CONFIDENTIAL

TECHNICAL SERVICE BULLETIN no: 90-05-1

subject: NONDESTRUCTIVE EVALUATION OF BRIDGES AND OTHER STRUCTURES made from wood and concrete	prepared for: Trac-Work Inc.- W.M. Bush
	prepared by: Harry T. de Beer
	date ...... : February 10, 1990

The integrity of bridges deserves close attention. Like other types of civil structures they are vulnerable to deterioration - as a result of operating conditions and environmental conditions. In the case of wooden bridges, components are subject to decay and mechanical destruction. Concrete bridges are subject to erosion, chemical attack and mechanical destruction. For these reasons bridges are inspected on a regular basis. This inspection consists mainly of visual examination of critical components. De Beer Applied Research has developed a special and innovative method to test the critical components of wooden and concrete bridges. The applied technology is old and proven; dating back to the late Thirties.

The method is based on sonic principles. Sonic compression waves travel through wood and concrete at specific velocities, and are subject to known attenuation or absorption - depending on the species and preservative treatment of the wood, and the type of concrete. Changes in material properties - decay, mechanical destruction and defects - change this velocity and attenuation. This change is proportional to the severity and extent of the decay, mechanical destruction and defects. The sonic wave is sent through critical parts by placing search units against the surface of the component at opposite ends of the suspected area. One search unit transmits the wave, while the second one receives it; after it has or has not been affected by material changes. Figure 1 shows two typical sonic wave paths: one travelling (from the transmission to the reception search unit) through a pole that contains decay, and one travelling through a square components that contains tension cracks. the sonic wave can be made to travel either through the interior of a component or along its surface. To complicate matters, in the case of wood the wave can be made to travel through the interior three different ways: radially - through the center of the wood or pith and across the grain, tangentially - along annular or growth rings and across the grain, and longitudinally - from end to end and along the grain. Figure 2 shows types of scans in wood except for the longitudinal scan, which is not a practical scan for nondestructive evaluation of bridge and other structural components. Figure 2 also shows the sonic wave path in relation to the annular growth rings and, in the case of the surface scan, the grain orientation. It is important to note that the specific velocity is different for each type of scan.

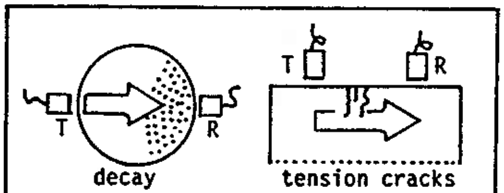

fig 1: TYPICAL SONIC WAVE PATHS

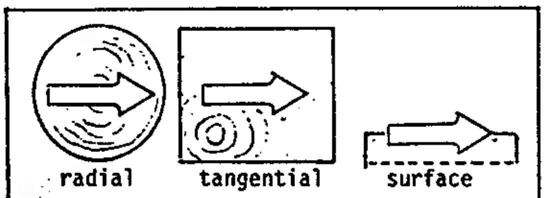

fig 2: TYPES OF SCANS IN WOOD

The purpose of nondestructive evaluation of bridges and other structures is to determine the condition of components: bents, piles, stringers, trestles, trusses, etc. - for maintenance reasons. Except in the case of failure investigation, only typical vulnerable locations are tested. See fig 3. It shows a beam or stringer supported by a pile. Scan 1, a surface scan along the top of the beam and near its center, looks for compression damage parallel to the grain. Scan 2, a surface scan along the

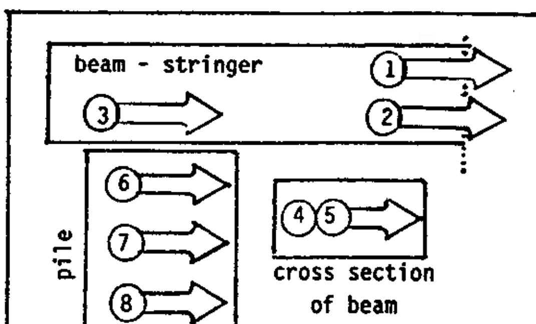

fig 3: SCAN LOCATIONS

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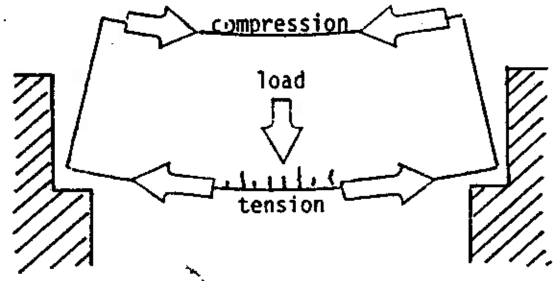

fig 4: A LOADED BEAM OR STRINGER

bottom of the beam and near its center, looks for tension damage (transverse cracking) parallel to the grain. Scan 3, a surface scan along the bottom of the beam where it rests on the pile, looks for mechanical destruction (crushing.) Scans 4&5, through the interior of the beam at Scan 2&3 locations, look for decay and internal defects. Scan 6, through the interior near the top of the pile, looks for mechanical destruction caused by compression parallel to the grain, decay, and internal defects. Scan 7, an interior scan halfway up the pile - other than looking for decay and internal defects - serves as a reference scan; to measure the specific velocity and attenuation at a less vulnerable location. Scan 8, an interior scan as close to the groundline or water level as possible, looks for decay, internal defects, erosion, and physical damage.

Nondestructive evaluation of a bridge or structure is a rather simple operation; provided that it is organized properly and in conjunction with the owner-operator's maintenance staff. Following is a step-by-step sequence of events.

Step 1 is to prepare a workplan that identifies which components are to be tested, which support services (scaffolding, lifting devices, flotation devices, etc) are required, and how long the actual test program is going to take.

Step 2 is to make critical components (beams, piles, supports, etc) accessible; if these are higher off the ground, water, or other access than a person can reach. This may require a ladder, scaffolding, mechanical lifting equipment, flotation devices, etc.

Step 3 is the actual nondestructive evaluation or testing. This requires a thoroughly trained technologist, a helper, and the necessary instrumentation. (This instrumentation is battery-powered and portable.) The technologist identifies critical components and locations to be examined, presses the transmission and reception search units (at opposite sides of these locations) against the component, and notes the data provided by the instrumentation. The instrumentation electronically:

- measures the velocity of the sonic wave (high is good; low is bad)
- measures the attenuation of the wave (How much energy was absorbed by decay, defects, etc.?)
- shows, on a cathode ray oscilloscope, what affected the velocity and attenuation

Step 4 is reporting. Reports list - for each component that has been subjected to nondestructive evaluation - the following information:

- its condition: acceptable, marginal, or unacceptable
- if identified: a probable reason for this condition - qualified and quantified
- the component's life expectancy under prevailing operating and environmental conditions
- maintenance recommendations: repair, replace, or re-subject to nondestructive evaluation after so many months or years

DE BEER

CONFIDENTIAL

TECHNICAL SERVICE BULLETIN no: 90-04-1

subject: NONDESTRUCTIVE EVALUATION OF WOOD RAILROAD TIES	prepared for: general distribution
	prepared by: Harry T. de Beer
	date ...... : February 5, 1990

QUESTIONS THAT EVERYBODY ASKS

What is the method called?	Nondestructive evaluation of wood railroad ties.
What will it do?	It will determine a tie's present condition: acceptable or unsuitable for further service.
	It will determine a tie's life expectancy under prevailing operating and environmental conditions.
What are the benefits?	Prevention of unnecessary tie replacement.
	Test results can be used for immediate maintenance decisions: leave the tie for a known number of years or replace it.
	Test results can be used for long term maintenance planning and budgeting.
	Test results determine the accuracy of visual inspection.
What are its principles?	Decay and mechanical destruction affect the behavior of sonic waves travelling through ties. Changes in behavior can be measured accurately and reliably. An old and proven technology dating back to the late Thirties.
Which defects, other than those found by visual inspection, can be detected?	Internal decay, spike kill, splitting underneath tieplates, and surface decay underneath tieplates and caused by entrapped water
Are test results available immediately?	For go-no-go results: yes.
	For life expectancy determination: the same day.
Does ballast interfere with the accuracy of test results?	No. Neither ballast nor surface moisture interfere with the accuracy of test results.
Can breaks in ties (as caused by derailment, impact, etc.) be detected?	Yes.
Can bad ties be graded between best and worst?	Yes.
What is a typical application?	A so-called "balloon track" at a power generating station is tested for reliability. The track is 3 miles long. Every 3rd tie is tested for condition and life expectancy. This takes 1 week and costs, including travel and subsistence, approximately $7,000. If the percentage of unacceptable ties is high, a decision must be considered to test more or all the ties.
How long does it take to test a tie?	For a go-no-go assessment: 10 seconds per tie.
	For life expectancy determination: 20-30 seconds per tie.

FORM NO: DARC-004

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DE BEER

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subject: NONDESTRUCTIVE EVALUATION OF WOOD RAILROAD TIES	prepared for: general distribution
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Is the required instrumentation portable?	Yes. It weighs less than 20 lbs.
How do we get our ties tested?	De Beer Applied Research supplies personnel and instrumentation on a consulting basis. The railroad company supplies a helper; to assist the De Beer technologist and coordinate testing activities with traffic movement.
What does it cost?	For one technologist and instrumentation: $800 per day plus travel and subsistence expenses. For the average type of assignment this amounts to $1.30-2.00 per tie.

OTHER RELEVANT INFORMATION

test results and contract related data	These are treated as classified and confidential information. Test results are not revealed to third parties with- specific and written instructions by the client.
nondestructive evaluation reports	Although recorded data are made available to the client as they are acquired, formal and final reports are submitted within 5 working days after completion of the contract. Due to their confidential nature, reports are sent by fax only if the client specifically requests this.
tie acceptance-rejection criteria	These are at the discretion of the client . If the client leaves the decision to De Beer Applied Research, guidelines detailed in the following publications will be applied: - Standard Handbook for Mechanical Engineers (Marks') - The Encyclopedia Of Wood (U.S. Goverment Printing Office)
nondestructive evaluation method/technique	Some aspects of the method applied by De Beer Applied Research Co., such as the test frequencies, pulse repetition rates and transducer characteristics, are confidential.

FORM NO: DARC-004

continued on sheet 90-04-3

DE BEER

TECHNICAL SERVICE BULLETIN no: 90-04-3

subject: NONDESTRUCTIVE EVALUATION OF WOOD RAILROAD TIES	prepared for: general distribution
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	date ...... : February 5, 1990

Railroad crossties (or ties) are structural members that support and restrain rails, and help transfer the load of railcars to the ballast. They are made from wood, concrete or steel. This technical service bulletin covers wood ties, which account for more than 99% of the one-billion ties in service in North America. The American Railway Engineers Association lists 26 suitable wood species; some softwood and some hardwood. Ties rest on and are partially embeded in ballast; gravel or crushed rock. They are slab-cut from trees, dried, and then treated with a chemical preservative. In most cases with a mixture of creosote and oil, and in some cases with pentachlorophenol. They are installed at 19½ inch centers, There are an average of 3,250 ties per mile of track.

Ties have an average life expectancy of 33 years. This is confirmed by the fact that, of the one-billion ties installed in North America, 30-million are replaced annually. The life cycle of ties is controlled by the wood species, operating conditions (car speeds and tonnages), environmental conditions (moisture and temperature), the quality of chemical treatment, and the quality of installation (alignment, fastening, etc.) The main life cycle limiting factors are decay and mechanical destruction: crushing, tieplate cutting, spike kill, splitting, and physical damage.

Ties are inspected on a regular basis. As often as once a year. An experienced maintainer "walks the track" - somewhere between 3 and 5 miles per day - and marks the ties that need to be replaced. The general concensus of surveyed maintenance of way personnel is that a considerable percentage of rejected (scheduled for replacement) ties - quoted estimates average out at 20% - are still suitable for several more years service. (We assume that this figure was arrived at by destructive examination.) Tests of discarded ties, conducted by DeBeer Applied Research, indicate that (1) the appearance of ties is often not indicative of the actual condition and (2) at least 20% of ties are replaced unnecessarily; while they still have between 5 and 15 years of useful life left. This shows the need for a method to supplement visual inspection.

While developing a method to test wood utility poles and structural members (as found in mine headframes, buildings, bridges and storage tanks), we were prompted by a major university to come up with a method for nondestructive evaluation of railroad ties. Such a method was subsequently developed. It determines the condition of ties (including the most vulnerable locations: near and underneath the tieplates.) Typical applications of the method are:

* for TRACK RELIABILITY SURVEYS. Installed ties of common categories (wood species, operating conditions, environmental exposure, suppliers, chemical treatment, etc.) are tested to determine their statistical reliability. Purpose: immediate and long term maintenance planning and budgeting.
* for TIE REPLACEMENT PROGRAMS. Installed ties - either all or just those rejected by visual inspection - are tested to determine which require replacement. Purpose:(1) to prevent unnecessary replacement and (2) evaluate the accuracy of visual examination.
* for QUALITY ASSURANCE. New ties, prior to installation, are tested to determine their quality. Purpose: to (1) confirm the absence of defects and (2) determine the quality of pre-treatment and treatment processes.
* for INSURANCE PURPOSES - to verify the integrity of tie portions of the track.

continued on sheet 90-04-4

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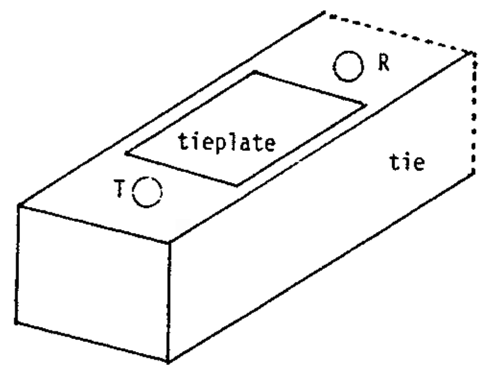

Fig. 1: TRANSDUCER PLACEMENT - SCAN

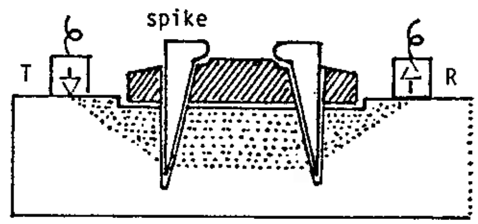

Fig. 2: SIDEVIEW AND SONIC WAVE PATH

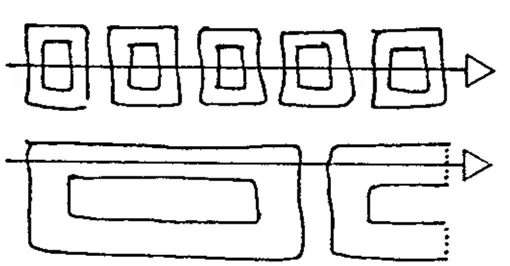

Fig. 3: SONIC WAVE TRAVEL THROUGH GRAINS

The method is based on sonic principles. Sonic compression waves at frequencies slightly beyond the audible range are sent through the vulnerable (to deterioration) parts of the tie: the area near and underneath the tieplates. Figure 1 shows one end of a tie and the locations where the transmission and reception transducers are usually placed. This replacement is referred to as scanning. Transducers are devices that convert one type of energy into another type. In the case of the transmission transducer: electrical energy into mechanical vibrations. In the reception transducer the opposite takes place. Due to the extremely wide beamspread of low frequency transducers, a considerable portion of the tieplate is covered by the sonic wave; meaning that this area is being tested. The wave penetrates to a depth of at least three inches. Figure 2 shows a sideview cross section of a tieplate area; including the coverage of the sonic wave being analysed. See the T(ransmission) and R(eception) transducers placed near the tieplate.

When a sonic wave travels through wood it chooses the path of least resistance. In this case the densest material: the cellulose cellwalls. Figure 3 shows propagation of the sonic wave across grains (the top display) and along grains. Cross-grain wave propagation is the result of radial scanning if the wave travels through the center (pith) of the original tree, and tangential if it travels along the annular (growth) rings. With-the-grain propagation is the result of longitudinal scanning. Since, in the case of installed railroad ties, only the top surface is exposed (not obstructed by ballast), De Beer Applied Research has developed a special with-the-grain sub-surface scanning technique. See figure 2.

When sonic waves travel through wood (and all other materials for that matter), they do so at a specific - for the species of wood - velocity. Due to the anisotropic properties of wood, the

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DE BEER

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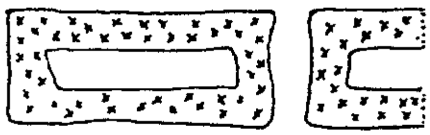

Fig. 4: MINOR DECAY OF CELLWALL

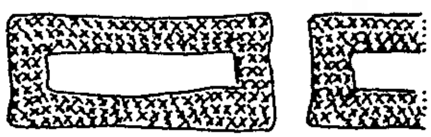

Fig. 5: MAJOR DECAY OF CELLWALL

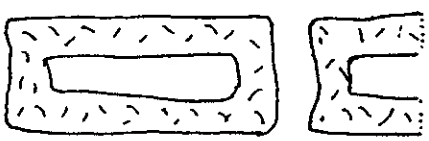

Fig. 6: MINOR MECHANICAL DESTRUCTION

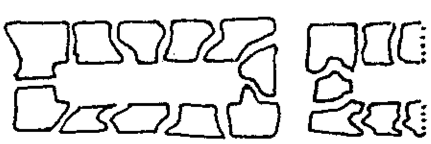

Fig. 7: MAJOR DESTRUCTION - FAILURE

Fig. 8: MAJOR DECAY AND DESTRUCTION, INCLUDING CELLWALL CRUSHING

specific velocity depends on the type of scan: Longitudinal, radial, tangential or surface. Differences between these velocities are quite pronounced. The velocity for longitudinal scans is approximately three times higher than for radial scans. The sonic wave velocity for a tie is the sum of the velocities for the materials through which it travels: cellulose (the cellwalls), lignin (which bonds the cells), and moisture (free and chemically bonded water.) If the sonic wave travels through a lot of lignin (which has a low specific sonic velocity), it slows down. That is the reason why cross-grain velocities (for radial and tangential scanning) are much lower than with-the-grain (longitudinal and surface) velocities.

Decay and mechanical destruction affect the behavior of sonic waves. They cause the wave's velocity to decrease and absorb part of its energy. This phenomenon is referred to as attenuation. Figures 4-5-6-7-8 show typical types of deterioration of cellwalls. Each of these conditions cause a decrease in velocity and attenuation. The degree of velocity loss and attenuation is proportional to the degree of deterioration - which in turn is proportional to loss of modulus of elasticity and compressive strength perpendicular to the grain. When the measured - by the subject nondestructive evaluation method - velocity and attenuation are compared with nominal values (those for new and unused ties), the condition of ties and their life expectancy can be determined accurately. This is the principle of the De Beer Applied Research method for nondestructive evaluation of wood railroad ties.