

# **Feasibility study of the life extension of a 100-year old timber truss rail bridge over the Grey River, New Zealand.**

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## **SYNOPSIS**

The existing Grey River Rail Bridge, built in the late 1800's, crosses the Grey River in Greymouth, New Zealand. The bridge, also known as the Cobden Bridge, is approximately 300m long and is made up of 80ft and 40ft timber truss spans and a small number of timber spans. The timber trusses include steel bottom cords and vertical ties to carry tension forces, while the timber truss members were designed to carry compression forces. The piers are made up of driven timber piles. In plan the bridge has a double-S curve which is believed to be unique in the world.

Over the last 100 years the bridge has successfully carried rail traffic and currently still forms a critical link in the transport of coal for Solid Energy International from the West Coast of the South Island to Lyttelton Port on the East Coast. Planning for substantial increase in coal exports has prompted both Solid Energy International and Tranz Rail to focus on the ability of the existing Cobden Bridge to carry the increased traffic volumes as well as increased axle loads. Holmes Consulting Group Ltd. was commissioned to undertake a feasibility study into life-extension options of the bridge.

The feasibility study included an initial qualitative risk-based assessment of the bridge condition. This study was supplemented by a structural analysis of all major bridge elements. The results of this analysis were modified to incorporate current deteriorated steel and timber member properties. As-built information was included in the study and actual and allowable stresses were compared to determine overall bridge condition.

The results of the feasibility study showed that the bridge had reached the point where it would not be cost-effective to extend its life to carry the projected increased coal tonnages. Recommendations have been accepted by Solid Energy International and Tranz Rail Ltd. to strengthen the existing bridge in order to extend the life of the bridge for a limited period of time, while a replacement bridge is designed and constructed. The paper describes the history of the bridge, the methodology followed in assessing the condition of the bridge, results of the feasibility study and remedial work required.

## **1 BACKGROUND**

The current condition of the 1890 timber truss bridge has raised concerns regarding the ability of the bridge to carry current loads as well as potential increased future loads. A number of replacement bridge options have been developed by Tranz Rail, but the option of maintaining

and/or strengthening the existing bridge to provide an acceptable level of service had not been fully explored. Holmes Consulting Group Ltd. (HCG) was jointly commissioned by Solid Energy and Tranz Rail to undertake a feasibility study into life-extension options of the bridge ranging from 5 to 15 years.

The purpose of this feasibility study was to determine feasible, practical and economically viable options for upgrading and extending the life of the Cobden Bridge and to reduce the risk of unplanned outages. In developing these options it was acknowledged that both Tranz Rail and Solid Energy have real interests in finding a solution that makes commercial sense. The Cobden Bridge, which is maintained by Tranz Rail, is exclusively used by Solid Energy to transport coal from mines on the West Coast of the South Island. The bridge forms part of an overall commercial contract between Trans Rail and Solid Energy for making use of the Rapahoe Line which includes the Cobden Bridge. To achieve an acceptable solution it was necessary to undertake the study in close consultation with both Tranz Rail and Solid Energy to determine commercial break points that will set the operational constraints, timing constraints, and levels of investments acceptable to both parties.

The feasibility study included an initial qualitative risk-based assessment of the bridge condition, initially based on visual inspection of all members. This study was supplemented by structural analysis of all spans and the results of this analysis were modified to include current deteriorated steel and timber member properties taken from as-built information.

## **2 EXISTING BRIDGE**

The Cobden Bridge is located on the north-eastern outskirts of Greymouth on the Rapahoe Line and currently provides the link across the Grey River for Solid Energy to transport coal to Lyttelton Port. The bridge was built in the late 1890s and has been modified a number of times since then. The earliest entry in the Tranz Rail file dates back to 1950. Over the past 50 years the bridge has had extensive maintenance work performed. In plan the bridge has a double-S curve, is believed to be unique in the world. This feature is shown in Figure 1.



*Figure 1: Cobden Bridge showing unique S-curve*

At the Greymouth end, the bridge has a left-hand curve, while it has a right hand curve at the Rapahoe end and the centre section of the bridge is straight. There is a down-hill grade running towards Greymouth with the first two spans on the Greymouth side showing a steeper grade than the rest of the spans.

## 2.1 Bridge Structure

The Cobden Bridge is approximately 300m long and is made up of 80ft and 40ft timber truss spans and a small number of timber spans. The timber trusses include steel bottom cords and vertical ties to carry tension forces, while the timber truss members were designed to carry compression forces. The piers are made up of driven timber piles.

The superstructure comprises two 40ft timber trusses, nine 80ft timber trusses and four standard rail beam spans. The timber trusses are supplemented with steel bottom tension cords and steel vertical tie rods. The timber members are hardwood. Figure 2 shows detail of superstructure components of the 80ft spans.



**Figure 2: Truss Member Detail**

The substructure comprises predominantly piers with eight driven timber piles per pier, together with a number of trestle piers supporting the 40ft timber trusses. The piers in the river are further covered by timber shrouding which has two functions: firstly, the shrouding protects the piers from hydraulic and flood loads and secondly, the timber acts as additional bracing for the piles. The piles are braced through structural timber cross members attached to the piles on the inside of the piers. The total number of elements on the bridge exceeds 3000.

The timber trusses are made up of hardwood timber and the design of the trusses ensures that the timber struts and diagonals are in compression with tension forces taken up in the steel bottom cords and vertical steel ties. The transoms are also constructed from hardwood. Timber thrust blocks are found acting as a joint between the bottom chord, timber diagonals and the steel vertical ties. The trusses are braced horizontally through timber cross-bracing members and the top compression cords are braced through diagonal timber members connected to the transoms. Figure 3 shows typical details of pier elements.



***Figure 3: Typical Pier Detail & Transom Beams***

The original drawings of the bridge have been lost, but a limited number of sub-structure and super-structure drawings have been located. These drawings and the Tranz Rail maintenance and inspection reports provided sufficient information to undertake the feasibility stage structural analysis.

Information regarding timber pile embedment, the current river cross-section, and the condition of the piles underwater could not be confirmed. A risk-based approach was used in compiling a risk profile of bridge members and identifying most at-risk elements. This assisted in development of mitigating systems and procedures.

### **3 FEASIBILITY STUDY SCOPE**

The investigation aimed to identify elements of the bridge that introduce the greatest risk of an unplanned outage as well as early warning systems that can be implemented to prevent outages.

The study would also investigate the likely cost and timeframe for upgrading the bridge to 18 ton axle loads and extending its life for 10 years, as well as the implications to extend the life for an additional 5 years.

The feasibility study was undertaken in two stages. The first stage was a Scoping Report(1) which brought together current technical knowledge of the condition of the Cobden Bridge, as well as identifying the physical and economical risks. The Scoping Report identified immediate remedial work which had to be undertaken. The second stage comprised a full structural analysis undertaken to supplement the qualitative structural assessment completed as part of the Scoping Report.

The following is a summary of work included in the Scoping Report:

### **3.1 Structural Inspection / Condition Survey of Bridge**

- Review Tranz Rail maintenance and inspection records.
- Identify critical elements for additional investigation, i.e. steel corrosion, timber decay and connections.
- Identify critical elements in need of immediate strengthening and/or replacement (necessary work regardless of outcome of feasibility study).
- Develop structural models for analysis of live, seismic and hydraulic loading.
- Identify critical spans which have experienced permanent displacement horizontally and vertically.

### **3.2 Hydraulic Analysis**

- Review historical Tranz Rail design assumptions.
- Review design flood discharges for bridge crossing and comment on appropriate design discharge.
- Assess scour profiles.
- Evaluate free board and debris loading.

### **3.3 Operational Requirements**

- Review load restrictions on the rail network.
- Review Tranz Rail operational requirements.
- Review Solid Energy's current freight requirements and future demands.

### **3.4 Development of Risk-Based Decision Framework**

- Propose performance measures covering areas of cost (both capital and maintenance), structural, hydraulic, seismic, operational performance (in-service and under-construction), warning systems and any other measures identified.

### **3.5 Confirmation of preliminary cost estimates for a replacement bridge.**

- Review previous cost estimates of replacement options developed by Tranz Rail.

The results of the feasibility study showed that the bridge had reached the point where it would not be cost-effective to extend its life to carry the projected increased coal tonnages.

Recommendations have been accepted by Solid Energy International and Tranz Rail Ltd. to strengthen the existing bridge in order to extend the life of the bridge for a limited period of time, while a replacement bridge is designed and constructed. The rest of the paper describes the history of the bridge, the results of the feasibility study, remedial work required as well as detail of the proposed replacement bridge.

Given the length limitations for this paper it is only possible to highlight a limited number of aspects of the study outcome. More detail will be provided in the oral presentation.

## **4 FEASIBILITY STUDY RESULTS**

### **4.1 General**

The first stage of the feasibility study (Scoping Report) identified immediate remedial work which had to be undertaken in order to ensure the continued use of the bridge in the short term. It was deemed necessary to undertake this work regardless of the outcome of the feasibility study. The overall condition of the bridge, based on the qualitative structural assessment undertaken as part of the first stage of the study, suggested that the bridge had come to the end of its service life. Engineering judgement was applied to the results and initial conclusions were that, without going into extensive structural and economic analysis, serious consideration should be given to replace the existing bridge.

Given the increased projected tonnages of coal and the requirement for a reliable link over the Grey River, Solid Energy, as the sole user of the Rapahoe line, agreed to fund the design and construction of a replacement bridge. This decision was driven by the overall risk of unplanned outages of the existing bridge, high ongoing maintenance and strengthening costs and the fact that it would not be possible to economically upgrade the old bridge to carry increased axle loads.

Immediate repairs and strengthening work were initiated while further structural analysis was undertaken as part of the second stage of the feasibility study. Removal of deteriorated timber shrouding around the piers revealed previously hidden extensive deterioration of the timber piles. This was due to the steel spikes driven into the timber piles to fasten the shrouding. With increased access to the bridge members due to the contractor's repair activities, it became more evident that the decision to replace the bridge was justified.

Once the decision to replace the bridge was taken, the focus on the old bridge changed to one of doing what is necessary to keep it in a serviceable condition during the planning, design and construction of a new bridge. A target date of mid 2005 has been set for the closing of the existing Cobden Bridge, bringing to an end the very distinguished life of a historic bridge.

### **4.2 Evaluation of Existing Bridge Condition**

The condition of the existing bridge cannot be described in a simple way owing to:

- different span configurations,
- different types and modes of deterioration of materials, i.e. steel corrosion and timber rotting,
- load distribution on members and the capacity of the members to withstand the loads,



- effects of types of loading, i.e. vertical train loads, lateral hydraulic forces due to floods and debris, and extreme seismic events,
- historic maintenance and repairs done to date.

### **4.3 Methodology for Evaluation of Bridge Condition**

A two day inspection of the existing Cobden Bridge was undertaken during March 2002. The approach taken was to inspect all of the accessible bridge members, to capture data relevant to the current condition, and to evaluate overall structural response in service. In dealing with a unique bridge structure like the Cobden Bridge, an evaluation of the condition is based on a number of factors.

A visual inspection of the bridge is one component of the overall process of determining the condition of the bridge. A combination of visual condition rating, actual member deterioration as determined by Tranz Rail maintenance reports (including timber boring investigations) and structural analysis of the bridge were used to determine the current ability of the bridge to safely carry service loads. During the two days spent on the bridge the structural response of the spans under fully loaded trains was experienced. Where applicable engineering judgement and common sense have been included in the review.

The condition rating assigned to members inspected based on the Deterioration Likelihood Scale has also been compared to the latest Tranz Rail inspection reports. Where applicable the ratings provided have been adjusted to reflect the results of timber boring tests. This approach removes some of the uncertainties and limitations of a purely visual inspection. The difficulty with evaluating hardwood is that the deterioration does not start on the outside but rather from the inside, which makes it hard to evaluate a section on a purely visual basis.

As part of the Feasibility Study undertaken by HCG, the following method was proposed:

1. Physical & visual inspection of the bridge to record qualitative assessment of bridge members. (Refer to Figure 4 below)
2. Structural analysis of the superstructure (spans) and substructure (piers and piles) based on 16 ton and 18 ton axles.
3. Review of current Tranz Rail maintenance and inspection records including repair works undertaken during the last number of years.
4. Based on the deterioration of members (timber and steel), the structural analysis was modified to incorporate modified (reduced) section properties.
5. The condition of members was evaluated by comparing the actual stresses induced by the current maximum allowable axle loads (16.3 ton) to the allowable material stresses of the members. Where actual stresses exceed allowable stresses, the members must either be replaced or strengthened.
6. For certain members/elements decisions regarding replacement or strengthening were done based on visual condition, function of members and engineering judgement. Specifically, pier shrouding, horizontal truss bracing and pier bracing did not require analysis. Thrust blocks on the superstructure spans fulfil an important role in that they transfer and resist compression forces. Many of these timber blocks are in advanced

stages of failure as a result of increased axle loads, as well as frequency of trains and general deterioration over time.

7. Evaluation of the condition of the piles was made difficult due to accessibility, amount of debris around the piers and limited knowledge of the underwater conditions of piles. It was decided that, before exhaustive investigation and analysis were undertaken, a risk-based approach to the substructure would be explored with Tranz Rail and Solid Energy.

The outcome of this approach has been that monitoring systems have been put in place as well as mitigating procedures to ensure that, under extreme events such as large floods, trains would be stopped from crossing the bridge. Contingency plans for reinstatement of spans in case of an unplanned outage were prepared as well as short-term alternative trucking options for transporting coal by road. Essentially Solid Energy accepted that, given the short period of time till a new bridge is constructed, the commercial risks were acceptable compared to the cost of strengthening the substructure.

#### **4.3.1 Deterioration Likelihood Scale**

Each bridge member has been visually rated on a 5-point scale according to the likelihood that the level of deterioration would adversely affect the structural capacity of the member. The scale is outlined in Figure 4 below **Error! Reference source not found..**

| Score | Interpretation                                                                                                                                                                                                                                                                              |
|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Bridge member is in essentially “as new” condition with only minor signs of deterioration, if any. There is a rare chance that the deterioration will affect the capacity of the member relative to the design load.                                                                        |
| 2     | Bridge member is showing signs of deterioration. It is unlikely that the deterioration will affect the capacity of the member relative to the design load.                                                                                                                                  |
| 3     | Bridge member is showing signs of deterioration. It is moderately likely that the deterioration will affect the capacity of the member relative to the design load.                                                                                                                         |
| 4     | Bridge member is showing significant signs of deterioration. It is likely that the deterioration will affect the capacity of the member relative to the design load, and the member may need to be replaced in the near future – frequent monitoring for further deterioration is required. |
| 5     | Bridge member has deteriorated to such an extent that it is unlikely that it can carry the design load – the member has failed and needs immediate replacement                                                                                                                              |

**Figure 4: Deterioration likelihood scale**

Note: An assumption is made based on engineering judgement that, where a score of 3 has been given, it is assumed a member will remain serviceable for a further 5 years. This means that these members, with frequent monitoring and maintenance, would be able to perform for a maximum of another 5 years.



#### 4.4 Results of Study

The combination of qualitative inspection and detailed structural analysis confirmed that the most critical members were transom beams, rail beams and thrust blocks. Theoretically most of these members are under-strength and have to be strengthened or replaced. Figure 5 shows the condition of a typical thrust block.



*Figure 5: Deterioration of a Typical Thrust Block*

Truss steel bottom cords need to be strengthened to compensate for the loss of section through corrosion. The structural analysis identified a number of timber truss members which are overstressed and/or deteriorated.

A refurbishment programme of the vertical steel tie rods was undertaken, but not completed, approximately 3 years ago. The programme did not extend to the 40 ft trusses. In general these ties are in an acceptable condition; however when the thrust blocks are replaced, a better evaluation will be possible at the points where the rods go through the blocks to the transoms.

Since remedial work has started on the bridge, more piles have become accessible and, through removal of pier shrouding, it has become apparent that there is extensive deterioration of piles as well. Previously the condition of the substructure was judged to be reasonably good. Details of strengthening for these piles have been developed.

## 5 PHILOSOPHY TAKEN IN REMEDIAL WORK

The Cobden Bridge is quite unique in its construction and the fact that it is still carrying heavy loads is a credit to the design and dedication of people who have maintained this old bridge to date. The study confirmed that the bridge is not in a healthy state, although it has been and still is carrying significant loads. However, there is no doubt that during the last 5 years there has been a rapid deterioration of the structure.

The unique design features of the bridge unfortunately make its maintenance difficult. Historically, changing a vertical rod, compression strut or thrust block has been a major operation. It is not simply a case of undoing bolts, slipping old members out and new members in; internal forces have to be transferred to other members. Two additional factors play roles. Firstly, the bridge crosses a river which makes supporting the existing spans difficult. Secondly, operational requirements render complicated tasks more difficult in that there are no sustainable alternatives to transport coal and any work has to be done between trains.

A philosophy of developing design solutions with input from the contractor and previous bridge inspectors has been adopted. Furthermore, the inherent residual strength of the existing bridge members is recognised and, as far as possible, use is made of the strength of existing members which are not replaced unless absolutely necessary. In the case of transom beams a solution has been adopted which requires the addition of steel side plates to form a composite beam with the existing timber. In this way conservative assumptions have been made regarding allowable stresses in the timber which have resulted in a more cost effective solution. The further advantage is that the existing transom does not have to be removed, thereby eliminating the need for long blocks of line. Figure 6 shows a fully loaded coal train on the first of the 40 ft truss spans. Remedial work must be done while trains operate.



**Figure 6:**  
**Coal**

***Train on 40 ft Truss***

## 5.1 Extent of Remedial Work

The remedial work required can be grouped into two categories.

### 5.1.1 Remedial work not requiring design

- Removal of debris between piles to reduce the risk of damage during flood conditions.
- Renewal of horizontal- and knee bracing on spans to reduce the overall flexibility of the bridge superstructure.
- Removal and replacement of pier shrouding members to increase the protection of the piles under flood conditions as well as increase the lateral stiffness of the pier bracing. (Refer to Figure 7)
- Strengthening of approximately 6 piers by installing external steel cross bracing. (Refer to Figure 1)
- Strapping of piles where driven spikes have resulted in damage to piles though steel clamps in order to prevent further potential vertical splitting of the piles.

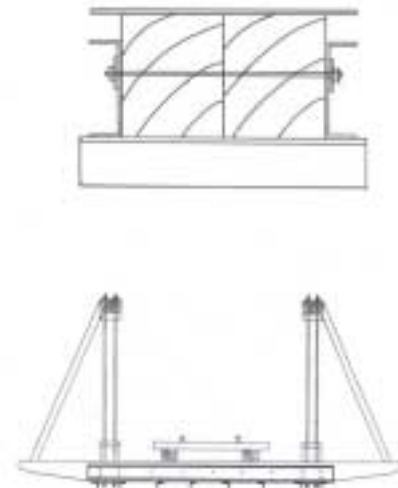


**Figure 7: Pier & Pile Bracing to increase Lateral Pier Stiffness**

### 5.1.2 Remedial work requiring specific design

- Strengthening of transom beams by adding steel flitch beams (Figure 8)
- Strengthening of the rail beams.
- Replacement and/or strengthening of timber thrust blocks.
- Strengthening of steel bottom cords where deterioration is becoming advanced.

- Overall strengthening of the piers by installing additional steel piles. This option has since been replaced by a risk-based methodology.



***Figure 8: Transom Beam Strengthening***

## **6 CURRENT PROJECT STATUS**

At the time of writing all work on the substructure has been completed and work is now underway on the superstructure. The focus is currently on transom beams, thrust blocks and steel bottom cords after which rail beams will be addressed. The contractor plays an important monitoring role, being on the bridge most of the time so that issues arising can be addressed immediately. The planning of the replacement bridge is in an advanced stage and expectations are that the new bridge will be tendered by mid-2004.

## **8 ACKNOWLEDGEMENTS**

Information used in preparing this paper has been sourced from Tranz Rail historical data, maintenance records and as-built information. A number of presentations prepared for Tranz Rail and Solid Energy have also been used. The authors acknowledge and thank both Tranz Rail Ltd. and Solid Energy International for the release of information used in this paper.

## **7 REFERENCES**

- 1 “Cobden Bridge Life Extension, Bridge 1 Rapahoe Line, Greymouth”. *Feasibility Study: Stage 1 Scoping Report, April 2002*