CONCRETE MAINTENANCE TIES – INTERSPERSAL IN EXISTING WOOD TRACK

Stephanie Haenny – Rocla Concrete Tie, Inc. (RCTI)
John Bosshart – Burlington Northern and Santa Fe Railroad

ABSTRACT

Cross ties are a constant focus of track maintenance programs as railroads continually strive for improvement. Cross ties are not the most expensive track structure component, yet their performance plays a vital role. Traditionally the wood cross tie has been the predominant cross tie of choice, however, increasing economic, environmental, and performance pressures have led railroads to look for alternatives.

In 1999 the Burlington Northern and Santa Fe Railroad (BNSF) expressed a strong interest in finding an alternate material cross tie that would be compatible with, and could be interspersed with, wood ties in existing wood tie track. They wanted a cost competitive cross tie that could be used in their standard maintenance programs. This paper discusses the concrete Maintenance Replacement Tie (MRT) developed by RCTI in the USA and Rocla Sleepers in Australia.

INTRODUCTION

In 1999 the Burlington Northern and Santa Fe Railroad (BNSF) expressed a strong interest in finding an alternate material cross tie that would be compatible with, and could be interspersed with, wood ties in existing wood tie track. They wanted a cost competitive cross tie that could be used in their standard maintenance programs. In Australia, Rail Infrastructure Corporation (RIC) had expressed similar interest several years earlier.

Using information that had been gathered between 1996 and 1999, a Project Team was put together with members from Rocla Concrete Tie, Inc. (RCTI) in the USA, Rocla Concrete Sleepers (Rocla Sleepers) in Australia, and Rocla Technology also in Australia; its sole purpose to expedite development of the concrete maintenance replacement tie in Australia and in the USA.

This paper discusses the concrete Maintenance Replacement Tie (MRT) developed by RCTI in the USA and Rocla Sleepers in Australia. Included is a development summary with details from key field tests, cross tie design and fastenings.

DEVELOPMENT SUMMARY

Strategic Field Tests - Australia

The first field tests for the MRT developed by RCTI and Rocla Sleepers took place in Australia. The following is a description of several of the first key tests on the RIC.

Gunning, NSW

This section of track on RIC's Main South sees 6 MGT per year, 10 to 14 trains per day, 40mph (65 kph) mixed freight and 45 mph (70 kph) XPT passenger trains. Tie spacing is 24 inches (600mm).

This test site has poor ballast conditions, with expected tie life not to exceed 15 years. Due to poor condition of the wood ties, the RIC Asset Manager had been unable to hold gauge in this section of track. In September 1999, 1,000 concrete ties were installed at this location, every fourth wood tie being replaced by concrete.

Remaining wood ties have tie plates with 2 cut spikes and 2 lock-spikes each. The concrete maintenance replacement ties or "partial replacement sleepers" (PRS) are similar in size to the wood ties; 7 in. (178mm) deep and 8 ft. 3 in. (2510) mm long. They have Pandrol e-clip shoulders.

Standard Pandrol e-clips, tie pads and insulators were initially installed with the ties. However, since the PRS were used to correct a problem with back canting and bring back rail gauge, the standard insulators quickly failed and were replaced with reinforced "heavy duty" insulators. The heavy-duty insulators worked and have held to date. According to an RIC Asset Manager in April 2002, the PRS were holding up well, providing lateral stability, maintaining gauge, line and surface, and saving money in track maintenance.

Thirroul, NSW

Fluor Australia, a private infrastructure maintenance provider, has held a contract with the RIC to maintain the Waterfall to Bomaderry line, in the Wollongong region, just South of Sydney. This line sees 10 - 12 MGT mixed freight and passenger trains. At the start of their maintenance contract, Fluor strategically invested in upgrading portions of this line to reduce their long-term maintenance costs. Improvements included the installation of 5,000 PRS in August 2001.

These ties were installed in 1:4 pattern in tangent track. Existing wood ties had Pandrol plates with wide gauge; the PRS was used to bring back and hold gauge. A 1:4 pattern was initially tried in the curves, however, it was discovered that this put too much stress on the elastic fastening system. Therefore, a 1:2 pattern was used in the curves. Remaining wood ties were redrilled and the Pandrol plates respiked after installation of the PRS.

Experience gained from additional trials after Gunning led to a RIC decision to intersperse the PRS in a set pattern rather than randomly. The RIC Engineering Standard established at this time is summarised as follows: In tangent track the minimum standard pattern is 1 in 4, however, variances of 1 in 3 or 1 in 5 are allowed in small patches to assist with the change out of life expired wood ties. The standard pattern in curves is reduced to 1 in 3 or 1 in 2 to further assist with gauge retention.

Australian PRS Program Summary

The 7 in. (178mm) deep PRS is no longer considered a test product in Australia. However, it should be noted that many of the PRS have been installed out-of-face; replacing wood ties altogether in track locations that do not see high tonnages. In these applications, the concrete PRS are being referred to as Low Profile, “medium duty” Concrete (LPC) sleepers. By the end of the year, 2003, Rocla Sleepers will have produced close to 480,000 low profile sleepers. There are plans to install 40,000 PRS in programs prior to the summers of 2003 and 2004 as interspersed ties on the Main South in similar track conditions to the original nearby Gunning test site. The first 40,000 PRS program has already been completed between Breadalbane and Galong, south of Goulburn, with the work commencing in July 2003.

Strategic Field Tests – United States

Transportation Technology Center Inc. (TTCI) - Pueblo, Colorado

Results at Gunning encouraged RCTI to run a test at the Transportation Technology Center (TTCI) in Pueblo, Colorado. While additional field tests were proceeding in Australia, testing at TTCI enabled the MRT to quickly accumulate higher tonnage while being monitored for stresses. BNSF needed the tie to withstand higher tonnages than RIC, and TTCI testing helped give BNSF the confidence they needed to proceed with field testing within their system.

In January 2001, 24 MRT, 8 ft. 3 in. (210mm) long were installed in tangent track in Section 33 of the High Tonnage Loop at TTCI. Tie spacing is 19.5 inches (495mm), with every fourth tie being concrete. The wood ties are fastened with cut spikes; the concrete ties have Pandrol Safelok elastic fasteners.

Tonnage accumulated on the MRT as of October 2002, was 105 MGT. Though no longer monitored, these ties are still in track. The ties performed well for this test; there are no fastening system problems. There is some evidence of ballast settlement around the MRT; however, the test zone has held surface and alignment without additional maintenance.

Dumas, Texas

In June 2001, 25 MRT were installed in BNSF track. This is Class 4 tangent track on the Boise Subdivision in the Texas panhandle, with 49 mph (78 kph) mixed freight traffic, 14 MGT. The Roadmaster marked wood ties that had failed due to centre bending for removal; the MRT were installed randomly rather than in a set pattern.

During installation, it became immediately evident that there was a problem with fitting the 132 RE rail base between the Safelok shoulders in the ties. Rail gauge was correct; however, due to a slight “over cant” caused by plate cutting, the rail base measurement was wide. This over cant created an out to out rail base measurement that averaged ¼ inch (6.25mm) wide.

The wide rail base gauge had not been anticipated and therefore created a delay in the installation. When the installation was completed the MRT ended up with custom thin post insulators on the field side and wide post insulators on the gauge side of the rail.

Upon completion of this test installation the following fastening questions / issues were raised:

1) Should the fastening components on the concrete ties have the responsibility to “force” the rail base back to the proper position and cant or should the fastening components try to accommodate the existing rail base location? Unlike traditional concrete tie out-of-face installation (P811S or new construction), the rail base as it sits on existing wood ties, may not be in the correct position. Even if rail-head gauge is accurate, there may be back canting or the rail may have rolled inward causing the rail base to be out of position.
2) If MRT are going to be used to bring back gauge, can the elastic fastening components withstand the additional lateral forces? Forcing the rail base back into position might induce additional stress on adjacent wood ties and the rail, while trying to accommodate varied rail base widths in the field might prove to be too complicated.
3) If the cast-in shoulder spacing is adjusted to accommodate varied rail base locations, how much variance could be practically accommodated?

4) Can cast-in shoulder spacing and other fastening components be adjusted to accommodate both 6 inch (150 mm) and 5 ½ inch (140 mm) rail base?

At this time, input provided by both fastening companies was critical to advancement. Both Pandrol and Airboss were brought in to the Project and consulted separately. Their ideas were put to use for the next phase of MRT testing.

Clarendon, Texas

Clarendon is on the BNSF Red River Valley Subdivision and sees 52 MGT of BNSF freight traffic (foreign traffic not included) per year. Trains are mixed freight and coal trains; maximum freight speed is 49 mph (78 kph).

In May 2002, 50 ties were installed in tangent track. The focus of this test was on fastening components; their relationship with the rail base and installation requirements. Different interspersal patterns were also set up. Using the experience gained in Dumas, the 50 ties had various cast in shoulder spacings and various insulator/clip configurations to accommodate 132 RE rail. Airboss and Pandrol provided fastening components for 25 ties each. Rail base measurements were taken prior to installation of the ties and ranged from 1/8 inch (3.8 mm) narrow to 1/8 inch (3.8 mm) wide. Results from this test were charted and reviewed with Airboss and Pandrol. The final fastening configuration is detailed in a later section.

Some lateral tie adjustment was needed to install elastic fastening components properly. This was done manually with hand tools. A hydraulic rail positioner that could manipulate the rail and / or the tie so that insulators could be properly installed would have been useful.

As of July 2003, no significant stress problems could be seen on the MRT, wood ties, or the fastening components. Feedback from the Roadmaster has been positive.

Centralia, Illinois and Lafayette, Louisiana

In June 2001, after the Clarendon test, BNSF committed to a large-scale test installation using an 8 ft. 6 in. (2.59 metres) MRT design. BNSF chose two locations for a test installation of 10,000 ties each; to test the feasibility of installing MRT using conventional tie gangs and equipment, and to provide a better opportunity to observe performance of the MRT in more realistic and challenging conditions. Larger scale tests also allow for a more accurate comparison of the performance of MRT and wood ties in rigorous environments and for a more accurate comparison of maintenance issues that would arise from interspersing MRT. These two test installations are described in detail further in this report.

TIE DESIGN

Cross Tie

RCTI's US concrete maintenance replacement tie is 8 ft. 6 in. (2590 mm) long, 7 in. (178 mm) deep, and 9 in. (229 mm) wide at the base. It weighs approximately 525 lbs (238 kg). This tie has been designed to match wood tie dimensions as closely as possible. Figure I.

A Finite Element Analysis (FEA) program was developed by Rocla Technology as a design aid to look at stresses and deflections in interspersed concrete ties and in wood ties under different loading conditions. Different model runs were made interspersing MRT with wood in patterns from 1:3 to 1:5. Different track stiffnesses were also looked at, including track modulus of 3,000 lbs/in/in (21.4 MN/m/m) and 6,000 lbs/in/in (42.8MN/m/m). Figure II shows one example of an FEA model run with 8 ft. 6 in. (2.59 metres) MRT interspersed in a 1:5 pattern, and a track modulus of 3,000 lbs/in/in (21.4 MN/m/m). The results from this example were compared to a similar analysis for an 8 ft. 3 in. (2.52 metres) MRT. The analysis showed a reduction in the top centre tensile stress from 940 psi (6.5 MPa) in the 8 ft. 3 in. (2.52 metres) concrete tie to 522 psi (3.6 MPa) in the 8 ft. 6 in. (2.59 metres) concrete tie.

Strain gauge measurements were taken from 4 of the 24 MRT at TTCI. Strain gauges were placed on the top surface of each of the 4 ties at the centre and at each rail-seat. Measurements were taken at different stages throughout the test as the TTCI train passed over at 40 mph (64 kph). An example of stresses calculated from these measurements is summarised in Figure III. These stresses are similar to measurements taken at Gunning, see Figure IV, and do not exceed allowable stresses in the ties.

The readings obtained at TTCI show that tensile stresses at the centre top surface of the MRT, caused by centre negative bending moments, are the critical design stresses. Figure III shows maximum centre bending stresses and equivalent bending moments needed to create these stresses. Observe that the equivalent bending moments do not exceed the design centre negative bending moment calculated using AREMA Chapter 30, Section 4.4.1.2, for out-of-face concrete ties spaced at 19.5 inch (495 mm) centres, 65 MGT, 40 mph (64 kph) and 39 ton (35 tonne) axle loads.

It is anticipated that the MRT will be interspersed in wood tie track with the following properties: secondary mains or mains with lower tonnages of 20 to 40 MGT; primary freight traffic with speeds of 50mph (80 kph) or less; medium to low quality ballast conditions with minimum annual maintenance, and deteriorated wood ties with short life expectancy. It can be assumed that these track properties will contribute to an increase in the centre negative bending moments in interspersed concrete ties. This, in addition to a proportionally greater load carried due to its greater stiffness, in respect to remaining wood ties, strongly suggests that the centre bending capacity of the MRT needs to be maximized. The data collected from TTCI and from Gunning supports this assumption along with Rocla Technology FEA model runs. All data collected supports maximising the centre negative bending moment capacity in the MRT.

Elastic Fastening Components

In the US, the MRT's elastic fastening system consists of components from "off the shelf" current technologies; it can be manufactured with either Pandrol Safelok or Airboss shoulders. Shoulder spacing can accommodate standard insulator post widths of 6.8mm. Special wide post and narrow post insulators are also available, allowing up to ¼ inch (6.3 mm) field adjustment for wide or narrow rail base gauge. This shoulder spacing will allow for both 6 inch (150 mm) and 5 ½ inch (140 mm) rail base with similar adjustment.

Rather than force the rail base back into its correct nominal position BNSF has made the decision to try and accommodate the location of the rail base in the field. Even though this has created logistical problems during installation, it helps prevent the creation of additional lateral stresses in the insulators, the rail, and in adjacent wood ties. If the rail is later replaced, this system also allows for new rail to be properly positioned by simply replacing the insulators.

It is important to note that the approaches chosen by BNSF in the US versus RIC in Australia are different. RIC has chosen to use the MRT and its fastening system to correct gauge problems and to bring the rail back and hold it in its proper position. After PRS is installed, tie plates on the remaining wood ties are typically adjusted and respiked for gauge and spacing.

BNSF LARGE SCALE TEST INSTALLATIONS

The goal was to find two test locations that would maximise all the possible challenges that the MRT could encounter. Those challenges include short wood tie life, and high rot, in a medium tonnage non-critical route.

Centralia, Illinois – The first 10,000 ties

Where, When, How

The Beardstown subdivision, Centralia, Illinois to Paducah, Kentucky route, has an average tie life of 20 years because of the humid environment and 23 MGT of predominantly unit coal train business. Loaded trains weigh 18,700 tons (16,965 tonnes) and empty trains are 4,000 tons (3,629 tonnes). Track speed is 50 miles per hour (80 kph) and the trains are equipped with rear end distributed power. 1,000 - 1,500 ties per mile (622 to 932 per km) are replaced each cycle and cycles are every 8-10 years.

Subgrade problems have been evident over this route for many years as fine soils are mixed with rains brought on by the effects of the Ohio and Mississippi Rivers. Shoulder ballast cleaning is almost an annual event in an effort to keep drainage open.

This project consisted of 19,000 ties originally planned for installation in September 2002 by a traditional mechanised wood tie gang. However, installation took place between November 11 and 27 2002. The 10,000 MRT were installed at the end of the project.

A traditional mechanised tie gang (TP2) has 47 persons and the following 28 pieces of equipment: 2 anchor spreaders, 4 spike pullers, 3 tie handlers, 3 tie inserter / removers, preplate machine, spike reclaimer, 4 double spikers, 2 anchor squeezers, 2 ballast regulators, 3 tampers, 1 double broom, 1 track stabiliser. When the MRT were installed, the gang stored the spikers and added 2 scarifiers and one clip machine. Many concrete tie hand tools were also added. Production with the MRT started with only 300 ties per day but after three days the production averaged 1,000 ties per day. The eight-hour daily production work windows were exceptional.

Material Distribution

The ties were distributed ahead of the tie gang using P811S concrete tie flat cars with a Herzog grapple equipped gantry. The gantry picked up five ties with each lift. Clips and insulators were distributed with the tie gang. Tie pads were distributed two different ways. Initially pads were adhered to the concrete tie rail seats, but because of handling and weather conditions it was recommended that in the future, the tie pads should be distributed by the tie gang, in an attempt to avoid the pads being dislodged and lost.

Evaluation

MRT distribution, installation, and clean up went as planned. Overall however, the timing of the installation (freezing weather and snow) and the spring rains had taken their toll. Was the track properly surfaced after installation? A surfacing gang followed within one month of the installation, but because of weather, tamping was not adequate.

Not only MRT but also wood ties have developed severe mud spots. The sub grade does not drain in all locations. The ballast shoulder becomes fouled easily. The entire Beardstown subdivision normally has shoulder ballast cleaning every two years. Every year the maintenance of way crew has a backhoe removing mud spots.

The mud appeared with the concrete ties in very roughly 1% of the MRT. The constant pressure exerted by the rail clips to the tie gave a constant motion to move the mud and water. The wood ties are held with track spikes and as a result 'breathe' except if the rail uplift exceeds ¼ inch (6.35mm) to ½ inch (12.7mm) of motion. If there is a propensity for mud pumping, the concrete ties seem to aggravate the problem sooner. Installation of multiple consecutive or nests of concrete ties appear to increase the likelihood of mud problems appearing.

Mud appeared in existing wood tie locations even though the ballast was not disturbed. The Roadmaster, reported of locations where new wood ties installed in similar conditions had only lasted one year. There are a number of solutions to remove the mud however it is not related to the installation of the MRT.

What was learned from the Centralia, Illinois location that can be applied toward the installation in Lafayette, Louisiana?

1) Tie pads will not be shipped with the MRT. The tie pads will be distributed as the ties are inserted.
2) Soil conditions may be very similar to Southern Illinois, thus it is essential that tamping be thorough. It is also recommended that no more than 3 MRT be inserted consecutively during initial installation.
3) Attenuating tie pads are recommended to reduce the impact loading to the subgrade.

Lafayette, Louisiana – The second 10,000 ties

Where, When, How

The Lafayette, Louisiana Subdivision has a creosoted wood tie life of 10-15 years. The climate is humid coastal and tonnage is roughly 22 MGT of BNSF 60 mph (96 kph) mixed freight business, along with AMTRAK trains at 70 mph (112 kph) six days a week. Additional foreign tonnage is not included. 1,200 - 1,500 ties per mile (750 to 938 ties per km) are replaced each cycle and cycles are every 8-10 years.

Ballast conditions are poor with fine wet soils fouling the ballast. However, there are no major subgrade problems in this route; this section actually drains better than the test section in southern Illinois. The Roadmaster reported that shoulder ballast cleaning has not occurred for over 6 years but even with heavy rains, drainage is generally not a problem.

This 27.3 mile (47.3 km) maintenance project had a total of 40,000 new ties installed. In addition to new wood ties, 10,000 MRT and 2,000 plastic composite ties were installed. The start of project installation was June 9 2003. Inclement weather slowed production throughout the duration of the project.

Plasser's automated THS 2000 tie gang was used for this project. The 35 member tie gang was modified to accommodate the MRT as follows: The front of the gang is very much like a traditional tie gang. The spikes are removed with 2 spikers and 1 spike reclaimer, the selected old ties are removed with 2 "Tie Knock Outs" (TKO's) and 1 tie crane, and anchors are removed with 1 anchor squeezer spreading field side of anchors only. One Plasser Crib Master is used in lieu of scarifiers. The MRT are carried to the site in custom gondolas attached to the insertion unit; a gantry moves the ties ahead toward the inserting system. An elevator lowers the ties and drops the ties on the rail above the insertion location. Two inserters then place the tie part way into the hole. Following the inserters a few cars equipped with a Herzog car topper pick up the scrap ties and load them into the emptied gondolas. After the rail seats are cleared of debris, tie pads are put into place and a trailing tamper-nipper machine finishes sliding the MRT under the rail and then lifts and tamps the tie tight. Trailing equipment completes the installation with a Herzog clip and insulator machine. The quality crew follows with a Kershaw clip machine and various hand tools. Following the gang is a production tamping consist with tampers, regulator and stabilising equipment. In summary, the traditional gang can enter a new area daily, install and remove wood ties, leaving the site completed and neat.

In order to accommodate the elastic fastening system on the concrete ties the spikers were removed from the traditional consist and a Herzog clip and insulator machine was added.

Daily tie gang production can be as high as 2,000 ties with the traditional system but the system daily average for 2003 is expected to be roughly 1,300 ties. For this project, 350 MRT were installed on the first day, with a maximum daily production of 905, and an average daily production of 700. As many as 1,700 ties per mile (1,063 per km) were replaced in some track sections. The lower numbers were influenced by weather, crossings and turnouts encountered in the town of Baldwin, Louisiana and the poor condition of the wood ties. The average work window was six hours.

Material Distribution

All material distribution is done with the THS2000 and the Herzog clip and insulator machine. Both the new and old (removed) materials were all carried by the gang to the specific work location each day.

Evaluation

Distribution, installation, and clean up worked well, however, overall installation was slower than expected. The tamper-nipper was key to placing ties under the rail and tamping up without getting debris in the rail-seat. However, the ballast removed from extra cribbing to get ties in, combined with the high number of ties removed and poor ballast conditions slowed the tamping process.

The Herzog clip and insulator machine was not designed for this use and did not work well. Lateral positioning of the tie, placement of insulators, and clipping slowed overall production.

ECONOMICS

Where and how ties are marked

If everything was perfect and wood rot / deterioration was a linear function then you could replace every third tie in each replacement cycle. However wood deterioration is on a distribution curve that could show a very small percentage of the tie failing very early and a very small percentage of the ties failing long after the theoretical average tie's life. BNSF established the policy of replacing failed ties only if the ties are consecutive (a maximum of three consecutive ties). Theory supports replacing a third of the ties, however, BNSF does not intend to replace a tie before its life has expired.

It is assumed that MRT installed in the first phase replacement cycle, will extend life of remaining wood ties. During the second phase tie replacement program a more even distribution may be considered. This would allow an almost random tie replacement as would be expected in a normal wood tie replacement program. BNSF "Tie Inspect System" is used to inventory every tie and will continue to play a strong role in replacement strategy in the future.

Net Present Value (NPV) Study

An economic (NPV) study would include the following considerations:

1. Interest rate
2. Tie life projections (wood & concrete)
3. Tie density per mile (or kilometre)
4. Daily gang production
5. Transportation costs (ties per car, distance) Wood tie versus Concrete tie
6. Gang equipment and costs required (wood & concrete)
7. Gang manpower and costs (ties per car, distance) required (wood & concrete)
8. Tie unloading costs
9. Tie cost (including fasteners as required for the concrete ties)
10. Tie disposal costs. These costs would be the same until all the wood ties are removed then this expense would disappear.
11. Credit (if any) for wood tie materials freed by the installation of the concrete ties. As an example: Scrap value for the rail anchors and track spikes. The tie plates will have a second-hand (SH) value as they can be reused at another location if they are 6" (150mm) base rail plates and 7.5" x 13" (191 mm x 330 mm) minimum size.
12. If the tie gang production is not equal on a per hour basis then it is appropriate to show train delay cost. In this case we showed that equal tie gang per hour production is expected.
13. Depending on your tie life you develop a NPV expense stream for each year over the life. Thus if you have a wood tie life of 15 years then an expense is entered for each year over the 14 year period. If the concrete tie life is expected to be a minimum of 30 years then develop that expense stream except that you may have expenses for only the years that you remove the wood ties.
14. Table I depicts a tie replacement strategy and would also coincide with tie disposal costs. It is projected that the remaining wood tie life will be extended by having consistent strong adjacent ties.

CONCLUSION

Is the concrete maintenance replacement tie (MRT) a viable option? Problems that arise through development of the MRT are being resolved and steady progress continues to be made. Contributing to the success is the inherent strength of the concrete tie, and the elastic fastening system.

BNSF will conduct additional field-testing with out-of -face installations of MRT to further evaluate performance. Another test installation under consideration would include “surgical” spotting of MRT in a 1:3 or 1:4 pattern, followed by installation of new wood ties to replace all other expired wood ties.

Field tests in Australia show that the MRT is:

- Working well in all applications,
- Prolonging life of remaining wood ties, and
- Helping to hold gauge and track surface.

Sites where the MRT is interspersed are not showing any signs of detrimental wear on rail, ballast, or remaining wood ties.

Field tests in the US show that the interspersed concrete tie appears to be working well under higher tonnages. The initial outlook is positive, however additional time is needed for true evaluation of performance in the rigorous climates of Centralia, Illinois, and Lafayette, Louisiana.

ACKNOWLEDGEMENTS

The assistance provided by Burlington Northern Santa Fe Railroad and Rail Infrastructure Corporation employees during all phases of field-testing is gratefully acknowledged.

Year	Wood ties required for maintenance of one track mile	MRT required for maintenance of one track mile
0	1067	1067
7	1067	
9		1067
14	1067	
19		1067

Assumptions:

One mile (1.6 km) of track with tie spacing at approximately 20 inches (508 mm).

1/3 of wood ties, in one mile of track, are replaced every 7 years, after three cycles all ties replaced by year 14.

Installation of MRT will extend following replacement cycle by 2 years.
[NOTE: Table 1 to be consolidated as illustrated]

Table I. Comparison of tie replacement schedule for NPV economic study

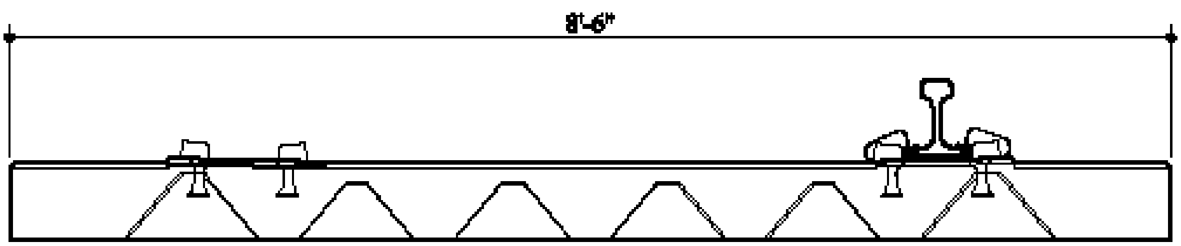


Figure I. 8 ft. 6 in. (2591 mm) concrete maintenance replacement tie (MRT)

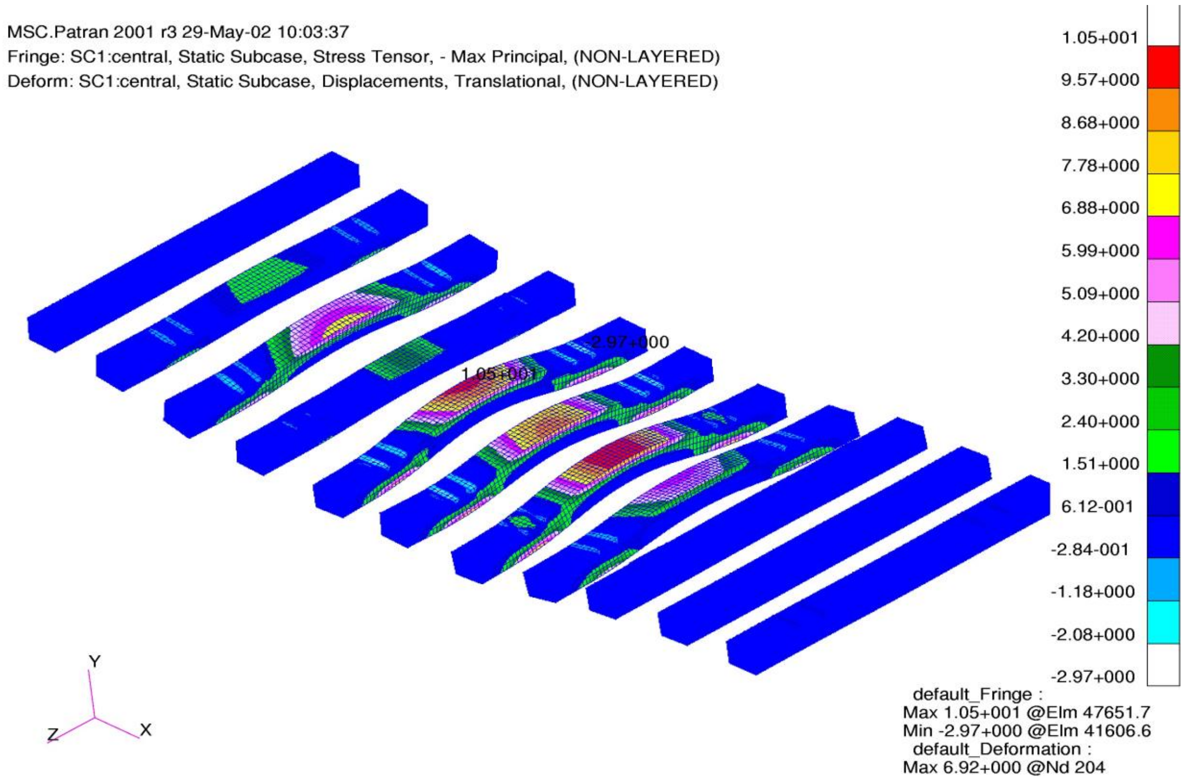
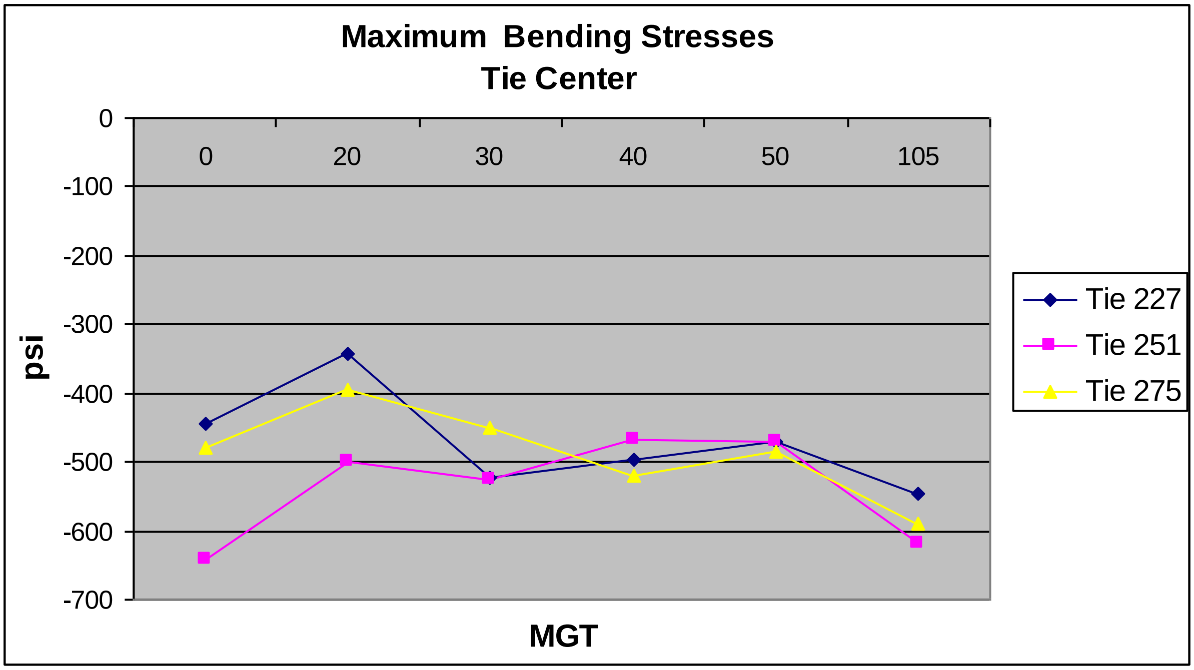


Figure II. FEA Model – 8 ft. 6 in (2591 mm). MRT interspersed with wood in 1:5 pattern, K = 3,000 psi (219 MPa)



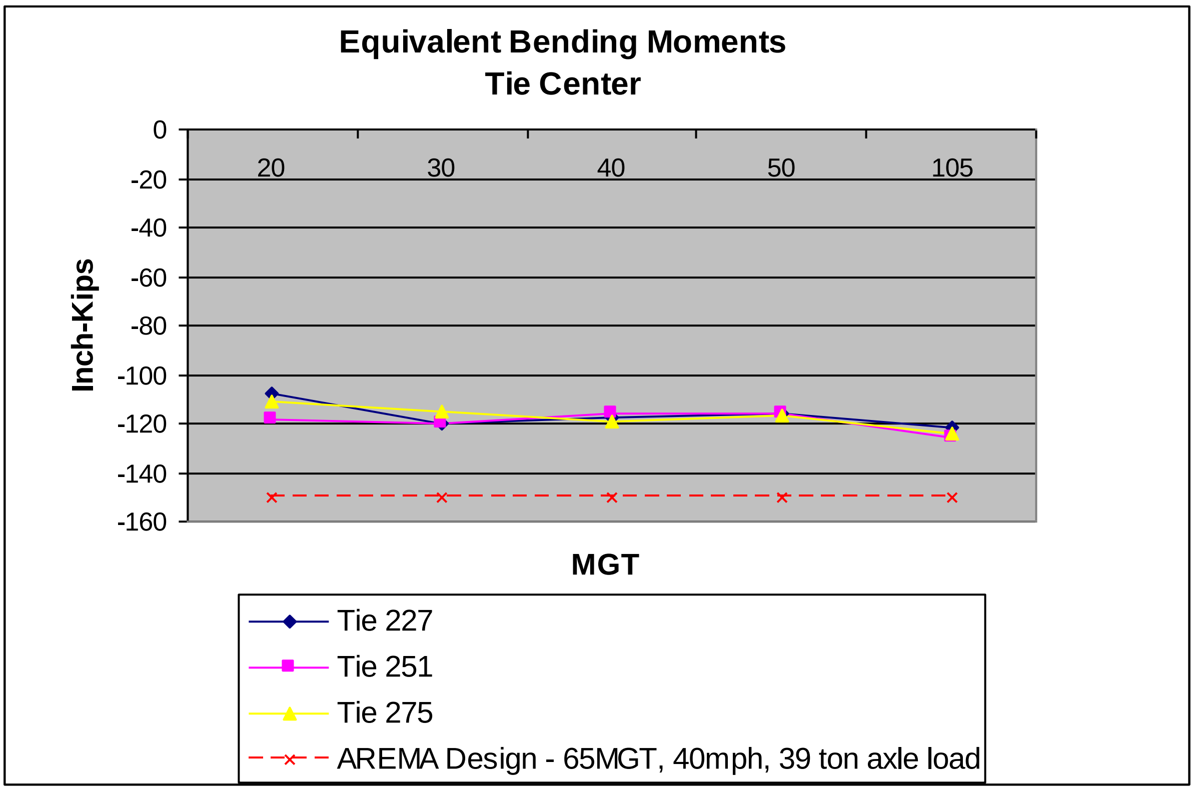


Figure III. Results from MRT Strain Measurements at TTCI

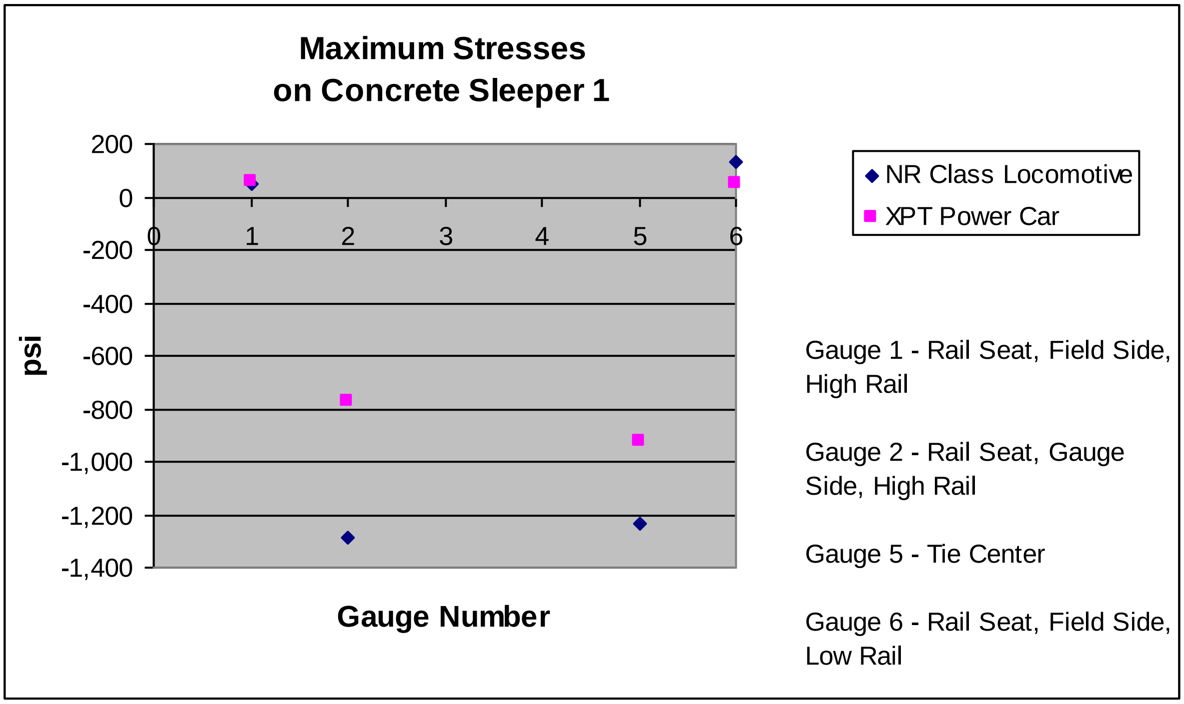


Figure IV. Results from PRS Strain Measurements at Gunning, NSW

Figure V. Installation at Centralia, Illinois-Mud Spots: MRT in main track, wood ties in siding

Tables

Figures