05-116 collapse of Bridge 256 over Nuhaka River, Palmerston North-Gisborne Line 6 May 2005

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Report 05-116

collapse of Bridge 256 over Nuhaka River

Palmerston North-Gisborne Line

6 May 2005

Abstract

On Friday 6 May 2005, at about 0720, pier 4 of Bridge 256 between Nuhaka and Opoutama on the Palmerston North-Gisborne Line suffered a catastrophic failure and collapsed while work Train 60 was being piloted across the bridge at the start of a 2-day work programme to underpin pier 4. A 60-tonne rail crane and the adjacent ends of spans 3 and 4 fell into the river.

There were 10 staff members making up the work gang, but because they had been moved off the bridge before the work train started to cross, there were no injuries.

The bridge was closed to rail traffic for several months until repairs were completed, including the recovery of the rail crane, the building of 4 new concrete piers and the installation of 5 new spans.

Safety issues discussed were:

- loss of corporate knowledge with successive organisational restructurings
- engineering resources and competencies
- degradation of timber piles in estuarine environments
- suitability of using 60-tonne cranes for routine bridge work
- extent of rail regulatory oversight of the rail transport industry in New Zealand.

Because of safety actions taken by Ontrack, no safety recommendations have been made. The Commission made a safety recommendation to the Director of Land Transport New Zealand as a result of rail occurrence report 05-123, relating to the regulatory oversight of the rail industry in New Zealand. This recommendation is equally applicable to this occurrence, so no new safety recommendation has been made to address this issue.

Collapsed Bridge 256

Contents

Figures

Abbreviations

Alstom	Alstom Transport New Zealand Limited
Bridge 256	Bridge 256 over the Nuhaka River at 324.84 km Palmerston North-Gisborne Line between Nuhaka and Opoutama
km	kilometre(s)
km/h	kilometre(s) per hour
LTSA	Land Transport Safety Authority
m	metre(s)
mm	millimetre(s)
NIWA	National Institute of Water and Atmospheric Research of New Zealand
NZGR	New Zealand Government Railways
NZRC	New Zealand Railways Corporation
PNGL	Palmerston North-Gisborne Line
PWD	Public Works Department
t	tonne(s)
Toll Rail	Toll NZ Consolidated Limited
Transfield	Transfield Services Limited
UTC	co-ordinated universal time

Data Summary

Train type and number:	work Train 60
Date and time:	6 May 2005, at about 0720[1]
Location:	Bridge 256 over the Nuhaka River at 324.84 km Palmerston North-Gisborne Line between Nuhaka and Opoutama
Persons on board work Train 60:	2 Toll NZ Consolidated Limited (Toll Rail)
Persons at worksite:	2 Alstom Transport New Zealand Limited (Alstom) 6 Transfield Services Limited (Transfield)
Injuries:	nil
Damage:	major to Bridge 256, diesel rail crane EL6019 and 2 attendant wagons
Asset Owner:	Ontrack
Investigator-in-charge:	Vernon Hoey

[1] Times in this report are New Zealand Standard Time (UTC + 12) and are quoted in the 24-hour mode.

Factual Information

1.1 Narrative

1.1.1 On Friday 6 May 2005, repair work was underway on Bridge 256, which crossed the Nuhaka River at 324.84 kilometres (km) between Nuhaka and Opoutama on the Palmerston North-Gisborne Line (PNGL). Work Train 60 had been scheduled to assist with the repair work.

1.1.2 At about 0700, work Train 60 stopped at the south end of Bridge 256. The train consisted of 2 DC class locomotives, 2 60-tonne (t) rail cranes each with an attendant wagon and 3 other wagons carrying bridge timbers and repair equipment. The train was crewed by 2 Toll Rail locomotive engineers.

1.1.3 A Transfield Services Limited[2] (Transfield) structures inspector, who had travelled with work Train 60 from Wairoa, alighted and walked across Bridge 256 in front of the stationary train. The structures inspector instructed personnel working from temporary scaffolding around pier 4 to vacate their worksite and assemble at the north end of the bridge.

1.1.4 The structures inspector and a leading hand positioned themselves on the northern embankment each side of the bridge level to monitor any visible rail deflection over pier 4.

1.1.5 At about 0720 hours, the structures inspector instructed the locomotive engineer to move the train across the bridge at 5 kilometres per hour (km/h).

1.1.6 After the 2 locomotives, 2 wagons of equipment and the first rail crane and its attendant wagon had travelled over pier 4, most of the pier collapsed. The ends of spans 3 and 4 that had been supported by the pier also collapsed.

1.1.7 The last 3 vehicles that were straddling spans 3 and 4 separated from the remainder of the work train. The trailing rail crane left the rails and fell into the river (see Figure 1). The 2 bridge spans, each still supporting a wagon, came to rest at opposing angles, with the ends that had been supported by pier 4 lying in the water. Nobody was injured.

Figure 1
Bridge 256 following the collapse

[2] Transfield Services was contracted to Ontrack for the inspection, maintenance and renewal of the rail infrastructure.

1.2 Site information

Nuhaka River

1.2.1 The sources of the Nuhaka River and its tributaries were about 30 km inland (see Figure 2). The water course and levels in the vicinity of Bridge 256 usually remained constant within the river's established channels.

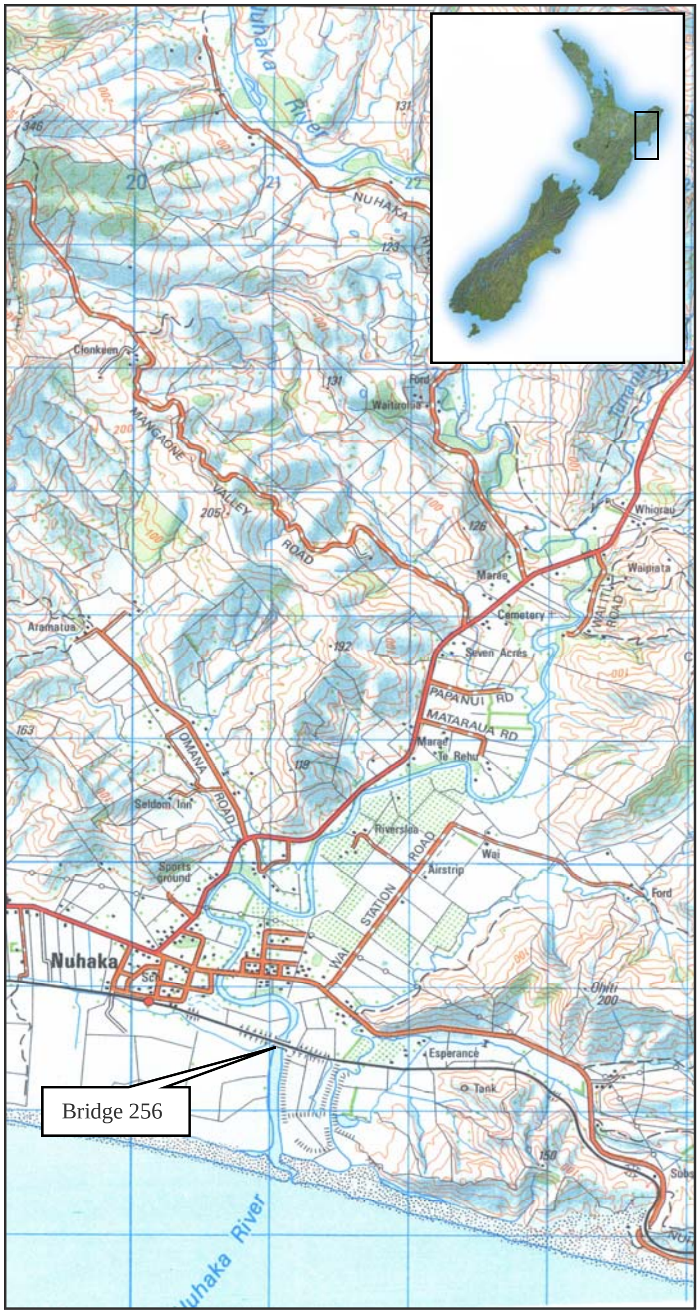

Figure 2
Map of Nuhaka River

1.2.2 The lower reaches of the Nuhaka River were slow moving and tidal in nature, creating an estuarine environment. The river mouth was often blocked by wave action that formed a physical barrier restricting the outflow to the ocean (see Figure 3). Regular maintenance with earthmoving machinery was carried out under local government supervision to clear the barrier.

Figure 3
Nuhaka River looking towards the coast

1.2.3 When the river mouth was unblocked, tidal salt water entered the river. Because the salt water was heavier than the river's fresh water, the salt water became trapped in the lower reaches of the river, including under Bridge 256, and without frequent flushing the fresh water did not readily mix with the salt water.

Palmerston North-Gisborne Line

1.2.4 The PNGL covered a distance of 390.40 km. Train movements and track occupations on the line were controlled from the national train control centre in Wellington. Toll Rail operated freight services between Wellington and Palmerston North to Napier, and ran a reduced service north of Napier (see Figure 4).

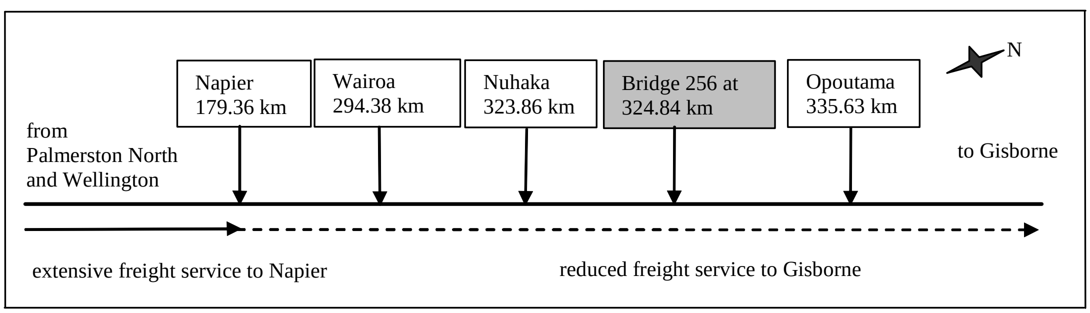

Figure 4
Site plan of PNGL (not to scale)

1.2.5 The line over Bridge 256 between Wairoa and Waikokopu, near Opoutama, was opened in 1924 and was operated in isolation from the rest of the network. The isolated section of line was linked to Napier in the south in 1939 and to Gisborne in the north in 1942, thereby completing the construction of the PNGL.

1.2.6 The working timetable maximum stipulated axle loading on the line between Napier and Gisborne was 16.3 t. However, a reduction to 14.3 t was mostly applied because of the condition of Bridge 290 between Muriwai and Gisborne. There was no rail weighbridge at Napier or Gisborne to verify the actual axle loadings of wagons travelling between these locations.

1.2.7 In the 4 months from 5 January 2005 to 6 May 2005, a total of 120 scheduled and special express freight trains ran between Napier and Gisborne. The principal freight moved on the northbound trains was bulk fertiliser from Awatoto in CF class hopper wagons to Matawhero, with southbound trains returning the empty wagons. The last 2 scheduled trains travelled across Bridge 256 on Wednesday 4 May 2005, 2 days before the collapse.

Bridge 256

1.2.8 Bridge 256 was built in 1922 by the Public Works Department (PWD) and was located about 1100 m from the coast.

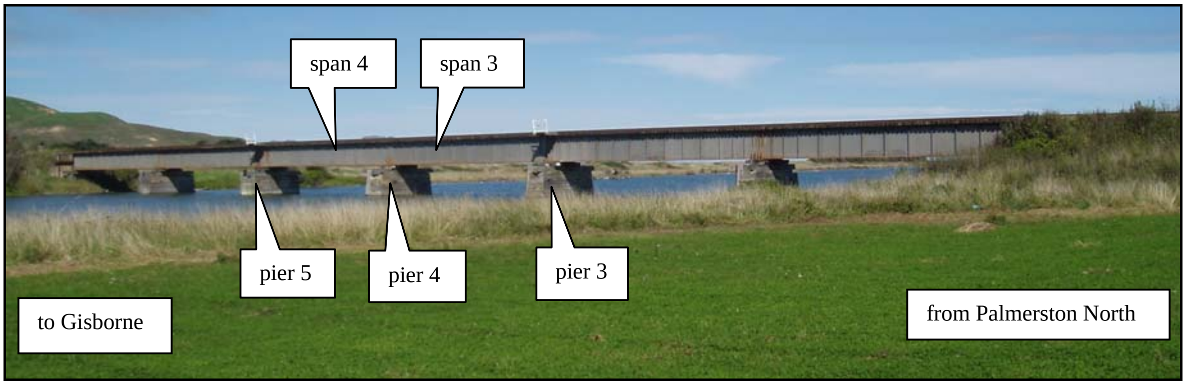

Figure 5
Bridge 256 looking towards the coast
(courtesy of Ontrack)

1.2.9 The bridge consisted of six 18.3 m (60-foot) long riveted steel deck plate-girder spans supported by hardwood timber pier sets (see Figure 5). Five intermediate piers and 2 abutment piers supported the 6 spans.

1.2.10 The bridge design standard was New Zealand Government Railways (NZGR) "1909 typical", based on a steam locomotive with three 14 t axles and a substantial impact allowance for the dynamic forces that steam locomotives imposed. Since diesel locomotives imposed lesser dynamic forces, the bridge, if in good condition, would also safely carry DX class locomotives and trains of loaded CF wagons, all with 16.3 t axles that, although heavier, imposed smaller dynamic forces.

1.2.11 Piers 2 to 6 inclusive comprised 2 rows of 5 driven ironbark timber piles. Each row of piles supported a timber cap (see Figure 6). Piers 1 and 7, the abutment piers, had one row of 5 load-bearing ironbark piles. Ironbark was an Australian eucalyptus hardwood noted for its strength and durability, and widely used for early rail bridges and wharf installations throughout New Zealand.

1.2.12 A feature of the original pier design was twin flitch caps. However, in line with later policy, these were progressively replaced with boxed-heart solid cap beams when the flitches or piles required replacing. The most recent detailed bridge inspection in July 2002 recorded that only pier 7 had flitch caps remaining.

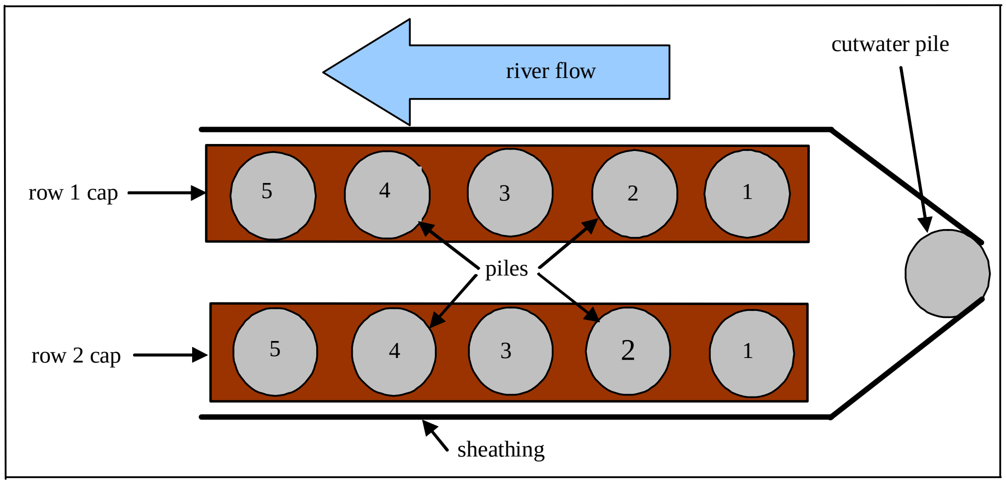

Figure 6
Plan of an intermediate pier arrangement on Bridge 256 (not to scale)

1.2.13 The 2 rows of piles in each intermediate pier stood vertically opposite each other, about 900 millimetres (mm) apart at their centrelines and the 2 parallel cap beams were positioned transversely on the top of the 5 load-bearing piles. The caps were slotted into the top of each pile with a tenon/mortise arrangement. Two bolted pairs of corbels supported the girders (see Figure 7).

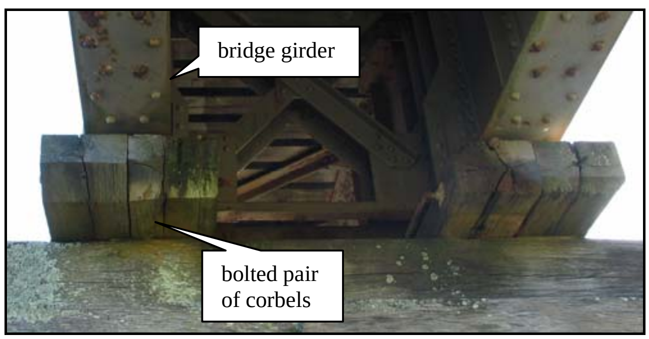

Figure 7
Close-up of corbel and girder arrangement

1.2.14 A single, non-load-bearing cutwater pile was driven upstream of the intermediate piers to form a bow to deflect any driftwood carried by the river (see Figure 8). Piers 3 to 6 were sheathed in timber to prevent any driftwood fouling the internal area of the pier structure.

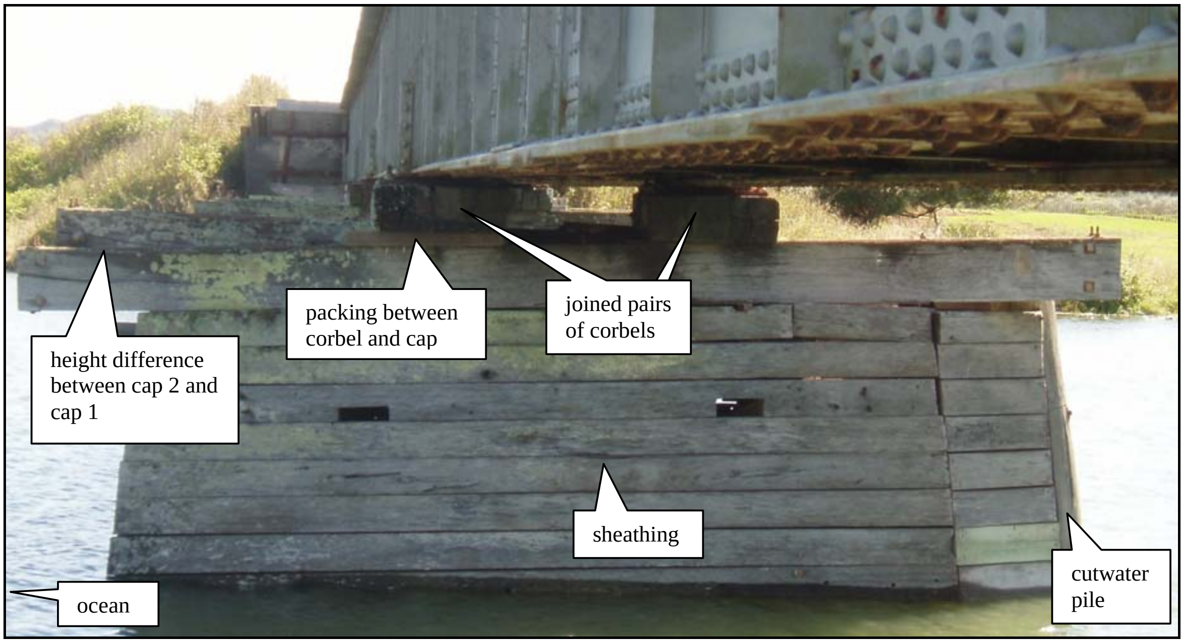

Figure 8
Pier 4, looking south
(courtesy of Ontrack)

1.2.15 In accordance with PWD policy at the time, the piles of pier 4 that supported the two 60-foot spans would probably have been designed to carry a total of about 180 tons (imperial weight). Since there were 10 load-bearing piles, the assumed safe bearing capacity of each pile would have been 18 tons.

1.2.16 The safe bearing capacity of a pile would have been estimated from the Hiley pile-driving formula, or a similar formula, based on the measured set per blow from a monkey[3] of known weight and measured drop. In the sands and gravels in which the piles were founded, that estimate would have been conservative. Since the original pile-driving records were no longer available, it was not possible to confirm the calculated bearing capacities with any accuracy.

1.2.17 Each 60-foot girder span and track weighed about 20 t, resulting in a 10 t dead load on each cap. The live load on each cap created by a typical train of loaded CF wagons hauled by 2 DC or DX locomotives was about 60 t based on the reduced axle load of 16.3 t. Combined, this gave a total load on each cap of about 70 t, which divided by the 5 piles under each cap, gave a maximum load of about 14 t on each pile.

Calculated maximum live loads on pier 4 applied by northbound trains, including work Train 60			
Train consist	Cap 1	Cap 2	Pier
DC loco and CF wagons loaded with 14.3 t axle load	53.4	54.6	88.3
DX loco and CF wagons loaded with 14.3 t axle load	53.2	53.9	90.7
Two DC locos and CF wagons loaded with 16.2 t axle load	60.7	58.1	107.8
Two DX locos and CF wagons loaded with 16.2 t axle load	59.4	59.5	101.3
Work Train 60 under DC locos	56.9	56.4	102.9
Work Train 60 under first 60 t crane	65.7	62.5	109.7
Work Train 60 under second 60 t crane	63.4	64.1	109.1
Pile-driving consist, crane on span 4	25.2	80.0	105.2

Note: Because of load sharing between the 2 rows of piles, maximum pier reactions were less than the sums of the maximum cap loads.

[3] Commonly used name for a pile-driving drop hammer.

1.2.18 Bridge 256 had not been subjected to any major rebuilding during its lifetime, although over the years a few of the bridge piles may have been stumped[4] or replaced. In 1969, the cutwater pile on pier 4 was replaced following flood damage.

1.2.19 Four rail bridges located in the Bay of Plenty area had piles wrapped with plastic sheathing in about 1974 to protect against marine borer infestation. Bridge 256 was not treated in this manner.

1.2.20 There was no record of any underwater pile inspection for Bridge 256 throughout its lifetime. Similarly, there were no records of underwater inspections at any nearby rail bridges.

1.2.21 Sleepers provided a connection between the rails, holding them to the correct gauge and to transfer the rail load to the ballast and roadbed, which in the case of Bridge 256 was to the spans. Ontrack's infrastructure engineering handbook specified that the maximum sleeper spacing on bridges should be 300 mm. Tables were included the handbook specifying sleeper sizes and fastening requirements.

1.3 Engineering organisations

At time of incident

1.3.1 At the time of the collapse of Bridge 256, Ontrack was the asset owner and access provider and was responsible for the long-term operation and maintenance of the rail network. Transfield, as contractor, was responsible to Ontrack for the safe physical execution of Ontrack's inspection and work directives.

1.3.2 Within the Ontrack organisation, the manager track and structures engineering (engineering manager) reported to the manager professional services for maintaining the safety of the infrastructure, including bridges. It was the engineering manager's responsibility to ensure that, at all times, each element of a bridge was in a suitable condition to carry trains under the authorised conditions, amended as circumstances required.

1.3.3 The engineering manager had a team of engineering support staff to assist with these tasks. All safety-related instructions were issued to Transfield either by him or within his delegated authority. For day-to-day detailed information about the state of the network, the engineering manager relied on information provided to him by Transfield, supplemented with such special inspections as were considered appropriate. The engineering manager did not normally undertake specific routine inspections, and neither did any of his staff.

1.3.4 Transfield's alliance manager had overall responsibility for the safe execution of the company's contractual obligations to Ontrack. On his staff, there were area coordinators who arranged the various inspections required by Ontrack and minor repairs within authority delegated by Ontrack. A structures inspector responsible for routine and special inspections of bridges and structures as required by Ontrack provided technical expertise to each area coordinator.

Historical

1.3.5 Most of the original bridges were constructed by the PWD from standardised pier and span designs of hardwood timber and steel that NZGR was able to maintain in a safe condition by piecemeal replacement of life-expired components, as and when required.

1.3.6 The fungi that caused hardwood bridge timbers to decay typically attacked from the inside or below ground level. Inspections to find and monitor the fungi required a team of bridge inspectors with the special skills to obtain and record information about the current condition of each individual structural timber of a bridge. The inspections extended from below ground level to the full height of the bridge.

[4] The action of removing a failed section of pile.

1.3.7 Maintaining reliable and up-to-date records of the condition of every timber member manually, without computerised databases, was a big task. The standard bridge inspection cycle was 5 years, plus supplementary inspections at shorter intervals for timbers known to be near the ends of their service lives. Consequently the inspection, assessment and replacement of timbers was a big and ongoing responsibility. Because of the limited communication and transportation infrastructure of the 19th and early 20th centuries, NZGR developed a decentralised engineering management organisation of up to 12 separate districts. Each was under the charge of a district engineer who was personally responsible to the chief civil engineer for the safe maintenance of all track and bridges within the district.

1.3.8 Through the middle and later 20th century, the railway network bridge inspection and maintenance workload diminished. Many branch lines were closed, and some high-maintenance timber bridges were replaced with low-maintenance steel and concrete structures. Concurrently, there were improvements in the road and air transport and communications infrastructure. Reorganisations of the engineering structure reduced the number of districts and increased their areas and, by 1987, the number of districts (subsequently renamed regions) had been reduced to 3. Throughout this period of change, the principle that responsibility for the safe condition of each bridge be allocated to an engineer trained in railway bridge maintenance was preserved.

1.3.9 From the mid-1950s the chief civil engineer's office included a bridge section that was principally concerned with the design aspects of new steel and concrete bridges, and of the existing steel structures, including viaducts. Maintenance of the old PWD-built timber bridges remained a district responsibility.

1.3.10 After 1987 the railway network had several different owners and several different engineering restructurings. The trend over this period was to centralise all top-level management, including those responsible for bridge maintenance. The districts/regions were consequently disestablished and most of their staff dispersed, taking with them in many cases years of accumulated institutional knowledge on individual timber structures that was not centralised in line with the reorganisations.

1.3.11 In summary, the following chronicles the restructurings of the rail industry up to the time of the incident:

Date	**Event**
Prior to 1877	Railway lines surveyed, laid and operated by Provincial governments.
1877	PWD creates a Working Railways Department that reports to the Minister of Public Works.
12 October 1880	New Zealand Railways Department formed by the Government of the day.
1 January 1895	NZGR Act passed into law and first General Manager appointed.
1982	NZGR converted into a state-owned corporation and called New Zealand Railways Corporation (NZRC) with a mandate to operate on a user-pays approach. First redundancies occur shortly afterwards.
1989	Transport industry deregulated and rail protection removed with passing of Transport Services Licensing Act.
1991	Rail industry split with the creation of NZ Rail Limited, a private limited liability company with the Government holding all shares. NZRC becomes caretaker of railway land and begins disposing of large areas of surplus land. Rail industry downsizing and staff redundancies started after 1982 continue as effects of transport deregulation realised.
30 September 1993	Consortium of merchant bankers consisting of Berkshire Partners and Fay/Richwhite etc and led by Wisconsin Central Railroad takes control of NZ Rail Limited after purchasing the business from the Government. Business moves into private ownership.
1993	Land Transport Safety Authority (LTSA) created from break-up of Ministry of Transport and Ministry of Works.

18 October 1995	NZ Rail Limited re-brands the business into Tranz Rail Limited.
12 May 2000	Management team members who previously led Australia-New Zealand Direct Line (shipping company) replace Wisconsin Central-appointed management team of Tranz Rail. Corporate headquarters subsequently move from Wellington to new office building located in Smales Farm in Takapuna.
1 March 2002	Tranz Rail outsources rail infrastructure maintenance to Transfield.
April 2002	Tranz Rail outsources locomotive maintenance to Alstom.
May 2002	Tranz Rail outsources wagon maintenance to Alstom.
5 May 2004	Australian-based Toll (freight logistics company) takes management control of Tranz Rail, establishing Toll Rail.
30 June 2004	NZRC takes over management of train control.
23 August 2004	Connex Auckland Limited takes over operation of Auckland suburban rail system.
1 September 2004	NZRC launches Ontrack brand name.
20 April 2005	Railways Act passed into law.

1.4 Timber bridge quality management

1.4.1 To provide and maintain a safe infrastructure, the early railway builders pioneered quality management procedures to mitigate or overcome the risks. Because of financial and technical constraints at the time, the PWD was unable to construct durable works that were capable of withstanding all extremes of flood, fire, wind, temperature, earthquake, decay and accidental damage. The structures the PWD handed over to NZGR were "fit for purpose" in normal conditions, but the service lives of their materials were limited and they were vulnerable to accidental and weather damage. Climatic conditions and topography meant that historically some structures were affected by slips, floods and washouts and other environmental hazards such as marine borers.

1.4.2 To mitigate the risk, NZGR used regular routine inspections to monitor the ongoing condition of the asset to show how it was performing, and whether any changes in the environment might create or increase a hazard.

1.4.3 From about 1880 to 1900, the main structural material used for NZGR bridge construction was imported hardwood timber, supplemented with a little iron and steel, and some mass concrete. After 1900, steel became widely used for spans but most new bridges built were still supported by driven hardwood piles. Because of technical and financial considerations, the piles of many bridges crossing rivers were not founded at depths that would be considered adequate by the standards applicable from 1960 onwards. For bridges in coastal environments, marine borer infestation was a potential hazard.

1.4.4 Before about 1990, trade-trained bridge inspectors (predecessors to structures inspectors) familiar with bridge maintenance carried out the bulk of routine bridge inspections on a regular cycle. They reported, in writing, on the condition of every structural timber in every bridge, but had no direct responsibility for overall bridge safety. They reported to trade-trained supervisors responsible for ensuring the on-time completion of scheduled inspections, and also for the safe execution of routine and specially directed maintenance work by both railway and contract staff. All renewals or replacements of bridge structural members were by special direction, so the supervisors did not have ultimate responsibility for the safe structural performance of a bridge.

1.4.5 The supervisor reported to a district engineer, who was then responsible to the chief civil engineer for the maintenance in safe condition of all bridges within their district. The district engineer maintained an inspection diary system and issued directions for the renewal or repair of defective structural member, monitored reports on the condition of all defective members until the work as directed had been completed, and amended the office records when certification of completion of every repair or renewal was received. The district engineer was also required to audit the work of supervisors and bridge inspectors in the field and they were required to inspect personally each bridge annually.

1.4.6 The chief civil engineer confirmed that district engineers were following prescribed procedures and maintaining their districts by regular and ad hoc visits and inspections. This was reinforced through regular audits by an inspecting engineer. The inspecting engineer was selected from the ranks of senior district-trained engineers. He travelled by trolley at low speed or on foot over the full length of every line on a 4-year cycle, looking (as well as at the track) at every bridge in sufficient detail to confirm the effectiveness of the district's quality management. An important secondary function of the inspecting engineer was to train recently appointed district engineers and the assistant district engineers for promotion. To a large extent it was through the inspecting engineer that the accumulated maintenance experience of the Way and Works Branch[5] was passed between generations of engineers.

1.5 1993 due diligence report prepared for the privatisation of NZGR

1.5.1 Extracts from a 1993 due diligence infrastructure report compiled by engineers within the rail industry have been included to provide an insight to the maintenance policy that applied to the rail industry as the business neared the completion of the privatisation programme.

> Generally, the old timber and steel bridges which made up the system were well suited to piecemeal renewal and upgrading as condition requirements dictated. Bridges, in theory, could be maintained indefinitely by the replacement of individual components.
>
> The fact is that the system incorporates so many old timber components (some timber was over 100 years old). Although the general condition of these members provides no cause for alarm at the present time, it can be anticipated that deterioration and decay must eventually require considerable numbers of these members to be replaced. There is a worldwide shortage of suitable timbers for this sort of work and it is unlikely we could sustain a heavy timber maintenance program for very long. The capital programme proposed allows for the progressive replacement of main line timber structures before substantial deterioration becomes a problem.
>
> Through the 1970s and 1980s, Capital Expenditure on bridging and related projects, generally between 12 million and 17 million dollars per annum in real terms, was mainly due to two major projects; the Mangaweka deviation and the Ohakune deviation. The lower level of bridging capital (between 1 million and 1.4 million) since 1990 reflects the significant reduction in major Capital works and the general economic climate in New Zealand.
>
> Maintenance of bridges is carried out on an as required basis derived from a condition monitoring process. Assets or components are replaced or repaired as their condition for service dictates.
>
> Asset Management is defined as maintaining the asset in such condition as to suit the short, medium and long term needs of the Company. Decision-making requires information to be provided in the following three areas:
>
> 1. The asset condition by monitoring and reporting.
> 2. Various courses of action relating to the asset, ie, re-engineering, renew etc.
> 3. Potential consequences of these courses of action.
>
> Technical detail must be presented as clearly as possible by those controlling the Company's actions.

[5] The branch of the NZGR department responsible for the maintenance of rail infrastructure.

Five elements of asset management can be quantified; these are:

1. Assessing asset condition and maintaining records.
2. Monitoring asset performance to meet company's targets of quality (safety), and operating efficiency.
3. Refining residual life calculations and performing risk analysis where required.
4. Justifying replacement where required.
5. Interacting with other who interface with the asset so as to maximise the asset usefulness to the Company.

During the eleven year transition from government department to privately owned company, maintenance staff numbers and operating and capital budget levels within New Zealand Rail Ltd have declined markedly. There is now less maintenance work being done and fewer upgrading projects being carried out in respect of structures assets that was the case prior to 1982. The question has to be asked as to how the assets are fairing and will they remain serviceable with present levels or attention into the foreseeable future. And further, what is the appropriate level of in-house resources required to manage these assets so they do in fact remain serviceable.

There were 3400 timber piers in bridges.

It can be seen that typical bridge maintenance costs and capital investment levels were each running at an average level equivalent to about 8 million [dollars] per annum for much of the past six decades. Bridge maintenance and investment levels are currently between 1 million to 2 million [dollars] per annum.

There were about 15 000 sticks of timber, mostly piles in bridges.

There was evidence of increased activity in timber renewals in the 1930's and from 1950 to the mid 1970's. It seems likely that piles which are now 60 years old were put in to replace much of the remaining native timber and beams of this age were necessary to strengthen the system for K class locomotives. Timber renewals during the 1950's and 1970's indicate that a considerable quantity of hardwood, then 60 to 70 years old was having to be replaced. At present, however, very little new timber is being put in as the general condition of the old timbers seems remarkably good.

The present situation is unlikely to last. Given that the average expected timber life can only be 50 years or so, a typical replacement rate for timber components has to be around 60 beams and 300 piles per year. Barely half a dozen piles are being driven each year at present.

Most old timbers are decayed to some extent, as is to be expected, but there is no evidence that the general rate of timber decay is increasing noticeably. This sort of trend is likely to become apparent shortly before any accelerated program becomes necessary. In the meantime it should be possible to continue timber maintenance at a low rate but considering the present range of timber ages, it is probable that very much more timber will have to be replaced within five to ten years.

Any accelerated one-for-one timber replacement program is going to cause difficulties. Good hardwood is a scarce resource. It is becoming more expensive to obtain and its use for bridge piling is likely to become increasingly unacceptable from an environmental point of view. Exotic softwoods are unavailable in the dimensions required for substitution purposes and a laminated product is not considered a reliable option for an exposed environment. Another point to be considered is that railway staff resources are not geared for high levels of bridge maintenance. The best long term solution is to systematically replace all timber bridges on major routes with concrete or steel structures and to recycle as much good recovered timber as possible to other lines as maintenance requirements dictate.

1.6 2002 LTSA review of Tranz Rail's policy change for infrastructure maintenance

1.6.1 On 18 March 2002, the LTSA contracted an overseas consultancy group to review the change in infrastructure maintenance by Tranz Rail to an alliance contract undertaken by Transfield. The requirement for the review was based on the LTSA's schedule of services dated 2 March 2002, which specifically raised the following issues:

- ministerial, parliamentary and employee group concerns brought to the attention of the LTSA
- implications of Tranz Rail outsourcing infrastructure maintenance. Tranz Rail had recently announced the outsourcing of infrastructure maintenance to Transfield
- a series of recent occurrences on the Tranz Rail network especially [a] the continuing incidence of heat buckle derailments and [b] derailments due to washouts/slips
- recent LTSA field observations of infrastructure non-compliance incidents, especially in relation to continuous welded rail
- the effectiveness of:
- infrastructure asset management
- audit processes (the audit processes are as set out in the Transport Services Licensing Act 1989, and as further described in the LTSA publication Rail Safety Licensing and Audit Guidelines).

1.6.2 Some of the key findings in the review report relevant to this occurrence are included below:

- On the basis of the staffing levels proposed by Transfield, the safety and integrity of the track and structure infrastructure are not immediately at risk. Transfield's decision to ensure inspection staffing is retained at the current levels ensures that the current safety level is at least maintained.
- The longer term safety of the infrastructure will be determined by the ability to undertake timely renewal works. There is a possibility that Transfield will experience an increasing backlog of renewal works. Some limited contracting resources are available, but there is an absence of experienced track personnel from which to supplement the workforce, and Transfield will find it difficult to employ adequate resources within New Zealand at short notice.
- Tranz Rail staffing (including the Technical Services Group) is insufficient to effectively monitor the transition phase of the contract, and Tranz Rail's engineering staff levels in key discipline areas are below those necessary to adequately support the existing network. Reliance on external resources (especially internationally based staff) as proposed by Tranz Rail is unlikely to be consistently adequate when short-term responses are required.
- The requirements in legislation and in Tranz Rail's Safety Management System indicate an emphasis on emergency response without a corresponding emphasis on proactive preventive measures in the area of engineering safety management.
- Procedures, standards and the overall condition of the infrastructure indicate that the rail network is fit for purpose. Tranz Rail has a capital works program to upgrade infrastructure assets and there has been significant investment in recent years on the main routes. Tranz Rail has well-maintained records of asset condition in its infrastructure database, and these are consistent with the observed field condition.

1.6.3 Some of the key conclusions in the review report relevant to this occurrence are included below:

- Our overall conclusion from this review is that the current infrastructure, procedures and management provide generally for the safe operation of the rail infrastructure. It is also our view that some of these resources appear to lack the support of appropriate systems and are operating close to their practical limits.
- We consider that many of the existing procedures and maintenance and management practices need to be reviewed and, where necessary, updated. Until Tranz Rail can demonstrate conclusively that inspection, maintenance and management practices will not result in deterioration of the network, then no reduction in resources (of Tranz Rail, Transfield or other external parties) should be contemplated.

1.6.4 Under the heading Tranz Rail staffing, the report commented as follows:

- In our Stage 1 report we noted that it was our view that the level and quantum of engineering expertise within Tranz Rail have been decreasing and may now be below what are necessary to provide an appropriate service. There has been no reason to change this view and we understand that further attrition has occurred within the Technical Services Group of experienced long-term Tranz Rail personnel. Unless it is Tranz Rail's intention to recruit staff then this attrition will require future reliance on international expertise in assessing technical issues and code changes. These external resources are not always readily available for the appropriate timing and duration to enable them to deal adequately with individual issues. Nor do they necessarily have the appropriate background to contribute efficiently to the process.

1.6.5 Finally the report commented as follows:

- In conclusion, and subject to the above findings and recommendations, it is KBR's [consultant] view that the rail infrastructure we have reviewed is, on the whole, fit for purpose (as the words are defined in this report) and that the infrastructure procedures and management provide generally for the safe operation of the rail infrastructure. KBR, however, believes that some of the component parts of the infrastructure lack the support of appropriate systems and are operating close to their practical limits, as identified in this report.

1.7 Invertebrate marine borers

1.7.1 There were many species of invertebrate marine borer living in the oceans around New Zealand. Marine borers thrived in softwoods and most hardwoods that were immersed in salt water. The larvae of marine borers were dispersed either by ocean currents or by attaching themselves to driftwood. Those that were dispersed by ocean currents and came into contact with a timber surface quickly bored into the timber fibres, leaving only small holes as evidence of their entry.

1.7.2 One of the most common marine borers encountered in New Zealand belonged to the mollusc phylum. The mollusc was a bivalve from the family *Teredinidae* and it was more commonly known as "teredo worm". Teredo worms burrowed into the timber fibre using 2 shells at the head of their body as a rasping tool. From the safety of their burrow, the crustaceans extended a pair of feathery siphons into the surrounding water. These siphons functioned in the exchange of nutrients, oxygen and waste products. At any sign of danger, the siphons were retracted and the surface hole was covered by a hardened pallet that protected the organism from attack. The protection of the pallet also allowed the marine borer to survive in wood that was out of water for 7 to 10 days.

1.7.3 Teredo worm had settled throughout New Zealand from North Cape to Stewart Island. During a test in 1964, in which untreated pinus radiata test panels were immersed into 20 marine harbours, a scientist found heavy to very heavy teredo infestation in Tauranga, Gisborne and New Plymouth harbours after the timbers had remained in the water for up to 12 months.

1.7.4 Although wood-boring organisms were marine species, they tolerated lower salinities and occupied an optimum salinity band on piles in estuarine locations. It was within this band and full marine locations that timber was prone to attack. The rate of destruction would vary from region to region and would also be dependent on the type of timber used and prior treatment that timber had received.

1.7.5 Information contained in the forgoing paragraphs was sourced from A Photographic Guide to Seashells of New Zealand by Margaret S. Morley (New Holland Publishers, 2004, ISBN-13:978 1 86966 044 4) and the National Institute of Water and Atmospheric Research of New Zealand (NIWA), which undertake biological research of species together and other scientific research.

1.8 Bridge management and inspection procedures

1.8.1 The NZGR Way and Works Branch inspection manual for bridges and structures dated 19 May 1982 stipulated that general inspections be conducted by bridge inspectors at intervals not exceeding 6 months. The detailed inspections were required to be undertaken at intervals not exceeding 5 years according to a programme laid down by the district engineer or resident engineer. The inspections were required to be undertaken by bridge inspectors, sometimes with the assistance of steelwork inspectors.

1.8.2 This frequency policy was changed and Tranz Rail's structures inspection manual W 200 dated 30 October 2000 stated in part that:

> **FOREWORD**
>
> The past eighteen year [1982-2000] period has seen the lean and efficient privately owned rail transport business of Tranz Rail Ltd emerge from a large, multi-disciplined government department. A flat management system is in place and staff empowerment operates at the workface. Many old ways of doing things and getting things done have gone and as a result, much of the information in the old Manual no longer applies.
>
> While there have certainly been many changes to the organisation in this eighteen year period, its infrastructure asset base is remarkably similar. A number of branch lines have closed, of course, and route kilometrage and the actual number of structural assets have reduced somewhat but the types of structures and the skills required to inspect and maintain these assets in an appropriate condition for the traffic using them have changed little.
>
> Structures Inspectors have a key role to play in the inspection, assessment, maintenance cycle applying to structural assets – particularly as these assets are required to cope with future traffic demands, which are expected to see increases in tonnage moved.
>
> **ENGINEERING MATERIALS**
>
> **3.8 Non-fungiodal Hardwood deterioration**
>
> Hardwood timbers may deteriorate for reasons other than rot or decay. This deterioration may be due to a mechanical or biological cause. It may be progressive or it may occur suddenly. Some of the principal reasons for deterioration are:
>
> Insect attack: Sapwood (if present) is considerable less durable than heartwood and is susceptible to insect infestation. A number of native and exotic insect grubs, including borers, feed on the timber creating a system of tunnels in the process. The timber can be seriously weakened, depending on the extent of infestation.

Marine borer: Teredo and limnoria are the worst culprits in this category. They are liable to attack piles and bracing in tidal waters. They attack all levels between high tide and the mud line but their activity is generally worst between 300 mm above and 600 mm below low tide level. The teredo is a worm that tunnels extensively in affected timber with little external evidence of attack although the tunnels themselves may be 10 mm in diameter. Teredo tunnels may extend to the centre of the pile or member and damage only becoming evident during inspection or when external timber spalls off.

The limnoria is a crustacean borer that confines its activity to a shallow depth within the timber. However, when the outer timber surfaces spall off, activity continues into the next layers. In a pile, the resulting loss forms a localised reduction in pile diameter. Turpentine piles have a natural resistance to both teredo and limnoria attack.

THE INSPECTION PROCESS

No matter how well built in the first place and how well they are maintained during their lives, all engineering structures deteriorate eventually and the materials from which they are constructed degrade. The process may be accelerated by adverse climatic or environmental conditions, through heavy usage or through inadequate maintenance. For safety and asset management reasons the engineer needs to know how adequately a structure is performing and in what condition it is. The engineer relies largely on the eyes of the inspector in the field to keep him informed of changes in an asset's structural condition.
It is the inspector's role to examine carefully each structure to prescribed intervals, to look for signs of damage and deterioration and report his findings both factually and accurately and in sufficient detail so as to convey a full picture to the engineer. The inspector must also use his experience and knowledge to interpret the nature of any defect.

General Inspection [at yearly intervals]: The approach to be taken by the inspector during the General Inspection is likely to differ from asset to asset. For rail bridges and other structures scheduled for both General and Detailed Inspections, the inspector is expected to make an overall examination of the site and structure noting and obvious defects or unusual features and looking for evidence of how the structure and the waterway (if any) is performing. Each individual structure component does not have to be examined in detail, but significant and obvious external changes to any feature or component since the time of the previous inspection are expected to be picked up.

Detailed Inspection [at 8-yearly intervals]: For the majority of engineering structures, the Detailed Inspection is the most thorough regular examination the asset will receive. Every component and feature associated with the structure and site must be carefully examined (as far as practically possible) and its condition or characteristics reported on. Non-destructive testing and inspection methods may need to be employed. The internal condition of hardwood timber is to be ascertained by inspection boring. In carrying out a Detailed Inspection the inspector is expected to identify and report on all defective components, deteriorating materials and serviceability problems and is expected to make observations and report on matters that could affect the safety of the structure or develop into future problems and difficulties. The report will also make recommendations regarding maintenance needs.

6.7 Inspecting Timber

Surface examination: In tidal waters evidence of marine borer activity must be looked for in piles and sheathing. Plastic sheathing (if it remains intact from a point above high water level to a short distance below bed level) can curtail marine borer activity so the integrity of any such sheathing will need to be checked. It may be necessary for a diver to carry out this work.

1.9 Recent inspections of Bridge 256

Detailed

1.9.1 The most recent detailed inspection of Bridge 256 was undertaken on 17 July 2002. The structures inspector used the report of the previous inspection carried out by a different inspector in 1996, as the basis for the 2002 inspection.

1.9.2 The inspection report noted minor deterioration at the top of 4 piles in row 1 of pier 4 and deterioration in the cap. A supplementary inspection of pier 4 was scheduled for 2006 as a result of these findings. The deterioration in the cap had been detected by boring in the area where piles 3, 4 and 5 joined the cap (see Figure 9).

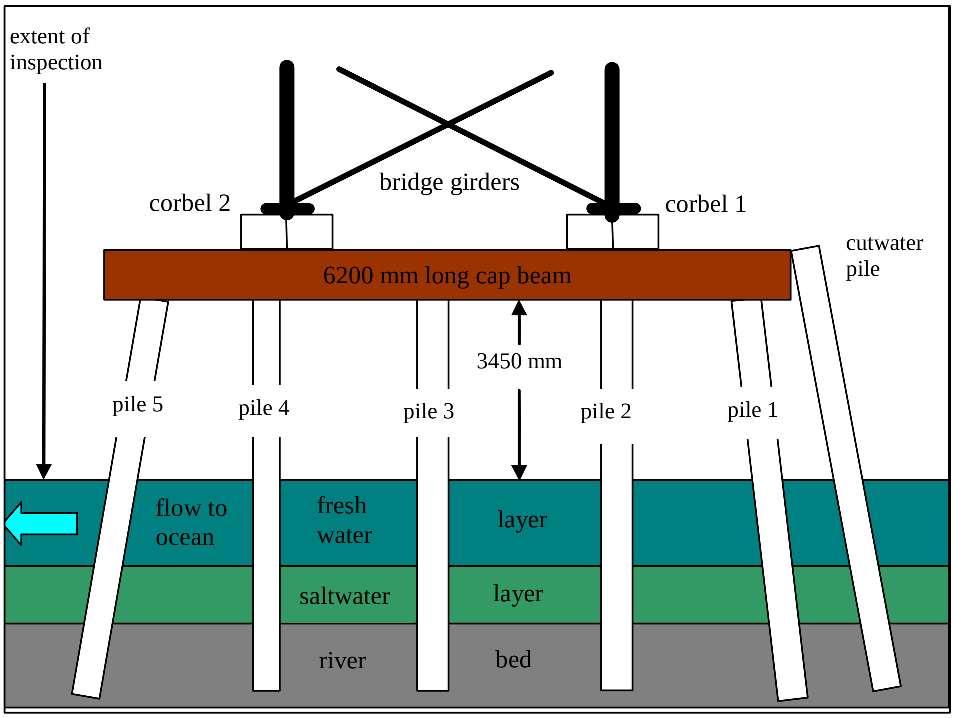

Figure 9
Elevation of pier 4 looking south (not to scale)

1.9.3 On row 2 of pier 4, the 5 piles and cap were reported as unchanged from their 1996 condition. The report noted that both pairs of corbels had been replaced in 1997 and were in sound condition. None of the 11 piles, including the cutwater pile, had dates or lengths chiselled into them that indicated when the piles had been driven, and the length the piles had been driven at installation.

General

1.9.4 The structures inspector performed the most recent general inspection on 2 December 2004. The report required an indexation of the inspection to be made on each component of the bridge as follows:

CONDITION INDEX	1 As new	2 Good	3 Fair	4 Poor	5 Unacceptable	6 Work order

1.9.5 No condition changes were noted since the previous inspection and the bridge was rated with an overall index of 2, but individual ratings on all the timber piles and caps were unchanged at index 4.

Ten-year rolling programme

1.9.6 Bridge 256 did not feature on the 10-year rolling replacement or upgrade programme and there were no comments on its condition within this programme.

1.9.7 Structural issues with nearby rail bridges

Bridge 297 Gisborne

1.9.8 Bridge 297 was located about 77 km north of Nuhaka and carried an extension of the PNGL across an arm of Gisborne Harbour to Kaiti. In 1929, the original totara piles were heavily infested with teredo worm. The piles were replaced with ironbark piles, the same timber used at Bridge 256. Inspections in 1991 and 2002 again revealed teredo infestation and the affected piles were replaced.

1.9.9 The infestations were discovered during low tides and no underwater inspections were necessary.

Bridge 254 Tahaenui

1.9.10 Bridge 254 was located about 6 km south of Nuhaka and carried the PNGL across the Tahaenui River. The Tahaenui River was smaller and carried a lesser volume of water in comparison with the Nuhaka River. Bridge 254 was located about 500 m inland from the ocean but the topographical map shows the river flowing in a southerly direction for about 1.5 km from the bridge before turning to the ocean.

1.9.11 In about 1974 a middle pier of the bridge began to sink. This condition continued and was most likely due to loss of bearing resulting from scour. The settlement was uneven so packings were used on a number of occasions to re-level the bridge. At some point all the piles in the settling pier were trimmed to maintain track level and avoid excessive packing. As at April 2005, no remedial work had been carried out and the situation was being monitored.

1.9.12 In the days following the collapse of Bridge 256, an underwater examination of the 2 piers under Bridge 254 revealed no marine borer infestation.

1.10 Local inspection process in Northland

1.10.1 Following the detection of marine borers infesting bridge piles in Northland, a local process developed to record underwater inspections at about 12-yearly intervals. Between 2000 and 2005, piles on 3 bridges were found with marine borer infestations and required major remedial work.

1.11 Events leading up to collapse of Bridge 256

1.11.1 On Friday 4 March 2005, during a routine weekly inspection, a track inspector driving a hi-rail vehicle saw and recorded top and line outside-maintenance tolerances on Bridge 256. He recorded the metrage of the track exceedance as being at 324.90 km and the matter was brought to the attention of the structures inspector 10 days later.

1.11.2 Following the notification, the structures inspector undertook a special inspection on Tuesday 15 March 2005, and recorded the following in part:

> Pier 4, row 2 piles on side 2 have sunk. Cap now approximately 80 mm lower than row 1 at end 2.
> Corbel 2 members are now tilted as per photograph.
> Row 2 cap has lifted above pile 1 due to side 2 sinking.
> Bridge piles observed under load [by a passing train], no signs of pumping.
> Track about 20 mm low above pier 4 with poor line.

A 25 km/h temporary speed restriction across the bridge was imposed.

1.11.3 The structures inspector telephoned these details to Ontrack's bridge office in Wellington and spoke to the engineer responsible for assessing his inspection reports. The engineer confirmed that a work order would be generated the next day to pack and level cap 2 at pier 4. It was standard work practice for Ontrack's bridge office to issue work orders for verbally reported minor maintenance work. Uneven settlement and the large thickness of packing required on this occasion would not normally be considered minor. The structures inspector contacted the Napier bridge gang and made arrangements for the work to be carried out.

1.11.4 On Wednesday 16 March 2005, a leading hand from the Napier bridge gang arrived at Bridge 256 and placed a jack between the cap and the underside of the girder. Having anticipated that he would need a small lift to insert a packing piece of about 15 mm in height to restore the track to level (zero cant), the leading hand found he was "getting nowhere" as he continued jacking until the lift took up and he achieved height parity with cap 1. Instead of needing a packing piece of 15 mm, the leading hand was required to insert a packing piece of 80 mm. When he re-measured the height difference at the end of cap 2, the difference had grown to 210 mm, an increase of 130 mm as measured by the structures inspector the previous day (see Figure 10).

1.11.5 The leading hand also noted that the gap between pile 1 and the end 1 of the cap had also increased from between 10 mm and 15 mm to 28 mm. Two packers were subsequently installed between the cap and the corbel with thicknesses tapering from 75 mm to 90 mm. When completed, the leading hand telephoned and reported all aspects of the bridge repair to the structures inspector.

1.11.6 The structures inspector then telephoned the assessing engineer and passed on the information. The assessing engineer's record of this discussion included that the first train over the bridge after this repair had resulted in a further 5 mm settlement which the structures inspector considered would be the packing taking up, and that it was considered that pile 5 had sunk during jacking and monitoring would occur after every train. The assessing engineer then verbally briefed the events to the engineering manager.

1.11.7 On 17 March 2005, the track gang realigned and refastened the rail on the sleepers 10 mm upstream of its original position above pier 4. Although the track was originally about 20 mm out of alignment, the lift that the leading hand had completed the previous day had partially corrected some of this. The track gang established a longitudinal string line along the sleepers between piers 3 and 5 so they could monitor further movement above pier 4.

1.11.8 On Friday 18 March 2005, the track inspector did not find any non-conformity with the track alignment above pier 4 during his routine track inspection.

1.11.9 Between Wednesday 16 and Thursday 24 March 2005, Toll Rail ran 10 trains between Napier and Gisborne.

1.11.10 On Monday 21 March 2005, the length ganger in charge of the track gang made a special inspection and found no change from the condition as seen 4 days earlier.

1.11.11 On Thursday 24 March 2005, the length ganger made a further inspection and found the track had again subsided above pier 4 and was slightly worse than when first recorded on 4 March. He estimated the track was 25 mm out of line and had 20 mm of cross cant. He reported this to the leading hand who passed on the details to the structures inspector. The leading hand returned to the bridge and drove the existing packers about 300 mm further under the corbels. He stopped the packing when the line and level of the track had been restored. The leading hand re-measured the height difference of end 2 of cap 2 and found it was now 250 mm below cap 1 and the gap between the cap and pile 1 had further increased to 36 mm (see Figure 10). The leading hand passed on these details to the structures inspector.

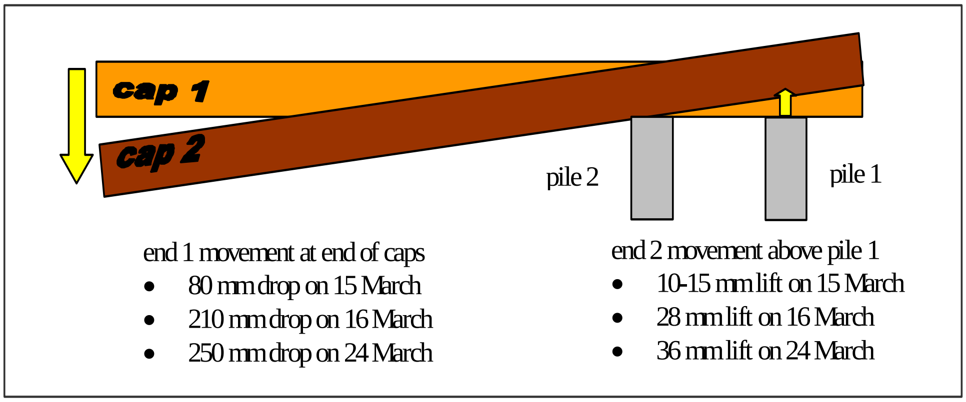

Figure 10
Amount of monitored cap movement above pier 4 (not to scale)

1.11.12 The structures inspector briefed the engineering manager with this latest information. By this time the engineering manager had received a report with accompanying photographs of the work completed on 15 March 2005. The engineering manager requested that the present temporary speed restriction be reduced to 10 km/h, briefed Ontrack's chief operating officer and arranged to meet the structures inspector on site on Tuesday 29 March, after the intervening Easter weekend.

1.11.13 On Tuesday 29 March 2005, the engineering manager, in company with the structures inspector, undertook an engineering inspection of pier 4. A longitudinal track profile measure showed the track level at pier 4 was about 25 mm below the expected track position relative to other piers. An inspection of the piles above water level showed no notable defects and no visible evidence of marine borer attack.

1.11.14 Their discussions then covered a potential below-water problem. As the water was higher than normal because of the blocked outlet and the water was murky with limited underwater visibility, they climbed down between the 2 rows of piles. A rod was used to probe down the length of the piles below water level but nothing untoward was found. Ontrack's report stated that "the nature of the bed material and previous experience at Bridge 254 nearby meant that the focus of concern and discussion was potential scour and end bearing failure. Damage from invertebrate marine borer was not considered as a factor in this locality. The weakness of the large packings, forming the temporary fix and options for an early remedial work involving the driving of 4 new piles and cross caps were discussed".

1.11.15 The engineering manager expressed concern at the lack of knowledge of the below-water-level condition of the piles and requested underwater inspections as soon as they could be arranged.

1.11.16 On Wednesday 30 March 2005, the structures inspector contacted a Napier dive company, which advised that it had the resources to undertake the inspections. Documentation was transmitted from Transfield to the dive company to formalise the inspection.

1.11.17 On Tuesday 5 April 2005, the engineering manager, along with other Ontrack management personnel who were undertaking a PNGL familiarisation trip, made a short stop at Bridge 256 to view and discuss developments.

1.11.18 On Wednesday 6 April 2005, the Napier dive company returned the forms, sent on 30 March 2005, partially completed. The dive company was told to complete the forms.

1.11.19 On Thursday 7 April 2005, the engineering manager met with local government representatives in Napier to discuss the planned repairs to the bridge and what compliances were required under the Resource Management Act. The engineering manager also met with the structures inspector and discussed the bridge further.

1.11.20 On the same date, the engineering manager created a work order No.9081903, the details of which were:

> Work to drive additional piles as per the direction of the engineer.
> Arrange materials and work train. Special requirements will be needed to run the rail cranes (for example – put runner wagons between the crane and loco, pilot the crane across bridges 218 and 254 PNGL).
> Monitor the pile closely until the work is undertaken. Close the bridge if required.
> Refer questions to the engineer.
> Priority 1 – but complete ASAP.

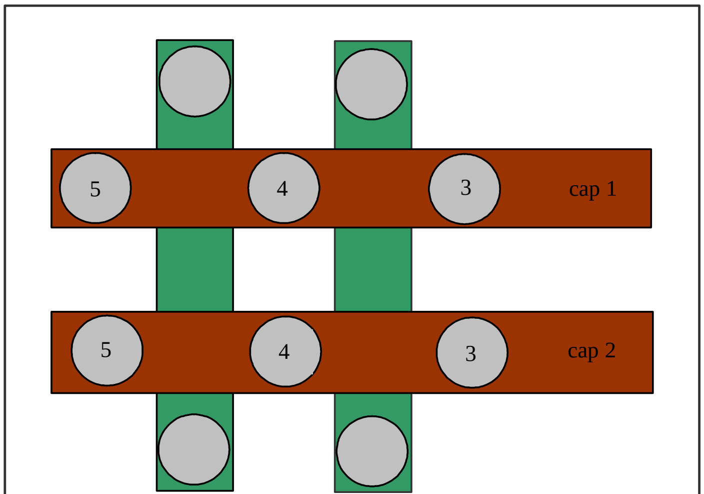

Figure 11
Plan to drive 4 additional piles at pier 4 (not to scale)

1.11.21 On Monday 11 April 2005, the dive company asked for a sample copy of the documentation to assist it in completing the forms.

1.11.22 On Wednesday 27 April 2005, an order was sent by Ontrack to Alstom[6] to provide logistics and staff to drive new timber piles at Bridge 256. The order also required Alstom to liaise with Transfield to identify all potential safety hazards and arrange a combined meeting before commencing the work.

1.11.23 On the same day, the structures inspector and leading hand conducted a measure-up for the planned work at Bridge 256. While working within pier 4, a northbound train conveying fertiliser travelled across the bridge and both members watched the gap between pile 1 and the cap on row 2. They saw no change in the gap and felt no pier movement.

[6] Alstom was contracted to undertake the inspection and maintenance of rolling stock to standards set by Toll Rail.

1.11.24 On Thursday 28 April 2005 and following insurance-related delays, the Napier dive company returned the incomplete forms to Transfield. The semi-completed forms were subsequently received on 5 May and forwarded to Transfield's management office in Auckland.

1.11.25 Meanwhile, it had been established that because of the girder flanges, piles to support the proposed transverse beam could not be driven in positions that would allow the transverse beam to clear pile 3 of both rows. Notches would have to be cut in the pile sides to accommodate the beam. Further, the overhanging ends of corbels supporting the girders would foul the additional piles during driving, so they would also have to be cut back. On 28 April 2005 the structures inspector faxed a sketch to Ontrack showing these details and was given verbal authority to proceed with the proposed modifications.

1.11.26 The second-hand piles were selected from a stockpile at Napier and were examined for teredo worm infestation as part of the selection process, but none was found.

1.11.27 Between Monday 2 May and Thursday 5 May 2005, the bridge gang prepared the bridge for the 2-day occupation. Scaffolding was erected around pier 4 and some bridge and track members were dismantled to permit access for pile driving (see Figure 12). On Thursday 5 May, the structures inspector travelled to Bridge 256 to check on arrangements and saw no movement when a northbound train travelled across.

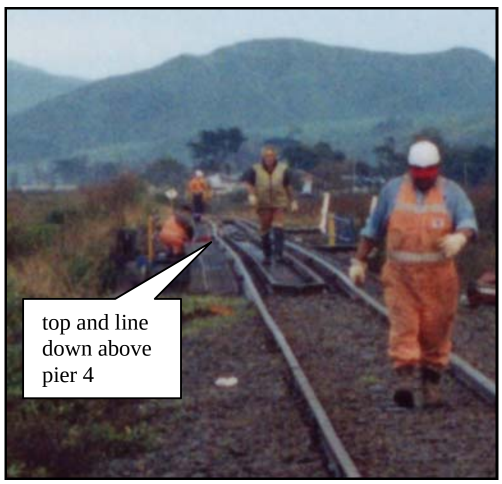

Figure 12
Bridge 256, before arrival of work Train 60
(courtesy of Ontrack)

1.12 Work Train 60 consist

1.12.1 Work Train 60 was marshalled at Napier on Wednesday 4 May 2005, and travelled to Wairoa on the following day. The train was made up with the following vehicles:

- locomotives DC4692 and DC4323
- USQ7133 carrying cap beams
- US7133 carrying 5 piles
- EL6002 rail crane with jib trailing
- EA7835 crane support wagon
- EA7904 crane support wagon
- EL6019 rail crane with jib leading
- US2894 carrying pile frame and monkey.

1.12.2 On Friday 6 May 2005, the structures inspector marshalled the work train consist prior to leaving Wairoa to facilitate the transfer of piles and other equipment between the 2 cranes. When this was completed he boarded the work train for the journey to the bridge.

1.12.3 The sequential plan for the re-piling work to be performed over the 2 days of the occupation was as follows:

1. work Train 60 arrives at south end abutment and traverses Bridge 256
2. EL6002 unloads piles from US7133
3. EL6019 detaches weight-relieving bogies and unloads monkey from US2894
4. work train sets back across bridge to south end abutment and EL6019 unloads pile frame and tool box
5. empty US2892 is detached and secured to track
6. work train positions EL6019 above pier 4 where pile frame is set up on bridge
7. work train moves EL6019 to north end of bridge, picks up first additional pile and returns to pile frame where pile is pitched into frame
8. work train moves EL6019 to north end abutment, picks up monkey and returns to pier 4 and commences pile driving
9. repeats process in item 8 with other 3 piles then replaces monkey and pile frame on US2894 prior to departure from bridge.

1.13 Rail cranes

Historical

1.13.1 Travelling rail cranes were generally grouped by NZGR into maintenance cranes of up to about 15 t lifting capacity and breakdown cranes with 40 t capacity or more. The former were suited to routine bridge maintenance tasks such as pile driving, the latter to lifting locomotives and other heavy rolling stock. Both types could make light lifts “free on rails” to the extent that they could remain stable and the track beneath take the wheel loads. For larger loads, both had to be blocked with outriggers to provide a wider support base to resist overturning. When blocked though, they could no longer travel.

1.13.2 In early years NZGR maintained a small fleet of steam cranes for maintenance and breakdown purposes. However, as the timber bridge inventory diminished, maintenance crane numbers were reduced. Steam-powered cranes became obsolete and some were scrapped and others replaced by diesel cranes.

1.13.3 In the early 1960s, NZGR ordered two 10-ton diesel cranes for lifting work within Mechanical Branch workshops, and four 15-ton diesel maintenance cranes and a 40-ton diesel breakdown crane for infrastructure maintenance and derailment recovery by the Way and Works Branch. During the next 2 or 3 decades the last remaining steam cranes were withdrawn from service. Between 1990 and the early 2000s, Tranz Rail, the then current owner of the business, disposed of all the diesel maintenance cranes with the exception of the two 60 t cranes.

Current

1.13.4 The two 60 t capacity breakdown cranes were owned by Ontrack, but were operated by Alstom personnel. Because of reductions to the fleet of rail cranes over recent years, there were no alternative rail cranes available for such work. The cranes were commissioned in 1979 and were the heaviest that had ever operated on the New Zealand rail system. With 60 t lifting capacity each, they were together capable of lifting the heaviest locomotives.

1.13.5 For comparison purposes:

- a 7 t steam crane weighed about 35 t on 4 axles and free on rails could lift 1.5 t at an 8.5 m radius
- a 10 t steam crane weighed about 43 t on 4 axles and free on rails could lift 1.5 t at a 12.2 m radius
- a 15 t diesel crane weighed about 65 t on 5 axles and free on rails could lift 1.0 t at a 12.0 m radius
- a 40 t diesel breakdown crane weighed about 68 t on 5 axles and free on rails could lift 2.8 t at a 9.1 m radius
- a 60 t diesel breakdown crane in operating mode weighed about 142 t on 6 axles and free on rails could lift 1.5 t at a 12.0 m radius with the counterweight forward, or 3.5 t with the counterweight back
- a DX class diesel locomotive weighed 98 t and had six 16.3 t axles.

1.13.6 Each crane was mounted on two 3-axle bogies with removable weight-relieving bogies positioned at each end of the crane (see Figure 13). In travelling mode, the weight-relieving bogies were attached to reduce axle loads. In working mode they were removed, raising the average axle loads for the whole crane with jib in line and stowed from 14.2 to 20.8 t, and the average for the heavier bogie (at the counterweight end) from 16.0 to 24.1 t. Axle loads of 16.3 t were the maximum normally permitted on the PNGL between Napier and Gisborne.

Figure 13
A 60 t rail crane and attendant wagon

1.13.7 The following table displays the actual and average axle weights and total crane weights in tonnes, with the weight-relieving bogies attached as at the time of the incident and removed as intended for the underpinning project. In both modes, the cranes' counterweights were positioned in the forward position. Axle 1 is at the right hand of the 60 t crane as shown in Figure 13.

Axle	Weight-relieving bogies attached in travelling mode	Average	Weight-relieving bogies removed in working mode	Average
1	11.4	10.7		
2	10.0			
3	13.0	14.6	16.0	17.5
4	15.7		18.7	
5	15.1		17.9	
6	16.0	16.0	22.5	24.1
7	17.5		26.5	
8	14.5		23.3	
9	13.2	14.1		
10	15.1			
Total	**141.5**		**124.8**	

Note: these axle loads were obtained from EL6002 and were measured after the incident. While the weights between both cranes would be similar, it was unlikely that each pair of equivalent axles on the 2 cranes were identical. It was possible that in travelling mode, one axle of the counterweight bogie of EL6019 was actually heavier than the heaviest axle in the same bogie on EL6002.

1.13.8 One of the principal purposes of a rail vehicle bogie was to distribute the total weight between its axles. In the case of the 60 t cranes, the design intention would have been for each axle to carry an equal share of the total weight on the bogie to minimise rail loads. In practice, small variations between axle weights were unavoidable, so a tolerance was normally permitted, typically 0.5 t or so. The centre axle of the counterweight end bogie of EL6002 in working mode as intended for the underpinning project would have been 2.5 t above the average, imposing a maximum 26.5 t axle load on a bridge deck normally required to carry up to 16.3 t.

1.13.9 The two 60 t cranes had been used on one occasion previously to drive piles on a bridge near Tauranga in February 2004.

1.14 Post-collapse inspection

Pier 4

1.14.1 Following the collapse, the bridge piles were salvaged from the Nuhaka River and were transported to Woburn workshops and made available for inspection. Of the 11 piles that made up pier 4, 2 remained upright and were relatively unaffected by the collapse and one was never recovered. It was not possible to match the 8 retrieved piles to their exact positions within the pier 4 structure.

1.14.2 Severe infestation by invertebrate marine borer was evident across the 9 load-bearing piles and the cutwater pile (see Figure 14). Five of the piles had been eaten completely through by marine borers, and of the rest, little sound timber was left to carry the vertical loads.

1.14.3 On all the piles, the area of infestation was about one metre to 2 m below normal water level, 5 to 6 m below the pile tops and about one metre to 2 m above bed level.

Figure 14
Severely infested pile from pier 4

Piers 3 and 5

1.14.4 In the days following the collapse, an underwater examination of piers 3 and 5 was conducted. Of the 10 load-bearing piles on pier 3, there was slight infestation on 3 piles and severe infestation on one pile.

1.14.5 On pier 5, there was severe infestation on 8 of the 10 load-bearing piles, with one pile completely eaten away about 1.2 m above the riverbed level. The other 2 piles showed signs of surface infestation.

1.15 Personnel

Engineering manager

1.15.1 The engineering manager joined the rail industry in 1997 after qualifying as a professional civil engineer and working in the construction industry for about 6 months. His first position was as a junior engineer in the bridge office where, under the guidance of other senior engineers, he developed solutions for some piecemeal replacement of timber components on timber bridges and designed new bridges to replace timber structures. During this time he also reviewed inspection reports from which specific work was arranged. He also undertook rating checks and was involved with planning the repair of the Ngaruawahia rail bridge that had been severely damaged following a derailment.

1.15.2 During this initial period as a junior engineer, the engineering manager was provided with a list of 50 bridges every 6 months to which he was required to travel and undertake engineering inspections. The inspections were carried out over a whole range of bridges, including concrete, steel and wooden bridges located on main and secondary lines. It was anecdotally known that a large proportion of the engineering problems faced by bridge engineers typically occurred at a relatively small number of bridges.

1.15.3 In 2000, the engineering manager was transferred to the regional office in Auckland where he took up a role of planning and field engineer. Field work involved problem solving and working closely with staff undertaking bridge and track maintenance. The tasks did not include planning the specifics of the work, but the role did allow him to gain experience with site supervision and project management. During this time he also continued with the ongoing repair work at the Ngaruawahia rail bridge.

1.15.4 The engineering manager explained that during this time he learnt from watching the structures staff performing different repair tasks on bridges, such as pile stumping and cap replacement. He also discussed with a local structures inspector the subject of a bridge on the North Auckland Line that had suffered a teredo worm attack, but he did not get the opportunity to travel to the bridge to see the situation for himself. Instead he saw photos and other pieces of information on the subject in about 2001.

1.15.5 During these formative years, the engineering manager kept a watching brief on historical pier settlement cases that had been managed by his predecessors and current cases that were being managed by his peers. The engineering manager returned to Wellington in about 2003 and shortly afterwards attained the position of manager track and structures engineering, which included the following responsibilities:

- rating or re-rating bridges on the network
- the development and maintenance of a system to manage the risk of bridges suffering steel fatigue
- putting into place strategies for structure maintenance processing that was in line with the organisational requirements
- arranging the review of structures inspectors' reports, the creation of work orders and monitoring of maintenance performance of the outsourced contractor
- overseeing engineering designs to solve maintenance problems.

The engineering manager said that once he had attained the role, he became heavily involved with bridge maintenance, renewals management and structural changes.

1.15.6 During this period, a bridge embankment was washed out at Rangitata on the Main South Line. This incident resulted in a network-wide bridge inspection of scour risk that involved the engineering manager in company with a river hydrologist. A further incident that occurred during this period was a failure to a cap beam on a bridge on the Midland Line, which resulted in a special review of bridges on that route. Theses 2 incidents triggered a significant drive in the business to eliminate timber bridges and resulted in extra inspections that focused on timber bridges on key routes, including passenger lines. This was a busy time for the engineering manager.

1.15.7 The engineering manager felt that the standard and frequency of ageing timber bridge inspections had fallen below desirable levels and this needed to be addressed. He also felt that there were insufficient engineering staff, because besides himself there was only one other senior engineer and a junior engineer. He considered that this created workload issues which, in addition to an imperfectly maintained asset, created some additional risks. To deal with this situation, he and his staff had their attention on a number of infrastructure risks and their aim was to intervene before a situation became critical.

1.15.8 The engineering manager felt there was no control over the workload, so when 2 major risks occurred at the same time an increase in work output generally occurred. At the same time he was trying to turn around the renewals programme, so he was heavily focused on increasing the amount of renewal work that was going on.

1.15.9 The engineering manager first became aware of the settlement on Bridge 256 on 16 March 2005. It was not until the report was received on 24 March 2005 that he became concerned and reacted by reducing the speed restriction from 25 km/h to 10 km/h.

1.15.10 The engineering manager benchmarked the settlement occurring to Bridge 256 against nearby Bridge 254, which for several years had had considerable settlement that had been managed by his predecessors through monitoring and repacking the piles. The fact that settlement at Bridge 256 had been managed this way over a lengthy period of time led him to believe that this was an appropriate course of action. The amount of pile settlement on Bridge 254 had been so great that his predecessors had even cut all the piles off, re-levelled it and put the cap back on. Because it was in a similar geological setting with a similar water body, he considered that he was dealing with a similar failure mechanism on Bridge 256.

1.15.11 The engineering manager wanted to apply a measured and logical approach to his management of the problem and organised a site visit on 29 March 2005. He harboured concerns that he was going to have to sell a cost-effective solution to Ontrack because he knew that some considered the Napier-Gisborne section of the PNGL as economically marginal. During the inspection the engineering manager talked about teredo worm with the structures inspector and about how there was no evidence of it around the water level. He recalled the recent experience with the East Coast Main Trunk bridge because the structures inspector had supervised the recently completed repairs there. Because the attack on the ECMT bridge had been around the inter-tidal zone and the rod examination at Bridge 256 had covered the same area, he concluded that there did not seem to be any similar problems detected at Bridge 256.

1.15.12 The geotechnical information gathered at Bridge 254 had showed that there were gravel pans as expected in an area of a river system, and the engineering manager cross-referenced this known information with the settlement that was occurring at Bridge 256. He built up a mental model that some of the piles had most likely been founded in a gravel layer and that because of repetitive loading, or other circumstances, a set of piles had punched through the gravel layer into a layer of weaker material. He added that there would have been a different response if the settlement had occurred on a bridge on the trunk [North Island Main Trunk] because it was a key route with passenger trains.

1.15.13 The engineering manager wanted to rule out any evidence of anything else happening when the request for an underwater inspection was made. He balanced up the delays in arranging the diving inspection with the settlement state that the bridge had attained and wanted to rule out anything obvious and help make decisions on the best repair methods.

1.15.14 During the period that the engineering manager was dealing with the settlement at Bridge 256, he said that they were just finishing the last of the February 2004 storm damage, which had created workload issues. Ontrack was also going through an organisational change, an engineer had just resigned requiring the recruitment of new staff members and he was trying to increase the momentum on the renewals programme, so his attention was focused on many issues.

1.15.15 During a subsequent visit, the engineering manager discussed the river bar being blocked with the regional council representative. He was aware of the tidal nature of the inlet but was also aware that, due to the entrance being blocked, the river did not rise and fall with the tide. He had discussed the matter of a teredo worm infestation with the structures inspector. Neither knew about the inversion layer where there was fresh water lying on top of a thinner layer of salt water. He was aware of an inversion layer phenomenon in Fiordland, but was not aware of it happening in coastal river systems. He was unaware of any marine infestations south of Tauranga, although he had later found out that the structures inspector was aware of the pile infestation on Bridge 297 in Gisborne.

1.15.16 The engineering manager felt that the segregation of the structures inspectors to Transfield from Ontrack's engineers discouraged free dialogue and mentorship with the inspectors.

Structures inspector

1.15.17 The structures inspector had joined NZGR in 1976 after working for about 11 years in the general construction industry as a builder. In 1982 he transferred to the bridge gang after completing 6 years of building maintenance. In 1998 he was appointed to the position of structures inspector Napier. His inspection area extended from Gisborne to Woodville. The role required him to undertake programmed detailed, general and special inspections of bridges and other structures as arranged by the area coordinator, to whom he also provided technical expertise.

1.15.18 The structures inspector received formal training before appointment to the position. He had attended 2 conferences prior to the incident that particularly focused on timber deterioration issues. The subject of marine borer infestation was not specifically addressed during these conferences but generic symptoms of timber in poor condition were covered. He and the area coordinator transferred to Transfield when the rail infrastructure maintenance contract was outsourced in March 2002.

Bridge gang

1.15.19 The Napier bridge gang was made of a leading hand and 2 structures maintainers. A leading structures maintainer and a structures maintainer had been brought from outside Napier to assist the gang with the piling operations scheduled for 6 May 2005.

1.15.20 All members were qualified for the tasks they were performing.

Crane operators

1.15.21 The 2 crane operators were employed as a locomotive maintenance engineer and a transport coordinator and held current certification to operate the cranes. Both members were based at Alstom's Woburn workshops, and although crane operating was not their primary role they were regularly called upon to operate the cranes within the workshop complex.

1.15.22 Both staff had operated the 60 t cranes to drive piles on a rail bridge over an estuary near Tauranga in February 2004.

Locomotive engineers

1.15.23 The 2 locomotive engineers were based in Napier and both held Grade 1 certification.

1.16 Locomotive event recorder

1.16.1 The locomotive event recorder was not downloaded, as the operation of work Train 60 was not considered a factor in this incident.

2 Analysis

The collapse

2.1 The collapse of Bridge 256 occurred when the concentrated load of the second rail crane in the work train consist was positioned above pier 4. It was likely that the pier had suffered some weakening with the passage of the locomotives and the first rail crane moments earlier. The collapse followed a severe weakening of the piles by marine borers in an area of stagnant salinity between the low water mark and the river bed. Although the lower reaches of the Nuhaka River were not considered to be, in a purest definition, a typical estuary with tidal ebbs and flows, the river mouth blockages regularly bottled in a layer of salt water. It was apparent that this layer of salt water had provided the teredo worm with a tolerable habitat to infest the bridge piers.

2.2 The infestation had infiltrated and spread through the piles over an extended, but immeasurable, period of time without recourse to a detailed scientific examination to calculate what that period could have been. Although piles in other piers had also succumbed to various levels of infestation, it was apparent that pier 4 had suffered the worst in comparison, possibly because it was the centre pier in the deepest part of the river.

2.3 It was fortunate that all the members of the bridge gang had been instructed by the structures inspector to move from the scaffold around pier 4 to the north embankment before the work train travelled across. Had the pier been a little weaker, the collapse could have occurred when the locomotives of the work train were travelling across, or for that matter while other scheduled trains were crossing the bridge in the weeks leading up to and including the period of the preparatory repair work. Alternatively, had it collapsed during pile-driving operations, a greater number of people would have been on the bridge at that time. The potential for serious injury and loss of life was high.

Precursors to discovery of the pier settlement

2.4 It was probable that at the time of the 2002 detailed inspection, several piles of pier 4 would have exhibited marine borer damage that could have been detected by an underwater inspection. The most recent detailed inspection was 3 years prior to the collapse, and there was another 5 years before the next detailed inspection was due. With 8 years between detailed inspections, a prudent measure would have been to conduct an underwater inspection in an area where marine borer infestation was not unknown. The 2002 report recorded track top and line at that time as satisfactory and also the measurements from rail level to bed level showed no significant change from those recorded during the 1996 inspection. No comment was made on sleeper condition, a track section responsibility, although the running rail was noted to be in good order and the guard-rail was satisfactory.

2.5 It was apparent that the 2004 general inspection, which rated the overall condition index of pier 4 as poor, did not generate any response. This rating index was unchanged from the previous year, and a continuing poor rating did not require any follow-up action other than the continuance of the normal scheduled inspections. The system was not clear on what course of action was required to manage a poor rating of the same bridge pier over 2 consecutive years. Without recorded pile lengths and driving dates for the timbers forming pier 4, it was also unclear why previous infrastructure owners had not addressed this matter and attempted to establish this information and update their records. Not having this information recorded meant that inspectors did not know for sure the ages of the piles and the nature of their installation.

2.6 Ontrack's quality management procedures at the time of the collapse did not include routine inspections by experienced professional engineers. In contrast, previous NZGR quality management procedures specified that district engineers' inspections were to be routinely critiqued by an inspecting engineer from the chief civil engineer's office. This earlier inspection regime provided a high degree of continued assurance for the condition of all track and bridges. District engineers typically had 20 years or more of railway civil engineering experience and extensive knowledge of the condition of both track and bridges within their areas.

2.7 A district engineer's inspection would visually check track line and level to see if any variations coincided with pier positions. The most common explanations for such variations would be loose or defective pier bracing or loose sleeper hook bolts. However, if no other cause could be found and the bridge was in an estuary, the possibility of marine borer damage would normally be considered. Although bridge inspectors were free to suggest underwater pile inspections, the detection of marine borer attacks was not considered to be part of their core responsibilities unless there was visual evidence on piles above the low-water level. Where there was not, the initiative for an underwater inspection could come from engineering or supervisory staff.

2.8 There was no record of when Bridge 256 had last been inspected by a professional engineer prior to the special inspection undertaken by the engineering manager about 2 months prior to the collapse. It was apparent that the condition of the ageing bridge was only being monitored during the scheduled general and detailed inspections. In the absence of any other instructions or policy, the inspector recommended and scheduled a supplementary inspection of pier 4 in 2006. In view of what was considered a reduced importance of the PNGL by Ontrack and Toll Rail, and their predecessors, and with other pressing engineering issues being managed during this period, the inspector probably considered this to be an appropriate course of action.

2.9 However, Bridge 256 was 83 years old and had been inspected many times by different levels of professional engineer throughout that time. Records showed that none of these engineering inspections had generated an underwater inspection. Although there was some history extending back several decades of marine borer infestations in some bridges in the Northland and Bay of Plenty areas, and a more recent infestation in a bridge in Gisborne, 77 km north of Nuhaka, there was no recorded history within the rail industry of an infestation in any bridges further south, such as at Nuhaka. It was probable that contemporary engineering understanding of marine borer infestations throughout the history of the New Zealand rail industry was that they were likely to occur in warm salt water locations in the areas mentioned.

2.10 The use of scuba diving did not become readily accessible in New Zealand until the 1960s, when technology and equipment became more available. Before then, NZGR had dealt with a number of instances of severe marine borer damage to piles mostly in the warmer northern waters. These either had become visible above low-water level during routine inspections or were identified when track line and level faults developed over piers. NZGR and its successors continued this method of detecting marine borer infestations until about 1990, when the use of underwater inspections by scuba diving was considered.

2.11 After 1990 however, successive business owners had implemented changes to quality management practices, and by 2000 the requirements for programmed engineering inspections had been discontinued. These changes principally occurred following the surface transport changes of the 1980s and 1990s as the railway business transformed from a government department to a state-owned enterprise, then to private and finally public ownership. During that period, manpower levels throughout the business were substantially reduced with one result being the loss of engineering expertise and institutional knowledge of timber bridge performance.

2.12 A direct consequence of these restructurings was that Ontrack inherited an under-resourced team of engineers and an inspection process with shortcomings.

Identification of the pier settlement

2.13 Although no details had previously been recorded, variations from track line and top in the vicinity of pier 4 could have been developing for some time before they became obvious to the track inspector. When they did reach the threshold that classified the situation as a track fault, the track inspector took appropriate action to advise the structures inspector and discuss the nature of the fault with him. When Ontrack was subsequently informed by the structures inspector, it became the responsibility of its engineering staff to identify the nature of the problem and to determine the remedial action.

2.14 Under previous regimes a number of engineers would have been available to analyse the settlement seen at Bridge 256. Although the cause of the pier failure was not apparent until after the collapse, there had been sufficient time after the change in track alignment had first been identified for appropriate action to be taken. Regular engineering inspections could have detected the problem earlier and could have provided a longer lead time for repair work to have been carried out. Nevertheless there was a 7-week opportunity during which there was time to analyse the cause of the settlement correctly and, if necessary, close the bridge until repairs had been made assuming resources were available to do so.

2.15 Throughout the 2-month period following the track inspector's initial report, both the engineering manager and the structures inspector made special inspections of Bridge 256 to monitor pier 4's settlement. Had the cause and extent of the problem been correctly determined during this time, the bridge and line should have been closed until effective repairs had been made.

Interpretation of the pier settlement

2.16 From the moment the track inspectors first reported the settlement, Ontrack's engineers and Transfield's structures inspector assumed the cause to be loss of pile-bearing capacity because of some unknown geotechnical problem. It appears they dismissed other explanations, including a marine borer infestation, as improbable. Also, it was clear that consideration was not given to the possibility that the distortions being seen were large enough to affect the way the pier components interacted.

2.17 The reason for the 10-day delay in relaying the information from the track inspector to the structures inspector was not explained. After receiving the track inspector's report, it was probably the first time the structures inspector had revisited Bridge 256 since the general inspection conducted on 2 December 2004, only 5½ months earlier. The structures inspector's measurements showed that end 2 of pier 4's cap 2 had sunk relative to cap 1; the track line over the pier was 20 mm low, probably meaning 20 mm off cant. The structures inspector could not recall what conclusions he reached when he saw that none of the piles pumped while a train passed over the bridge. The subsequent actions taken by the structures inspector to impose a 25 km/h speed restriction for trains and advise Ontrack's assessing engineer were reasonable, but such substantial deformations of a bridge in such a short time were unusual and had the engineering implications been properly understood, a more urgent reaction to the problem might have ensued.

2.18 Nevertheless, the assessing engineer's work order authorising the packing and levelling of cap 2 on pier 4, with the work to be completed in 7 days, did restore the track geometry. Implicit in this action was an assumption that, although the piles had settled, they still provided sufficient support to the caps to support trains and the packing would at least temporarily restore track geometry.

2.19 When the bridge gang arrived to carry out the work order on the following day, they probably placed the jack on cap 2 just above pile 3, and lifted the bridge span so that they could insert the packing between the corbel and the cap. It was a lift of probably about 15 t in weight by a jack standing on a cap designed to support over 90 t. The gang was presumably surprised when the span did not go up, but the cap went down. Eventually though, the lift "took up" after further jacking. The cap stabilised and the packing was able to be inserted. It was not the expected 15 to 20 mm, but 80 mm, a substantial difference.

2.20 Piles 3, 4 and 5 had all probably settled during the jacking, and end 2 of cap 2 was now 210 mm below cap 1, whereas a short time before it had been only 80 mm. However, piles 3, 4 and 5 of row 2 had settled under an applied load much less than they had been designed to carry. Also, the gap over pile 1 had increased from 10 mm to 15 mm. Under the first train, a 5 mm settlement was measured, probably meaning that the track had gone off cant by 5 mm. Independently, the track gang then realigned the track over pier 4. The structures inspector advised the assessing engineer, who was reported to have considered that the 5 mm settlement may have been the packing taking up.

2.21 However, it was unusual for the piles under cap 2, which had clearly settled during the jacking procedure, to have settled under loads much smaller than their normal working loads. Normally piles loaded beyond their ultimate capacities in load-bearing tests would slowly settle until the load was reduced to less than the ultimate. They would, though, retain their abilities to support lesser loads without settlement. Hence the pier 4 settlements observed during the jacking process were incompatible with the assumption that earlier settlements had been due to axle loads from rail traffic that was loaded to only 14.3 t, somewhat less than the pier's ultimate capacity. There had been no known recent increases in numbers of trains or of axle loads, and no discernable scour that might have reduced the piles' ultimate bearing capacities.

2.22 It was also unusual for cap 2's rotation to be about pile 2, causing the cap to lift clear of pile 1. It would have been apparent that the 4 piles were now sharing the load previously carried by 5. Whereas piles 3, 4 and 5 had been observed to settle under less than their usual working loads, pile 2 seemed to be supporting without distress not only its own design load, but also that from pile 1.

2.23 Another question apparently not considered at the time was why there should suddenly have been such dramatic differences in the apparent bearing capacities of adjacent piles of presumably similar lengths within pier 4, presumably driven to the same sets and presumably founded in the same soil material. Piles 3, 4 and 5 of row 1, each less than a metre from their counterparts in row 2, seemed to have retained their bearing capacities throughout the 2-month settlement period.

2.24 A further query not resolved was what stresses were now being imposed on cap 2. The principal function of a cap was to distribute the load from the corbels to the supporting piles beneath. The theoretical share of the total load each pile would take, and the bending moments in the cap that would result, were statically indeterminate and were difficult to calculate because of the elasticises of both caps and piles, especially without modern calculating equipment.

2.25 For such problems, the PWD engineers who designed standard piers for the early railway bridges relied on practical experience to produce solutions that would work within reasonable limits. In this context, reasonable meant the cap being supported on piles of similar lengths, driven to similar sets, and cut off at the same level. In situations like Bridge 256's pier 4, two 15-inch by 8-inch flitch caps had been specified. Because of maintenance problems, flitch caps were replaced with a single solid cap whenever repairs were needed. Pier 4's cap 2 was replaced in 1971 with a 400 mm by 300 mm boxed heart timber beam. It probably had about 85% of the stiffness of the flitch caps, but was still sufficient to transfer reasonable proportions of the loads to all 5 piles in normal circumstances.

2.26 The large pile settlements that occurred in March and April 2005 resulted in support conditions for cap 2 being very different from those that would have been envisaged by the earlier engineers. There was a predicable increased risk of the cap suddenly failing because of the extent to which the settlements may have resulted in increased bending stresses in the cap.

2.27 On 24 March 2005, and 8 days after the track had been returned to correct line and the cant removed, track staff again found the track over pier 4 was 25 mm out of line and 20 mm off cant. These were large discrepancies for straight track. Transfield's bridge gang promptly returned and repeated the procedure it had used to carry out Ontrack's work order 8 days previously. Again, piles lightly loaded during the jacking process settled substantially. Bringing track cant back to zero increased the height difference at end 2 between cap 2 and cap 1 to 250 mm. This discrepancy again demonstrated that although row 2 piles 3, 4 and 5 were only capable of supporting much reduced loads, pile 2 was now supporting more.

2.28 The structures inspector was concerned and that day brought the matter to the attention of both the assessing engineer and the engineering manager. The engineering manager directed that the train speed restriction on the bridge be further reduced to 10 km/h and arranged to inspect the site personally on 29 March 2005. As part of the inspection, the bed profile was checked to see if it had scoured (a possible explanation for loss of bearing capacity), but it had not. It was subsequently reported that the "focus of concern and discussion was potential scour and bearing failure". Regardless of the implications of the pile settlements under light loads during the packing process and their contrasts with pile 2 and the other piles of row 1, the engineer and structures inspector continued to believe that the cause of the settlement was geotechnical in nature.

2.29 The engineering team and the structures inspector were aware that they did not fully understand the cause of the pier settlement, hence the request for an underwater inspection. Given that they did not fully understand the reason for the pier settlement, the 38-day delay in arranging the dive inspection should have caused more concern than it appeared to.

2.30 By early April, the engineering manager faced technical issues that he considered serious, and without the results of the dive inspection he did not have all the necessary information to complete his analysis. To resolve it, his proposed long-term solution was to underpin the end 2 of both caps in pier 4 as soon as possible with 4 additional piles, adding their bearing capacities to those piles that were settling. Although with hindsight it was obvious that there was now substantial information that conflicted with an assumption that the problems were geotechnical in nature, at the time neither the engineering manager nor his colleagues, his superiors in Ontrack or the structures inspector had extensive technical experience of timber railway bridges to recognise that their reasoning was mistaken. Additionally, the situation was aggravated by heavy workloads that limited their available time to consider the evidence sufficiently, and by commercial pressure to provide a quick, cost-effective solution without closing the line.

2.31 To reduce short-term risks, the engineering manager lowered the 25 km/h speed restriction to 10 km/h, although the resulting decrease in impact forces would have had minimal effect on the pier's foundations. Transfield was instructed (in effect the structures inspector) to continue to monitor pier 4, and to close the bridge to traffic if necessary. The engineering manager's instructions were consistent with an assumption of bearing capacity as the cause of the settlement.

2.32 The engineering manager apparently anticipated that any further pile settlement would follow further plastic deformation of the material surrounding and below the pile tip, a slow process that would result in equally slow deformations of the bridge structure above. The engineering manager's implicit assumption was that the caps could continue to distribute loads from the corbels to individual piles without overstressing. If the rate of pile settlement accelerated or circumstances changed for any reason, it could be detected by monitoring, and there would be time to make a decision to close the bridge to traffic. It was evident from this that the engineering manager did not envisage a sudden, brittle failure.

2.33 The engineering manager's instruction to monitor the ongoing pier condition and close the bridge if required, consequently made the structures inspector accountable for the ongoing safety of pier 4 under rail traffic until underpinning began. The reasonableness of the instruction was questionable given the structures inspector's limited engineering knowledge. Details of how this was to be accomplished were left to the structures inspector's discretion. The structures inspector was not given any technical guidance on what "monitor the pile closely" meant or under what parameters he should close the bridge.

2.34 Providing those guidelines was properly a matter for a person with more formal training in and experience of railway engineering. It would have been reasonable for the engineering manager to have informed the structures inspector what additional inspections were required, by whom and when they were to be carried out, and what they should include. Considering the already large pier 4 pile settlements and rotation of cap 2, the structures inspector should also have been given the maximum limits of further settlement and cap rotation that the engineering manager considered acceptable.

The underpinning project

2.35 The underpinning proposal would have been an appropriate solution had the problem been one of end bearing failure, and it would have also provided a temporary relief from the real cause of the settlement problems. However, it seemed that no-one understood the implications of using such a heavy crane free on rails to drive the piles. Nor did it seem that anyone questioned whether the distortions that pier 4 had suffered had weakened it to a point where it would not support the work train.

2.36 The steam and diesel rail cranes of the NZGR maintenance and breakdown fleets were technically travelling cranes and could be described as cranes mounted on wheels. They were able to be conveyed to any part of the railway network, but their lifting and slewing capabilities, free on rail, were severely limited by the strength of the supporting track and by their need to retain stability and not overturn on NZGR's narrow gauge track. For lifts approaching their maximum rated capabilities, they had to be supported by outriggers.

2.37 When cranes were required to work on bridges free on rail, not only were rail and sleeper strengths important but also the structural abilities of the bridges to support them. If cranes had to work on bridges blocked, they needed specially built structures strong enough to take the outrigger loads. Any person taking responsibility for the safe working of cranes free on rail on bridges needed knowledge and experience of bridge, track and crane technologies. For routine, simple lifts in earlier years, a member of a district's works supervisory staff, akin to a structures inspector but more experienced would have been assigned to take charge. For the heaviest and most technically difficult lifts, and those with 2 cranes, the district engineer or an experienced assistant district engineer would have been assigned to take charge.

2.38 The only travelling cranes currently available for pile-driving jobs were the two 60 t cranes. Rail cranes as low as 7 t capacity would have been sufficient for the job, but previous owners of the rail business had disposed of the diesel maintenance crane fleet except for the two 60 t cranes. Rail cranes are not essential for bridge pile driving but are the most convenient tool for the job. It was reported that the 60 t cranes had been previously used for pile driving on one previous occasion and based on this experience, it was probably agreed to use them again on Bridge 256. It was unlikely that anyone understood or considered the inherent risks that decision brought.

2.39 One of the inherent risks was the heavy shear loads the cranes imposed on the bridge sleepers. In travelling mode the 60 t cranes weighed some 142 t, half as heavy again as a DX class locomotive. The relieving bogies reduced the average load across the 10 axles to about 14.2 t and gave the cranes widespread running rights across the network. However, the average axle loads in the bogie under the crane body were about 16 t, provided the crane was properly balanced. Nevertheless, the axle loads on the undamaged crane were found to be out of balance, to the extent that one axle weighed 17.5 t. It was not known what the equivalent weights were for EL6019, the crane that was submerged, but they were presumed to have been broadly similar.

2.40 In working mode and with the relieving bogies detached, the cranes weighed about 125 t supported by 6 axles, averaging 20.8 t each. By comparison a DX locomotive, the heaviest authorised to cross Bridge 256, weighed 98 t but had 6 equally loaded axles of about 16.3 t each. However, because of their very nature, the axle loads on the 60 t cranes were not equal, and the heaviest axle in the heaviest bogie was measured free on rails with no load at 26.5 t, although this could vary up or down depending on counterweight setting, jib luffing and slewing position and any load on the hook.

2.41 Diesel locomotives were symmetrical about the track centreline and therefore the maximum wheel load for a DX locomotive was nominally 8.15 t. The 60 t cranes, operating free on rail, were only symmetrical about the track centreline when their jibs were in exactly fore and aft position. When the jib was slewed to either side, and unless by chance the counterweight exactly balanced the overturning moment, the wheels on one side of the axles would be heavier or lighter than those on the other. Depending on hook load, lifting radius, counterweight setting and slew angle, the maximum wheel loading of either crane free on rails, but working within its stability rating, could have been in excess of 13.25 t. It was therefore possible that in working mode, but without their outriggers deployed, wheel loads reaching double that of a DX locomotive could happen.

2.42 In the schedule of movements planned for the underpinning project, it was proposed that EL6019, with the locomotive's assistance, travel over various spans of the bridge with various loads, such as the pile frame, monkey and the 4 piles, on its hook. It would have been reasonable to assume and interpret the schedule as certification that the sleepers on the bridge were of sufficient strength for the proposed movements. Ontrack engineering staff, though, did not appear to have understood the severity of the sleeper loadings that would result or carried out the necessary sleeper condition inspection and evaluation. Since some bridge sleepers would have had to be removed at pier 4 locations where piles were to be driven between the rails, it would also have been prudent for Ontrack to warn Transfield that all sleepers must be in place and taking their full shares of the wheel loads whenever crossed by the crane.

2.43 Another issue that should have been considered was the heavy loads the crane would impose on the pile caps during pile driving. Assuming that EL6019's counterweight was in forward position and jib in travelling position, the maximum calculated live load on cap 2 was 80 t, although while working it could have been higher. By comparison, for the usual PNGL train consist of 2 DC locomotives and a train of CF wagons with 14.3 t axles, the maximum cap load would have been about 55 t. For the heaviest authorised train (not normally used for operating reasons) of 2 DX locos and CF wagons with 16.3 t axles, the maximum calculated live load on cap 2 was about 60 t. The live load on cap 2 at the moment of failure was estimated to have been about 64 t. Had Ontrack's assumption that the pile settlement problem at pier 4 been correct, and considering the amounts of pile settlement caused by the passage of a few fertiliser trains, the settlements to be expected from a 60 t crane standing on span 4 while 4 piles were driven could have been large.

2.44 Ontrack and Transfield appointed the structures inspector responsible for the safety of the underpinning operations. Apart from the bridge gang, he had no engineering assistance. As well as supervising the pile-driving work he was required to monitor continually the stability of pier 4. If Ontrack's assumption of pile-bearing failure had been correct, though, the live load of the heavy crane and the vibrations of pile driving would have caused substantial further pile settlements and rotation of cap 2.

2.45 The structures inspector had been given no guidelines to follow on what additional settlements and rotation were permissible. Decisions such as when to stop work temporarily and pack the track back to level, or to stop work altogether, were left entirely to his discretion. This was an unreasonable expectation placed on a trade-trained inspector with limited experience of pile driving and supervising a 60 t crane working on a bridge so severely distressed. He did not have the engineering knowledge to foresee the risks of sudden cap failure that had also seemed to have escaped Ontrack's professional staff. The underpinning work should reasonably have been carried out under the direction of a professional engineer with knowledge of, and practical experience in, railway bridge maintenance.

2.46 Until about 1990, there was a pool of civil engineers with the qualifications and district training appropriate to provide site supervision of a project so intrinsically hazardous. In the following decade or so the pool had been depleted and with them went much of the expertise in railway timber bridge maintenance accumulated in over a century. Such expertise was no longer available, and there remained an unsatisfied need in railway maintenance for professional engineering skills at field level. Notwithstanding the shortage of experienced railway civil engineers, Ontrack or Transfield could have, and should have, provided at least some on-site engineering expertise to support the structures inspector on this occasion.

2.47 The primary cause of the pier collapse was severe marine borer damage to several of the supporting hardwood piles. NIWA identified the presence of one crustacean species and 2 mollusc species in the damaged pile sections. The first indication of the failure was the loud sound of cap 2 breaking, followed immediately by the collapse of the pier, spans and crane into the river. It was not possible to identify which of several recovered pile pieces were at what locations in the piers, so exact details of the collapse mechanism and immediately preceding events could not be established.

2.48 In general terms though, marine borer attacks on several piles in pier 4, one or 2 m below water level, progressively reduced the load-carrying capacity of some and completely severed others. As individual piles in the pier lost their support capacities, the remaining piles took increasing shares of the total live and dead loads in the pier. Compressive stresses in their wasted pile sections rose and so did stresses in the foundation materials at the pile tips. The pile settlements observed at various times were the result of the crushing failure of wood fibres in the wasted sections of the piles and/or plastic deformation of the overstressed founding material supporting their tips. It could not be determined whether the collapse was initiated by the axles of EL6019 moving into positions that the piles supporting cap 2 could not sustain, or moving into positions that cap 2 could not sustain with the support it was receiving from the piles, or because a sleeper suddenly failed. Nevertheless, cap 2 failed catastrophically with a large release of energy.

2.49 Given that the structures inspector had been given instructions to complete the work, and the fact that he had not been told otherwise, he had no reason to stop the work train crossing the bridge on the day of the collapse. If there had been further settlement of pier 4 since the last recorded measurements on 24 March 2005, its extent was not reported. The Figure 12 photograph showed the track over pier 4 visibly below grade line, that being the plane of the running surface of the rails taken over the whole bridge. It was not possible, though, to infer from the photograph the extent, if any, of cross-cant of the track over pier 4 that may have developed since the packing was last adjusted on 24 March 2005.

2.50 No-one in either Ontrack or Transfield had considered the potential for sudden failure of one of pier 4's caps, or warned the structures inspector of the risk. On the contrary, the engineers on whom the structures inspector could reasonably rely had led him to expect that visible signs of potential failure would be detected by observation and, by implication, he would then act to avert or mitigate. The structures inspector had been given no criteria on which to base a judgement that the bridge had become unsafe for the work train.

Regulatory oversight

2.51 The events leading up and contributing to the collapse of Bridge 256 stretch back many years through the history of the New Zealand railway system. The infrastructure and the supporting engineering services had been allowed to deteriorate over the years through a succession of ownership changes and restructures. While there might have been an acceptable reduction in the standard of the rail infrastructure to a point where the system still remained safe, there was no one independent body controlling where that point lay.

2.52 The bridge collapse had a high potential for fatalities and it was more by good luck than good management that no-one was injured. The accident served as a timely reminder to those in the industry that standards need to change. The 1993 due diligence report made clear reference to the lack of resources going into the maintenance and renewal of timber bridges in particular, and the problems that were likely to ensue if circumstances did not change. The timing of this report coincided with the forming of the LTSA.

2.53 In 2002 the LTSA-sponsored review of Tranz Rail's policy change for infrastructure maintenance gave some clear indicators that engineering resources were not sufficient to support the current and future state of the rail infrastructure. In spite of these comments, the amount and quality of engineering resources further deteriorated to the point where they were not able to cope effectively with correctly assessing and rectifying the problem encountered with Bridge 256 before it collapsed. There were clear signals from 2 separate, independent reports that the ageing rail infrastructure and the reducing level of engineering expertise available to manage and maintain it were putting the rail system at risk, yet there was little if any intervention from the regulator over the years to ensure the risk was managed at an appropriate level.

2.54 The Commission has commented on the need for an increase in regulatory oversight of the rail industry in its report 05-123 involving a braking irregularity on a suburban passenger train. A recommendation was made to the Director of Land Transport New Zealand that he adopt a more hands-on approach to regulating the New Zealand rail industry consistent with the generic principles used in other modes of transport where industry rules and standards come under the control of the regulator. This recommendation is equally applicable to this report.

3 Findings

3.1 Pier 4 of Bridge 256 catastrophically failed under the weight of work Train 60 because most of the 10 piles making up pier 4 had been severely weakened by an infestation of marine borers.

3.2 The usual signs of marine borer infestation in the piles around the low tide mark were masked by the water salinity layering effect caused by the slow-running nature of the Nuhaka River, but the relatively warm estuarine environment was typical of a marine borer habitat, and Bridge 256 should have been regularly inspected for an infestation.

3.3 The level of engineering experience in the rail system was not sufficient to support the inspection and maintenance of the rail infrastructure in the years leading up to and at the time of the bridge collapse.

3.4 A lack of engineering resource contributed to:

- the misdiagnosing of the cause of the piles sinking on pier 4
- the incorrect assessment of remedial work to correct the sinking pier
- poor appreciation of the effect of using a heavy crane in working mode to effect repairs to a weakened bridge
- the assumption that the cause of the pile settlement was the same as the longstanding scour that led to a bearing problem at a nearby bridge.

3.5 The structures inspector did not have sufficient engineering expertise to oversee the underpinning project safely and make a decision on whether to close the bridge at any stage.

3.6 The weight and axle loadings of work Train 60 were within the original design limits of Bridge 256, but exceeded the failure point of the aged and weakened structure.

3.7 The reduction in the replacement of timber components in rail bridges during successive periods of ownership and structure of the rail system, together with a reduction in the frequency and quality of bridge inspections, increased the risk of a catastrophic failure beyond what would normally be considered safe.

3.8 An appropriate level of regulatory intervention in the rail industry should have picked up and acted on the warnings in 2 separate independent reports that the rail infrastructure would be at increased risk unless material-replacement programmes were improved and engineering expertise was at least maintained.

4 Safety Actions

4.1 On 2 August 2005, Ontrack advised the Commission that it had initiated the following safety actions:

> Following the collapse, an immediate check of all timber piers in potentially exposed marine or estuarine environments throughout New Zealand was carried out by underwater inspection and action on those found to have unacceptable levels of marine attack. This initial one-off inspection is currently being supplemented by a more detailed inspection for selected bridges involving further boring and consideration or core sampling. Once the results of all inspections are collated and assessed, Ontrack intend compiling an underwater inspection regime based on defined bridges and frequencies to ensure all bridges receive appropriate underwater inspection.
>
> Ontrack have recognised the need for a strategic approach to the problem of aging timber bridges and are preparing a strengthening and replacement programme on standardised cost effective solutions.

4.2 On 31 May 2006, Ontrack advised the Commission that the 2 rounds of inspections had been undertaken. The remaining issues had been completed and are mentioned in paragraph 4.3 following. The strategic work mentioned in the second paragraph was still ongoing.

4.3 On 31 May 2006, Ontrack further advised the Commission that it had initiated the following additional safety actions:

- The inspection programme has since been completed. Bridges where issues were found to have had mitigation measures put in place to manage and risks identified. For some bridges the best short to medium term strategy is to renew them. Of the 51 bridges with timber piers in marine environments, one will have to be replaced by the end of May 2006. A further eight bridges are currently in the process of having a Resource Consent obtained to renew them. Preliminary planning has commenced to replace a further group of timber pier bridges in marine environment once the priority work is under way.
- The Code Supplements for Bridges and Structures and the structures Inspection Manual W200 (refer paragraph 1.6.2) will be amended to clearly articulate the background, guidelines and inspection methods for underwater inspections. It will draw heavily on the detailed information gathered and experience gained through the investigations and follow up work. At the annual Structures Inspectors conference which will take place later this year (August or September 2006), a special session will be held to reinforce the amendments.
- At the Structures Inspectors conference held in Spring 2005 (after the incident), the subject of marine infestation was covered in detail. The main

topics covered were techniques for underwater inspection, practicalities of detecting infestation by boring, how to brief divers and capture the information they collect, and, being aware of the possibility that there may be a layer of fresh water over the top of a salt water layer such as at Nuhaka, meaning that there will be no evidence of marine infestation at the inter tidal zone.

- A system should be implemented to control the use of 60 t cranes for maintenance work on bridges, both when travelling and in working mode, which matches the loading effect of the cranes with the rated capacity of both spans and structure.
  Since the Nuhaka incident the remaining crane has not been used for maintenance work on bridges. The relevant railway codes will be amended to capture the intent of this action.

- A sophisticated series of spreadsheets has been developed where the spatial coordinates, member sizes and the applied load to timber piers are entered. This then produces various rating information. The spreadsheets have been developed by three consultant and in house engineers. The spreadsheets have also been peered reviewed by a number of other engineers. Development of the spreadsheets has nearly been completed and the timber pier bridges on the coal route have been used as a pilot study. Ontrack have recently hired a contract engineering technician whose role is to interrogate the various railway data bases to enter in the pier information for the rest of the network.

- As a result of the Nuhaka incident, Ontrack reviewed the engineering team. The finding was that there was the necessary expertise and experience. However, because of the legacy issues from previous railway organisations, there was insufficient engineering resources to adequately deal with all the engineering issues and initiatives for the whole nation network and also have the capacity to dedicate engineers to specific problems which arise. Since Nuhaka occurred, the structures resource has been increased and improved by the following means:

  - Ontrack have recruited three additional engineers, a graduate engineer and an engineering technician (separate from the person mentioned).
  - Five in-house contract engineers and two engineering consultants are being used to help manage the bridge asset.
  - The Manager, Track and Structure Engineering role has been divided into two positions so that structures issues have closer management focus than before.
  - Another structures Inspector has been employed taking the total to 10 inspectors.
  - Two former experienced Structures Inspectors directly report into the Structures engineering team. These people are used to provide peer reviews to the regular inspectors, are available for provide second opinions on particular issues that arise, and when required take charge of the issue so that regular inspector does not fall behind on other safety critical work.

- An engineering hierarchy has been developed since Nuhaka which utilises the additional engineering resource:

  - The Structures Inspectors role of “if in doubt” about an issue close the structure or put a speed restriction has been reinforced. These actions will not draw criticism as taking a precautionary approach is what is expected.
  - A “buddy” system has been initiated where each Structures Inspector has a particular engineer who they discuss issues with. The buddy engineer is the first point of contact. The Inspectors are

aware of secondary engineers who they can speak to should their primary contact not be available.

  - The buddy engineers have all been briefed on particular case studies and structural issues to look out for and the required actions to take.
  - If there are particular difficult issues, these are elevated to an overview group consisting of the Manager of Structures Engineering, a Senior In-House Engineer and a Senior Engineering Consultant.

As there are many different possibilities that may arise, it is difficult to prepare guidelines to cover every eventuality. The engineers use experience, technical analysis (where possible) and professional judgement to deal with the individual circumstances of the issue.

- The customary routine procedure of packing at pile head to achieve track level needs to be carefully monitored with experienced engineering input taking into account pile condition, past history of pile/pier performance, soil conditions, pile driving records, test bores and if necessary structural capacity checks. The skill and experience of engineers doing such monitoring is of paramount importance.
- The historic culture or repeating certain inspection and maintenance procedures because they were done a certain way needs a critical review. Aging timber components develop subtle but structurally significant defects which can go undetected by less discerning inspectors and engineers.
- Maintenance works involving non-standard features such as the unusually large and rapid settlement at Bridge No.256 require method statements and appropriate risk assessment. The bridge inspection assessment and work order system should be amended, with appropriate guidelines, to achieve this.

5 Safety Recommendation

The following preliminary safety recommendation, related to rail occurrence report 05-123, is included in this report because it is equally applicable to this occurrence.

5.1 On 26 September 2007 the Commission recommended to the Director of Land Transport New Zealand that he:

> Note the failures of the regulatory system to detect shortcomings in the maintenance of infrastructure (as presented in the Commission's report 05-116; collapse of the Nuhaka Bridge under a work train) and shortcomings in the construction and commissioning process for newly modified rolling stock (as presented in this report) and,
>
> Take a more strategic approach to risk management of the rail industry, and in particular take more of a leadership role in setting, changing and monitoring compliance with national standards for rail infrastructure and rolling stock, and the interaction between these components of the rail system. (035/07)

5.2 On 26 September 2007 the Director of Land Transport New Zealand replied in part:

> Land Transport NZ has recently reviewed its regulatory activities within the co-regulatory New Zealand rail system and plans to take a more strategic, proactive and risk based approach in its monitoring of, and involvement with, the rail industry. Land Transport NZ notes the failure of the maintenance system that led to the collapse of the Nuhaka Bridge and in the commissioning and construction process associated with the construction of SD passenger cars, as outlined in the TAIC reports.

Approved on 20 September 2007 for publication

Hon W P Jeffries
Chief Commissioner

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