison between actual/expected concrete cover, and with the minimum specified in NZS 3101:2006, provides insight into the susceptibility of the bridge beams to corrosion.

### 5.1 Exposure classification descriptions

The exposure classifications used in this section are taken from NZS 3101:2006 and apply to above ground exterior environments. The classifications are briefly described in Table 1, and full details are given in chapter 3 of NZS 3101:2006 including maps showing the boundary between the A2 and B1 exposure categories.

<table>
<thead>
<tr>
<th>Exposure Classification</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A2 (Inland)</td>
<td>Inland areas with less risk of reinforcing steel corrosion. Defined by maps given in NZS 3101:2006</td>
</tr>
<tr>
<td>B1 (Coastal Perimeter)</td>
<td>Areas which do not fall into any of the other categories</td>
</tr>
<tr>
<td>B2 (Coastal Frontage)</td>
<td>Within 100 m of the high tide mark. Or between 100 m and 500 m of the high tide mark in the direction of a prevailing or other common wind</td>
</tr>
<tr>
<td>C (Tidal/Splash/Spray)</td>
<td>Offshore and up to the high tide mark. Or up to 30 m inland of the high tide mark in the direction of a prevailing or other common wind</td>
</tr>
</tbody>
</table>

### 5.2 Double hollowcore

Figure 13 shows the distribution of the two hundred and fifty one double hollowcore bridges in New Zealand. While there is a scatter of DH bridges in the North Island, there are two notable concentrations around the far north and Coromandel regions. The majority of these bridges will be in exposure categories B1 or B2. In the South Island, there is a concentration of DH bridges along the west coast, which is another region where many bridges fall into exposure categories B1 or B2. The large number of double hollowcore bridges located in B1 and B2 exposure categories means that they should be considered a high priority for further assessment.

![Image of double hollowcore bridges](image)

**Figure 13: Distribution of double hollowcore bridges in New Zealand**
5.3 I-beams

The locations of all two hundred and thirty two NZTA I-beam bridges in New Zealand are shown in Figure 14, and it can be seen that these bridges are well distributed throughout the country. By comparison with the ‘Exposure classification maps’ found in NZS 3101:2006 it is concluded that a significant proportion of I-beam bridges in the North Island and a large proportion of I-beam bridges in the South Island fall within the B1 or B2 exposure classification. The large number of I-beam bridges constructed in the earlier age categories and the high proportion of those that are located in the B1 or B2 exposure categories indicates that I-beam bridges should be considered of high priority for further assessment of corrosion risk.

5.4 Log beams

The distribution of log-beam bridges is centred in the middle of the North Island, and scattered about the South Island, as shown in Figure 15. The majority of log-beam bridges in the North Island, and about half in the South Island, fall under the ‘A2’ exposure classification. However because of the large proportion of log beam bridges constructed in the earlier age categories log-beam bridges which do not fall in the A2 exposure category should be considered a high priority for detailed assessment and further risk analysis.

5.5 T-beams, U-beams & single hollowcores

Due to the relatively low number of T-beam, U-beam and single-hollowcore bridges in New Zealand, Figure 16 shows the combined distribution of these bridges using the following identifying markers:

- T-beams
- U-beams
- Single-hollowcores

Bridges are scattered around the North Island, apart from the expected concentration in the Auckland region, and there is a fairly even split between bridges in the A2 zone and those in the B1 or B2 zones. In the South Island there are few of these bridges, with the majority of these located along the east and west coasts, resulting in many having a B2 exposure classification. It is concluded that T-beam, U-beam and single-hollowcore bridges should be considered a moderate priority for the further stages of corrosion risk analysis, with the exception of U-beam bridges.
in the South Island, which should be considered as high-priority.

5.6 Miscellaneous & others
As these bridges will need to be assessed on a case-by-case basis there is little value in analysing their distribution, and the location of each bridge will be used to individually assess its corrosion risk.

6 SEVERITY ANALYSIS

The severity analysis aims to assess the durability performance of each of the identified beam types and age categories. The present condition of a range of bridges will be assessed and the remaining service life of each bridge will be estimated. A previous study has already been conducted for I-beams from the 1962-1966 and 1967-1975 age categories (Bruce et al., 2008). The severity analysis will use a similar investigation technique to the I-beam study, but will expand the scope to include all of the age categories and the other beam types.

6.1 Proposed field investigations

Approximately thirty four detailed field investigations are proposed on a sample of bridges selected to reflect the distribution of the bridge types in the overall State Highway bridge stock. The proposed number of field investigations on each beam type from each age category is given in Table 2. The gray boxes indicate the tests performed by Bruce et al. (2008) in the previous study on I-beams.

<table>
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</table>

6.2 Proposed investigation methodology

Each field investigation will consist of a visual inspection of all bridge beams, followed by measurements conducted on a sample of two to six beams from each bridge. The visual inspection will aim to identify cracks, spalling, rust staining and areas with exposed reinforcement or poor compaction. The measurements taken will include a cover depth survey, chloride ingress, carbonation depth, porosity and compressive strength.

7 CONCLUSIONS

This study used the NZTA’s BDS to assess the risk of prestressing corrosion to New Zealand’s State Highway pre-tensioned concrete bridges. Age categories were developed that aligned with events in the concrete industry which resulted in changes to design and construction procedures for pre-tensioned concrete bridge beams. These categories separate the bridges into groups with similar durability properties.

Typical bridge designs from each of the different eras were identified and tools were developed to assist with remote assessment of the likelihood of pre-tensioned reinforcement corrosion. An accurate visual geographic representation of all pre-tensioned concrete bridges on the NZ State Highway network was developed, allowing for an analysis of the distribution of the different age categories and bridge beam types throughout New Zealand.

A field investigation was designed to assess a sample of bridges from each age category and beam type for susceptibility to pre-tensioning steel corrosion. The data from the field investigation, combined with the described tools, will allow an estimate of the risk of pre-tensioning reinforcement corrosion to any pre-tensioned concrete bridge in New Zealand based on its age category, beam type and location.

8 ACKNOWLEDGEMENTS

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9 REFERENCES


Google (2009). Google Earth: Google Earth is free software which provides an interactive three dimensional model of the Earth constructed from satellite imagery., http://earth.google.com/.


