STRATEGY RELATED MANAGEMENT OF RAIL TRANSPORT STRUCTURES

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ABSTRACT : The NZ railway track and structures infrastructure is managed by the New Zealand Railways Corporation (trading as ONTRACK). The civil asset consists of 4,161km of mainline track, 6.45 million sleepers, 1582 rail bridges, 149 tunnels with a cumulative length of 87km, and 12,900 culverts. There are a number of infrastructure challenges faced by ONTRACK due to the asset age and condition combined with changing expectations of the level of service required of the asset and increasing demand. These challenges are significantly influencing the short to medium term asset management strategies currently being devised. A selection of brief case studies on the rail sector will be presented in the paper, demonstrating how lessons can be reinforced or learned by the wider transportation profession. Case studies will be selected from the following areas: railway approaches to risk management; deterioration modelling of treated pinus radiata sleepers; culvert risk analysis; strength rating of timber bridges and innovative design solutions to replace large numbers of timber bridges. The case studies will use a mixture of empirical physical examples and also present the results of engineering analysis and modelling.

1.0 Introduction

This paper seeks to raise the general awareness of responsibilities and selected engineering activities in the railway industry as it re-emerges as an increasingly important Land Transport player in New Zealand. Emerging issues which are driving railway civil infrastructure asset management will be discussed.

Selected parts of the civil asset will be focused on in this paper. These being: culverts and drainage; and, managing the large quantities of timber track and bridge components.

Some examples of ONTRACK’s strategies relating to managing the railway asset and their associated risks will be described. Many of the broad asset management strategies utilised by the railway are equally applicable to other transport providers.

1.1 Overview of the NZ Railway Industry

Relatively recent changes in railway administration have resulted in infrastructure management being separated from the locomotive and rolling stock operation of the railway.

In 2004, the Government re-purchased the railway infrastructure to secure a vital part of New Zealand’s transport infrastructure in the national interest. The Government is committed to retaining the existing network, to investigating the development of a number of new railway lines, and to maximise the use of railway transport.

The New Zealand Railways Corporation (an entity that uses the trading name ‘ONTRACK’) is an instrument of the Executive Government of New Zealand and is a State Owned Enterprise.

ONTRACK’s responsibilities to Government include:

- ownership, management, operation and development of the national rail network;
- the control of all operations of the network (e.g. signalling and train control);
- the control of access to the network, including the setting of track access charges;
- the implementation, co-ordination and maintenance of an approved safety system for the network;
- the management of rail land, property and leases; and
- the provision of advice to the relevant Government Ministers.

The funding for ONTRACK day-to-day operations and renewals is primarily through track access charges. Relatively smaller amounts of funding are obtained from public funding sources.

There are currently two major upgrading projects being undertaken in the Auckland and Wellington metropolitan networks. At present the other main railway stakeholders are:

a) Toll NZ who own and operate the freight rolling stock, run the Wellington Commuter Trains and long distance passenger trains;
b) The Auckland Regional Transport Association and Veolia who own and operate respectively the Auckland Commuter Trains; and
c) the Wellington Regional Council who provide funding and are helping initiate network upgrades for the Wellington suburban rail network.

Each year there is approximately 15 million tonnes of freight and approximately 15 million passenger trips carried on the rail network in New Zealand.

2.0 Civil Asset Overview – Selected Issues

The civil rail asset consists of 4,161km of mainline track, 6.45 million sleepers, 12,900 culverts, 1582 rail bridges and 149 tunnels (with a cumulative length of 90km and 87km, respectively).

The Railway lines in New Zealand were first started to be constructed in the late 1800's, however the majority of the asset was constructed in the first half of the twentieth century. For bridges this means the average age of the asset is between 60 and 70 years old. Given the time since lines were first opened and that track components last between 20 and 40 years, the track asset components have been replaced 3 to 4 times since the lines were initially constructed.

New track constructed today consists of heavy weight rail (50kg/m) and concrete sleepers. New bridges are made out of concrete and steel. However, when the lines were first built and then refurbished over the decades, a considerable amount of timber was used for sleepers and bridge components. Therefore, high proportions of timber still remain in the asset to this day.

Tables 2.1 to 2.3 summarise the amount of timber used in the track and bridge asset by percentage of the total asset:

Material	**Percentage**
Timber Sleepers	68%
Concrete Sleepers	32%

Table 2.1 – Track Sleeper Material Types.

Material	**Percentage**
Timber Piers	30%
Mixture of timber and steel or concrete piers	8%
Concrete/masonry piers	60%
Steel or Iron Piers	2%

Table 2.2 – Bridge Substructure Material Types

Material	**Percentage**
Timber Spans	17%
Mixture of timber and steel or concrete spans	2%
Concrete/masonry spans	22%
Steel or Iron Spans	59%

Table 2.3 – Bridge Superstructure Material Types

The failure modes of timber components are a combination of age based decay/deterioration and the loads exerted on them. With the average age of the asset, much of the remaining timber based railway asset will need to be renewed within the next two decades. Developing replacement strategies and managing the timber components until they can be replaced represents one of the greatest challenges faced by the railway in the short to medium term future. Innovative solutions are often required to ensure maximum line availability and to minimise disruptions and the time the tracks are not available.

ONTRACK and the Government has ambitions to increase axle loads and the annual gross tonnages carried on the rail. Because of this, timber is no longer a viable material to use for new construction. Additionally, timber members of the quality and sizes required are not now readily available or cost effective.

There are also approximately 12,900 culverts in the national rail network and a network of predominantly longitudinal drains down either side of the tracks for the entire network. They are extremely important but often are an overlooked part of the infrastructure. In recent years, failure of the drainage and associated culvert network has resulted in a significant amount of avoidable damage, operating restrictions and rail line closures. Undertaking targeted improvements of the culvert and drainage infrastructure has been identified as a method to yield significant overall benefits to the railway network.

3.0 Case Studies in Rail Asset Management

3.1 Culverts

Providing an adequate and effective culvert drainage system is essential for running and sustaining a railway network. In the last two decades failures of the culvert and drainage system on the New Zealand network have been the single biggest cause of infrastructure-related line closures, derailments, geotechnical instability, decline in track formation condition and deaths/ injuries. Due to the relatively low profile and unglamorous nature of the culvert and drainage systems, it is a somewhat overlooked part of the infrastructure asset.

In order to raise the profile of the culvert and drainage asset and to develop tools to understand and communicate culvert risk more effectively a special study was undertaken by Alex McIver and Professor John Mander (2006).

The flooding risks associated with railway culverts were quantified using hydrologic and hydraulic principals, flood intensity and culvert capacity. The principal inputs were:

- Culvert diameter and number of barrels;
- Depth of the culvert below track level (to allow for a degree of ponding);
- Length of culvert;
- Culvert condition; and
- Local rainfall characteristics.

Using these inputs, culverts in a 14km sample stretch of track on the North Island Main Trunk from Kakahi to Mananui were studied. Three damage states were identified:

- **No damage** – normal service;
- **Moderate damage** causing loss of track alignment – partial line closure or speed restriction; or
- **Major damage** in the form of a washout – line closure, possible derailment or injury/death.

The risks associated with these losses were converted into costs using generally accepted scheduled rates of repairing damage, disruption costs, damage to rolling stock and assumed costs for injury/fatalities. In the 14km long study section, it was found that 10% of the culverts were responsible for 97% of the expected financial losses. Another important finding of the study was that over a reasonable period of time, most of the losses are from frequent small floods rather than the less frequent extreme weather events.

These findings have been useful for justifying increased maintenance and inspection expenditure on the national culvert and drainage system and targeting the limited resources available to where the greatest benefits can be obtained. The risk analysis study generally followed the National Rail Safety Standard / 4: Risk Management (2004) methodology.

The study also assisted ONTRACK to examine how it manages culvert and drainage risks. On the spectrum of risk management treatments, it can range from highly engineered solutions to eliminate the risk altogether through to risk management treatments where no engineering works are undertaken and appropriate monitoring systems are employed. Both risk management treatment options are deemed appropriate depending upon factors that include the probability and the consequence of an event occurring.

With the large number of culverts on the rail network it is not practical to utilise fully engineered treatments, if they are found to be substandard. As the railway system is a controlled network (in comparison to a road based network that is dependent upon individual drivers / road users),when adverse weather events occur a number of measures can be employed to manage the risk of these extreme events (e.g.):

- special patrols can be initiated to ensure the track is safe for train passage;
- speed restrictions can be applied to trains;
- train running is ceased altogether until the weather event is over and the track checked; and
- infrastructure staff are ready to respond and rapidly repair damage to reopen the line as soon as possible.

While the principal philosophy of managing the asset is to have all railway lines available for use at all times and to provide a robustly engineered asset capable of withstanding large weather events, this is not always economically feasible. The New Zealand funding and resource limitations mean that the most appropriate asset management technique is a pragmatic balance between highly engineered physical solutions and other methods where the risk is managed by processes rather than physical works (e.g. special patrols and condition monitoring).

Since the pilot study, ONTRACK has been working to extend the culvert risk analysis to other mainlines in the network to gain catchment specific data and to gain more confidence in the current cashflow predictions for future maintenance and renewal programmes.

3.2 Rail Track

As noted in section 2.0, there is a large proportion of timber sleepers currently installed in track throughout New Zealand. When the railway was first built, sleepers where cut from New Zealand native species. Generally, these were all softwood sleepers and decayed rapidly. These sleepers were then over time replaced with imported Australian Hardwoods up until about 1950. However, the quality and availability of the Australian Hardwoods started to dwindle as forests available for felling decreased.

In the 1950’s, large quantities of Pinus Radiata grown in New Zealand started to become available. This coincided with timber preservative treatment technology developments making it viable to utilise softwood for a greater number of applications. From 1960 Treated Pinus Radiata (TPR) sleepers began to supplant hardwood sleepers and from 1965 virtually all new sleepers were TPRs.

Of the 68% of timber sleepers in the national rail network, 89% of these are TPR and the remaining balance are Hardwood. From general track asset experience, the serviceable life of a TPR sleeper is between 25 and 35 years. Looking at the age profile of TPR sleepers installed in track (refer to Figure 3.1), it quickly becomes apparent that huge numbers of TPR sleepers will be reaching the end of their serviceable lives in the short to medium term future.

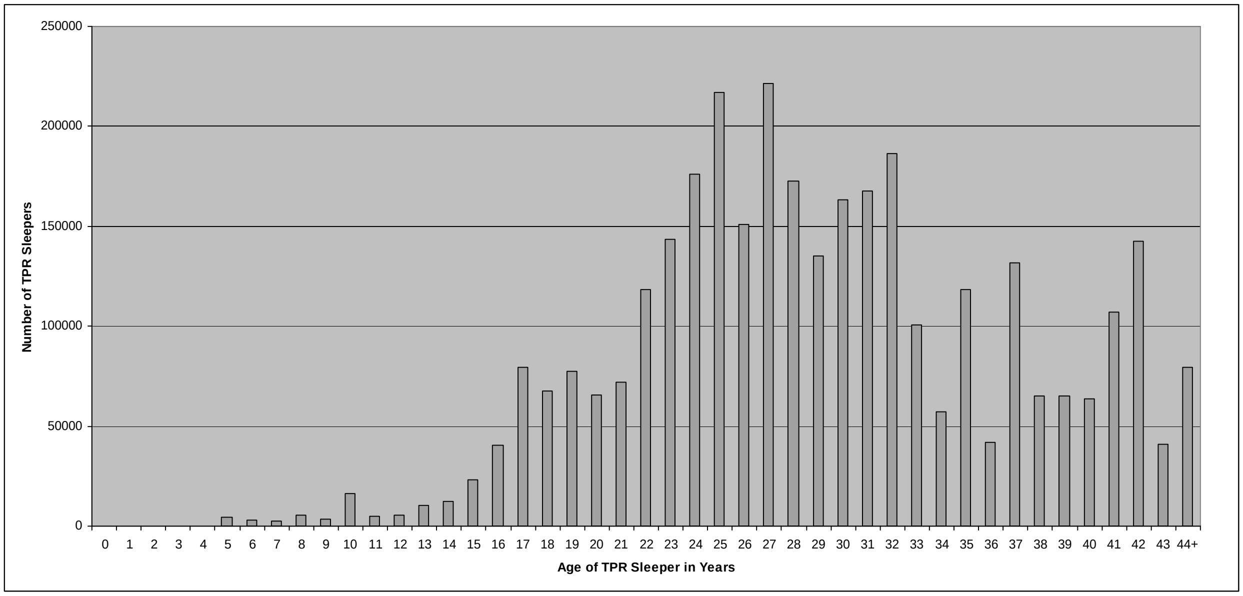

Figure 3.1 – Age Profile of TPR Sleepers on NZ's Main Railway Routes

The failure modes of TPR sleepers consist of various degrees of either one or a combination of:

- cracking, splitting and decay;
- rail bedplates cutting into the top face of the sleeper ('cutting in');
- loose screw spikes where the timber forming the hole for the spike is unable to provide sufficient purchase for the screw's thread; and/or
- the sleeper has broken or snapped.

Figure 3.2 shows an example of typical failure modes.

Figure 3.2 – Left: TPR sleeper with a large split running down its length. Right: bedplate supporting the rail cutting into the top of the TPR sleeper.

The current asset management condition assessment process for TPR sleepers involves a field engineer inspecting the track annually at walking pace and giving the sleepers an average condition grade. The grading system is then divided into five condition bands from number 1 to 5 (5 being as new and 1 being poor condition and due for replacement). There are a number of weaknesses with the current subjective grading system in that condition bands are poorly defined and the field engineers use personal judgement and experience to grade the sleepers. Additionally, the track sections containing TPR sleepers may extend over radically different track geometries. For example, a group of TPR sleepers being graded together may extend over a straight and a tight radius curve. The sleepers on the curve will usually be in a poorer condition because of the higher loads they endure due to the train curving forces. However, the field engineer will balance the poor condition of the curve sleepers with the relatively good condition of the sleepers on the straight resulting in an averaging of the condition grade for that section of track. The same scenario can occur if there is a wide range of sleeper conditions within a homogenous track length. A ‘dynamic’ sectioning method that divides the asset into analysis sections that are the ‘lowest common section distance’ between various distresses or management sections, (similar to that used in the NZdTIMS System for the roading asset), could be utilised in the Rail asset database if a computerised method of collecting automated condition data can be combined with inventory and management data in the future.

Using age alone as a predictor of sleeper life is also problematic as it doesn’t take into consideration the actual condition of the sleeper. This may result in TPRs being replaced prematurely or not soon enough. Consequently, a study by Rushbrook (2003). was undertaken to develop a new condition grading system. The objectives of this study was to:

- devise a reliable and repeatable condition rating system and reduce the potential for subjective judgements as far as possible;
- develop a system that was simple to understand so that intense training was avoided and/or a large amount of technical background being required;

- develop systems that could easily be incorporated into existing inspection processes so that inspection costs and time do not increase, and
- develop procedures whereby the data could be used to create a deterioration model which in turn can be used to predict the remaining life of the sleepers.

The study involved precisely defining five condition bands. A pilot study was undertaken on a length of track 33km long. Within the sample area there was 19km of track that had TPR sleepers. The lengths of TPR sleepers were divided up into homogenous lengths determined by whether they where on a curve or a straight. The entire track length was walked to inspect the TPRs. A sample of sleepers within each homogenous TPR length were graded. The most pragmatic inspection routine in terms of collecting a suitable amount of information at a reasonable rate was inspecting three consecutive sleepers every fifteen paces.

A weighted average condition indexing system was used to analyse the condition data collected as shown in Table 3.1 For four of the five condition bands a condition weighting was applied. A simple condition index was then calculated as demonstrated below.

Condition Number (condition digit used to record grade in the field)	**Condition Weighting Number (Y)**	**No. of TPRs with Particular Grading (f)**	**Weighted Grades (fY)**
5 (as-new condition)	10	0	0
4	9	14	126
3	7	42	294
2	4	1	4
1 (poor condition)	0	1	0
		58 (∑f)	424 (∑fY)

Table 3.1 – Condition assessment data from 437.8493km to 438.165km North Island Main Trunk

Average Index of condition for the group (I) = $\sum fY/\sum f = 424/58 = 7.3$ **Eq - (3.1)**

Where:

Y = condition weighting number based on prior engineering experience and likely time to ‘failure’ or ‘intervention’

f = number of TPR’s with the particular grading.

The weighted average condition index versus the year of installation for each sample length of TPR sleepers was then plotted. When a sample of sleepers reaches a condition index of around 5, they have reached a point where they need to be renewed. By making some basic assumptions, it was found that a typical ‘J’ shaped predictive deterioration trend line could be fitted to the data (Refer to Figure 3). The coefficient of correlation for the trend line was $R^2 = 0.37$ which is considered reasonable where many variables are combined together. To predict the remaining service life of an individual TPR sample length, the J curve was applied to each data point individually. This way the age and current condition of a sample length of sleeper was used to more accurately predict the remaining life of the TPRs.

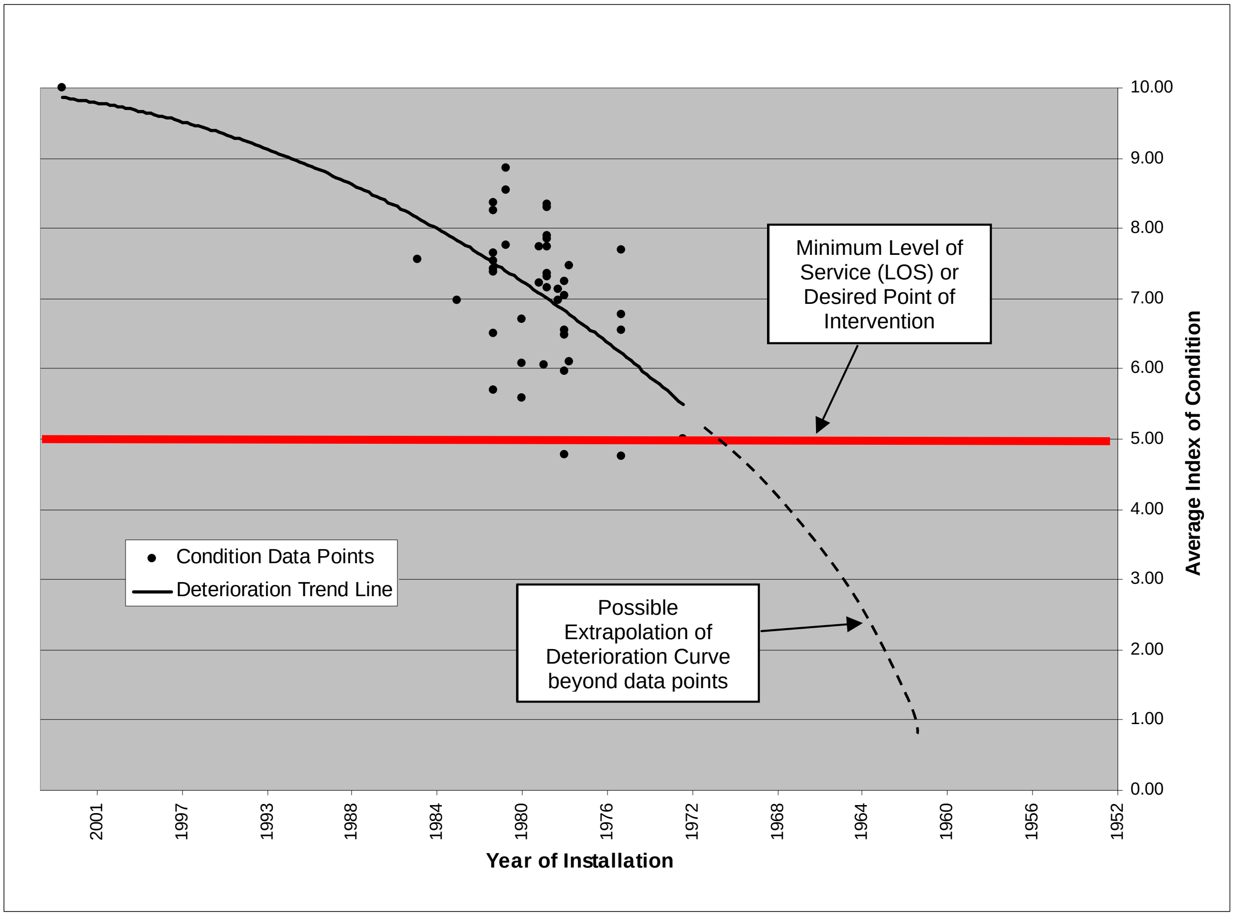

Figure 3.3 – Condition Index Data with Deterioration Lines Fitted.

The study concluded that by only using age for predicting the remaining life of the TPR's sleepers results in an imprecise renewals forecast. As TPR sleepers are a natural product there is high variability in the rate at which they deteriorate. A more accurate method of predicting the remaining life of a sample of TPR sleepers is gained by using both age and current condition. Using the deterioration curves, for the pilot study area it was determined that to ensure the track remained fit-for-purpose the rate of TPR renewals needed to increase by 159% from 820 sleepers per year to 1300 sleepers per year.

The main lessons that can be learned by the wider transportation profession are how a relatively simple weighted average condition system can be created for a particular class of asset. The system is fast to create, can be implemented by moderately skilled technicians, produces more objective and representative condition ratings and the results can be used for deterioration modelling. Therefore, a better prediction can be made of the future renewals of the asset. ONTRACK is currently exploring using the weighted average condition rating for the individual members of a bridge to give an overall bridge condition index.

3.3 Timber Bridges Members

As indicated in Section 2.0, timber has been widely used for bridge construction in New Zealand. The timber utilised was principally Mixed Australian Hardwood. Currently there are 640 timber spans in the network and 2962 timber piers. The results of field inspections of timber bridge components started indicating that increasing numbers of bridge members were reaching a point where they needed to be replaced or monitored more closely. The main drivers of timber deterioration are age and the magnitude of the applied load and gross loading the members receive.

Given the variable engineering properties of timber and the wide range of timber ages, ONTRACK engineering staff decided to focus on the only known parameter that readily could be calculated – the loads exerted on the timber beams. Given the large amount of timber bridge components in the network and in order to help focus attention on the members most at risk, timber components with the highest stresses could then be identified.

Unfortunately, as there has been frequent and ongoing changes of administration since the railways was formed, original structural design calculations for the timber bridges no longer exist. Therefore, a very ambitious and time consuming inventory data project was embarked on where all the nodal coordinates and timber member sizes were input into spreadsheets for each bridge on the rail network. From here standard equations were then used to calculate the shear and flexural loads.

While the technique was quite broad in scope, this method enabled an appropriate focus to be applied to bridges potentially at risk and to help prioritise where renewals funds should be directed. From this analysis, the replacement of timber bridge components has been determined to be the main focus for the rail structures renewal programme for the next two decades. The large amount of timber that needs to be renewed has led railway engineers to develop innovative standard designs to meet the need for increased bridge building. A plan has been devised called the Timber Superstructure Elimination Project (TSEP). Standardised steel ‘I’ beams that have the same height dimensions as timber beams (about 350mm to 400mm deep) have been designed for the replacement of existing timber members. Refer to Figure 3.4.

Figure 3.4 – Left: example of a standard steel ‘I’ beam unit after fabrication. Right: a TSEP unit complete with sleepers installed being lowered into place on a bridge.

This standardised design is relatively light weight and can be installed with relatively small track mounted railway machines. The ease of installation means that a TSEP unit can be installed in a bridge with short line closures of as little as 5 to 8 hours. The success of this initiative is evident in the fact that 1195m of TSEP beams have been installed over the last three years. This rate of TSEP installation is programmed to increase and then continue for the foreseeable future.

Replacing the large number of timber piers in the network is more problematic as the logistics of replacing piers is more involved. Additionally, there is a high degree of variability in the ground conditions to contend with. Similar to the TSEP concept, railway engineers have devised a standard substructure solution.

The concept consists of driving two steel ‘H’ piles that are used to create a new pier driven either side of the bridge and opposite each other. The new substructure is designed so the piles can be driven a sufficient lateral distance away from the railway line so that trains can continue to run while the new substructure is installed (Refer to Figure 3.5).

Figure 3.5 – Top Left (A): ‘H’ Pile being driven. A digger holds the pile in the correct position while a crane with driving gear installs the pile. Top Right (B): An installed ‘H’ pile after the concrete cylindrical collar has been formed. Bottom (C): a concrete pre-cast cap being lowered onto the ‘H’ piles during a rail shut down. In this example the cap also incorporates bridge abutment wing walls.

Due to the large number of timber piers that need replacing, it is not practical to undertake comprehensive geotechnical testing. Hence, the construction philosophy used to build the timber piers in the first place are assumed for the new ‘H’ piles. When the timber piles were originally driven, little or no geotechnical investigation was undertaken. Instead, when they drove the timber piles, if insufficient bearing capacity was not achieved a further length of pile was attached and they kept on pile driving until sufficient bearing capacity was achieved.

As the timber piers have been successfully in place for many decades, empirically it can be deduced that a similar foundation system can be utilised again. The ‘H’ piles come in 14m lengths. They are driven until the required bearing capacity is achieved then trimmed. Alternatively, if insufficient founding is obtained within 14m a further length of 'H' pile is welded on and continued to be driven.

The top of the 'H' pile is encased with a concrete cylinder. A pre-cast concrete cap is then utilised to span between the two adjacent 'H' piles to provide support for the superstructure.

To date four bridges have been successfully renewed using this foundation system. Now that the system has been trialled and the design optimised, an accelerated programme has been developed to use similar solutions for other timber pile bridge locations. This system is now ongoing and is called the Timber Pile Elimination Project (TPEP).

The key principals that can be utilised by other infrastructure asset providers are that by examining the engineering and operating constraints it is possible to come up with pragmatic and innovative solutions to replace infrastructure whilst working around constraints and gaps in existing asset knowledge. By standardising the design process, investigation and design costs can be minimised to enable as much of the limited funds that are available to be utilised primarily for physical works and furthermore construction timeframes can be significantly reduced.

4.0 Conclusions

As with most infrastructure in developed countries, much of the rail asset in New Zealand was developed just prior and/or post World War II. These assets and/or their individual components are in many cases coming to an end of their economic and /or condition lives. Innovative, pragmatic, efficient and effective maintenance and renewal programmes and management systems are needed to be developed to keep the infrastructure assets in perpetual use for existing and future generations of New Zealanders.

Whilst the rail asset is quite different in its components in comparison to other transport infrastructure assets, a number of lessons can be learnt or reinforced from rail infrastructure asset management processes. These are:

- undertaking pragmatic asset studies can assist in identifying parts of infrastructure that are at highest risk and consequently where the best results will be obtained from applying limited resources. As has been discussed in this paper ONTRACK has undertaken a number of these studies relating to culverts, TPR sleepers and bridge strength rating systems;
- developing simple condition asset grading systems and methods of analysing the results enables valuable data to be gathered and deterioration/replacement predictions to be made. By keeping the grading system relatively simple it can be understood and implemented by moderately skilled technicians. The sleeper condition grading system with associated weighted average condition index piloted by ONTRACK can be readily adapted by other asset providers;
- by having a good understanding of asset risks and the operating environment, a pragmatic and optimal balance of risk management can be determined between highly engineered physical solutions and non structured methods where the risk is managed by processes rather than physical works.;and
- by developing innovative standardised designs asset renewals productivity can be maximised. Additionally, the design and administration costs can be minimised ensuring that the maximum amount of available funds can be used for the physical works. This paper illustrates this principal through the more 'standardardised designs' being used to replace timber super and sub-bridge structures.

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