1.0 CHAPTER 1 - TIMBER

1.1 CHARACTERISTICS OF TIMBER

Timber is a material made up of cellulose, which is the main constituent of carbohydrate fibre cells which are orientated in the longitudinal direction. The cells are cemented by lignin. Since this intercellular connection is not very tight, timber is fairly porous and subject to decay as well as fire damage. From an engineering point of view, timber is an elastic material, has low thermal and electrical conductivity, and displays fairly large volume changes in response to changes in moisture content.

The most important property of timber is its strength. Timber is an anisotropic material, which means that its strength properties depend on the direction of the grain. In contrast, steel is said to be isotropic, meaning that a test specimen can be cut out of a larger member in any direction, without affecting any of the strength properties. This is not the case with timber, and any test sampling procedure must contain an instruction with respect to the direction of the grain of the sample.

There can be up to 3 principal grain directions in a timber sample: longitudinal, radial, and tangential. Correspondingly, normal and shear stresses can be parallel to the grain, perpendicular to the grain radially, and perpendicular to the grain tangentially. For most design considerations it is sufficient to differentiate between directions normal and parallel to the grain. Below is a table of typical strength parameters for Douglas Fir and Hemlock. Note the wide range of strength values, which is due to variable grades of a particular species. Some suppliers can provide stress graded timber whereby certain minimum strength values are guaranteed as a result of every piece passing an automatic grading machine which checks its deflection under a standard load.

Properties	Douglas Fir (MPa)	Hemlock (MPa)
Bending	5.0 to 13.6	3.8 to 9.7
Tension Parallel to Grain	3.4 to 8.6	2.4 to 6.2
Horizontal Shear	0.5 to 0.8	0.5 to 0.7
Compresson Perpendicular to Grain	3.1	1.6
Compression Parallel to Grain	4.4 to 9.6	3.7 to 7.9
Modulus of Elasticity	10,610 to 13,300	8960 to 11,160

Table 1.1 Strength Parameters of Douglas Fir and Hemlock

1.2 FACTORS AFFECTING STRENGTH

1.2.1 DECAY

Certain living fungi are capable of breaking down wooden cells for food. Their seeds are called spores and are carried into the wood by wind, insects, rain, melting snow, and condensation. They require certain conditions to grow. These are oxygen, favourable temperature, food and moisture.

Only a small amount of oxygen is needed for fungus growth. If the supply of oxygen drops below a given minimum, the fungus goes into a dormant stage. Total absence of air containing oxygen, as is the case with piles that are totally immersed in water, will prevent decay of this nature.

Fungi grow in temperatures ranging from 10 to 32 degrees Celsius. Decay ceases at temperatures below 2 degrees Celsius or above 38 degrees Celsius. The upper extreme temperatures are lethal to fungi. Only dark wood exposed to sunlight will occasionally reach elevated temperatures of 38 degrees Celsius and above.

Food stuff includes sapwood (the outer part of the tree) and heartwood, although the latter is more resistant to rot due to fungal attack.

Water is a necessary ingredient in fungal growth. The essentially hollow wood cells can easily hold a moisture content of 20%, at which point there is sufficient water available to initiate some fungus growth. This condition advances to a more serious stage if the moisture content increases to 30%, which is usually above the fibre saturation point. The fibre saturation point is defined as that moisture content which saturates the cell walls without overflowing free water into the hollow cell spaces. Normally fungus spread becomes a concern only after this saturation point is passed. Hence, timber is seasoned or kiln dried to lower its moisture content below the fibre saturation point. Once this condition has been attained, humidity in the air will not cause the moisture content to climb into a range that supports the growth of fungi.

The invasion of spores is further promoted by naturally occurring cracks in timber, which are called checks. Checking may be due to cycles of shrinkage and swelling, which are responses to alternating loss and gain of moisture in the cell walls only. Moisture content changes due to changed water contents in the cell cavities do not change the dimensions of timber.

Decay producing fungi cause timber to be darker in colour. The surface softens and becomes spongy, stringy, or crumbly, depending on the type of fungus attacking the timber. Fungi that feed on cellulose cause "brown rot", creating the appearance of charred timber. Timbers so diseased become brittle and crack across the grain. If the attack goes on unabated, the timbers shrink and finally collapse. Weight loss of only 3% can be responsible for strength loss of 50% or more.

A different type of fungus, feeding both on cellulose and lignin, causes "white rot". The affected area looks similar to normal wood, is light in colour and does not show any cracks across the grain. Unless this type of rot goes on for a long time, the affected timbers retain their shape and do not shrink or collapse. However, conditions promoting "white rot" are conducive to "brown rot" as well.

Structural members that are in contact with the soil, such as posts, piling, abutments, and wingwalls, are at risk of decay due to the variable moisture range of the ground. Conditions are less favorable to decay above ground as those areas are subject to fewer cycles of wetting and drying.

1.2.2 CHECKS

Checking in timber is the separation of grain resulting from rapid lowering of the surface moisture content combined with a difference in moisture content between the inner and outer portions of the wood. As a result of the restraining forces of the inner portion resisting shrinkage of the outer layer, which is more capable to surrender its moisture to the environment, stresses develop that split the outer layer.

Checks affect certain strength properties, and are classified as to type and severity. Surface checks are shallow checks in the surface of the timber. End checks occur at the sawn end of a member. Through checks or splits are checks that extend from one surface of the piece right through to the opposite face. Heart checks radiate outward from the pith, i.e. from the center of the yearly growth rings.

1.2.3 SPLIT

A split is a lengthwise separation of the wood due to failure in the wood cells. Splits are classified according to their lengths. A short split is so described if the length of the split is less than one sixth of the length of the piece, and less than the width of the piece. The length of a medium split may exceed the width of the affected piece, but must still be less than one sixth of the length of the piece. If the length is more than one sixth of the length of the piece, the split is classified as a long split.

1.2.4 SHAKE

A shake is a separation along the grain between annual growth rings. The width of separation is classified as fine if the shake is less than 0.8 mm (1/32") wide, or medium if the shake is 0.8 mm to 3 mm (1/32" to 1/8") wide, and wide if the shake is more than 3 mm wide. Shakes are also classified as to whether the circle of separation is complete or not. A round shake is one completely encircling the pith. A cup shake only partially encircles the pith. A through shake is one that extends from one end of the piece right through to the other end. A pitch shake is a clearly defined seam or opening between the grain of the wood which may or may not be filled with granular pitch.

1.2.5 CHEMICAL ATTACK

Wood, unlike concrete or steel, is not affected by deicing salts. In fact, salts have the opposite effect, acting as a wood preservative. However, there are three mechanisms by which chemicals can cause wood to deteriorate. Cycles of wetting cause swelling and weakening of the fibres. Acids cause hydrolysis of the cellulose, and alkalis cause delignification. Spillage of chemicals, industrial pollution, and animal wastes are common sources of these aggressive solutions.

1.2.6 FIRE

Timber bridges are vulnerable to the effects of fire. Many preservatives increase the risk of fire. On the other hand, timber that is exposed to fire forms a self-insulating surface layer of char which provides a certain degree of fire protection. Even though the surface is charred, the timber underneath which is not burned retains most of its strength and will support loads in accordance with the computed capacity of its uncharred section. There is some permanent loss of strength properties upon prolonged exposure to high temperatures. Note that steel and concrete undergo considerably more weakening due to the heat of a nearby fire even where there was no loss of section. The fire endurance and excellent performance of heavy timbers are attributable to the size of the wooden member and the slow rate at which the charring penetrates the wood.

1.2.7 ABRASION

Abrasion is mainly a result of mechanical wear due to tire contact. Typically this action takes place on top of deck planks in the wheel tracks. The planks sustain loss of section, and the wear is compounded by decay which infiltrates and weakens the wood further.

1.2.8 COLLISION AND OVERLOADS

Like steel and concrete bridges, timber bridges are subjected to damage due to impact and overloads. In the case of impact damage, the collision site is characterized by shattered, splintered, or deformed timbers, and large longitudinal cracks. Overload damage usually displays signs of sagging and buckling in the girders. If sections can be distinguished as being in compression and in tension, the former will show a wrinkled skin, whereas the latter will show timber that is pulled apart at failure.

1.3 TESTING METHODS

Like concrete or steel, timber can be evaluated by destructive and non-destructive testing techniques. Destructive testing techniques include probing and core sampling. Non-destructive testing techniques include visual inspection, sounding, ultrasonic testing, and the use of moisture meter.

1.3.1 DESTRUCTIVE TESTING

Destructive testing relies on the boring of core samples or drill chips which may be further analyzed. The major objective of these tests is to determine the moisture content of the wood and the presence and extent of rot. The inspector uses drills and increment borers for this purpose.

The increment borer is a coring device which produces a thin, round core sample inside the central part of a hollow drill bit. Ordinary drills are also used to produce drill chips that are then analyzed visually and/or in the laboratory.

None of the procedures are very involved as compared to concrete coring for instance, and the only obstacle to performing this type of sampling is access to the member that is suspect. Inspections of this type should take advantage of winter ice on the river. The Department regulations require that any holes so created be filled with treated timber dowels or plugs. The inspector should therefore carry an adequate supply of these with properly fitting diameters when heading out on an inspection trip involving any timber structures. Despite these provisions of back-filling test holes, the borings do result in some loss of section, and the quantity and location of such test holes should be carefully determined in advance.

1.3.2 VISUAL INSPECTION

The inspector should be trained to look for evidence of bridge damage in a systematic fashion. In the case of timber bridges this includes a lookout for decay evidence such as characteristic fungus fruiting structures, and abnormal surface shrinkage, sunken faces, or deformations. The inspector should also be aware of signs of insect activity that may affect timber structures, though none are known to be a factor in Alberta.

In addition, the inspector should look for water marks that point to potential decay areas. These include permanent staining or other water marks, rust stains created by water passing by such fasteners as steel bolts, nails, screws, or drifts, appreciable growth of moss or other vegetation on bridge members, and accumulation of soil and debris on wood surfaces which trap water and promote decay. Special areas easily overlooked are joint interfaces, mechanical fasteners, and wood adjacent to other water trapping areas which are potential sites of decay, fungus growth, as well as checks or cracks that trap water.

Visual inspection has the advantage of being quick and simple, but its major limitation is that it fails to detect internal decay. Inspection of timber piles below the water line can further be complicated if these members are coated with asphalt or protected with a steel or concrete casing.

1.3.3 SOUNDING

Next to visual inspection, sounding a timber member with a steel hammer is one of the simplest methods of procuring indications of its integrity. Normally, a sharp ring is heard when timber is struck with a hammer, whereas internal decay may return a dull or hollow sound. This method requires a few precautions and interpretations. A check or shake may be mistaken for internal rot, and incipient rot may escape detection. For this reason, other tests mentioned below are required where an area remains in doubt.

Another concern has been raised when reviewing sounding practices involving heavy, pointed steel probes that were routinely driven by hand into treated timber to test for rot. Later it was discovered that spores were able to travel through the openings into the unprotected timber interior, causing rot in bridges as a result of such injurious probing techniques. Hammer sounding should therefore be carried out with the flat side of the hammer only and rely on the auditory return for information about rot.

1.3.4 ULTRASONICS

This technique uses high frequency sound waves that are propagated through the timber by a James 'V' meter. Rot may be detected by the resulting time delay in receiving the ultrasonic pickup in one of its terminals, the other one being the transmitter. Sound timber propagates the signal much faster than decayed timber. Factors affecting the wave velocity in timber are timber species, treatment, direction of grain, density of the timber, moisture content, and degree of decay.

1.3.5 MOISTURE METER

Timber displays resistivity which varies proportionately with moisture content in the lower ranges. As a result, resistivity meters can be utilized to measure moisture contents of up to 20%. Beyond this margin resistivity meters lose accuracy, and wetter samples need to be tested by oven drying and gravimetric testing.

1.4 COMPARISION OF TEST METHODS

A careful visual survey supplemented by a depth of penetration device or increment borer is sufficient to identify and estimate the severity of most types of deterioration. Ultrasonic techniques may be a useful supplement, especially where an indication of the strength of the timber is also required. Specific identification of decay, fungi, chemical attack, and preservative treatment or the actual measurement of strength is best performed by removing samples for laboratory analysis.

Defects	Techniques			
	Visual	Depth of Penetration	Moisture Content	Ultrasonics
Surface Decay and Rot	G	G	F	N
Internal Decay and Voids	P	G	F	G
Weathering	G	F	N	G
Chemical Attack	F	F	N	N
Abrasion Wear	G	N	N	N
Note: G= Good; F=Fair; P=Poor; N=Not Suitable				

Table 1.2 Comparison of Investigative Techniques For Detecting Defects in Timber Structures

1.5 MAJOR INSPECTION ITEMS

The following items should be considered during a timber bridge inspection.

1.5.1 FASTENERS

Check connections for deterioration, loose fit, or soft bolt holes and splices. All fasteners and connecting hardware should be examined for corrosion. It should be noted that although chemical attack does not very often affect timber, it does often weaken metal connectors by corrosion. One of the methods used in the detection of loose connections is to listen for excessive vibration or noise during passage of vehicles over the bridge.

1.5.2 WEARING SURFACE

Timber decks that have an asphaltic concrete wearing surface should be examined for wear, ruts, potholes, reflective cracks, and aging. If there is no asphaltic wearing surface, check the decking, planks or sheathing for surface cracks, gaps between deck panels, signs of swelling, and tightness of connectors. The drainage should be checked for evidence of ponding, blocked passages, or pot holes. Note however that most timber decks were designed to allow drainage between planks rather than through special drain pipes in the deck.

1.5.3 STRINGERS AND CAPS

Stringers and caps should be checked for internal decay at ends and by sounding the length of the member. This should be done underneath the bridge, with particular attention paid to contact areas with the decking. Check stringers for misalignment, lateral buckling, excessive sagging, cracking, and canting by sighting along the length of the member. Also check for excessive movement under heavy trucks which may be evidence of overloading damage in the past.

1.5.4 PILES

Check piles for soundness as in the case of stringers and caps, paying special attention to possible decay above the water line. Bleeding of the creosote may be indicative of reduced resistance to fungal attack. Check if any piles appear to crush into the cap because of uneven bearing. This may be caused by improper pile elevations due to settlement, or by rotting of a part of the cap.

1.6 TIMBER TREATMENT

Timber use for bridge construction is normally treated to prevent rot.

Preservatives are classified as oil type, organic solvent solutions, and salts. Only the latter two are paintable, but it is the former category that is used most in bridge construction and maintenance. Pentachlorophenol is diluted in spirits or heavy oils; coaltar creosote is used in extreme exposure, either diluted in oil or as is. It is not only harmful to spores, but to any other living matter, and has been banned by many government agencies as a result.

Inorganic salt preservatives are dissolved in water solutions before they are applied. As a result they are more easily washed away again by water supplied by the stream or precipitation, thus requiring periodic re-application and maintenance. Most of these are also environmentally hostile, e.g. ammoniacal copper-arsenate and chromated copper-arsenate. Lacking oil, they do not contribute to waterproofing at all, which accounts for their short service life. As well, these chemicals will attack some metals. Therefore, stainless steel, silicon bronze or copper should be substituted for ordinary steel fasteners.

In Alberta creosote is the most common treatment for timber used in bridge construction. Chromated copper-arsenote (CCA) is used for some applications such as strip decks where contact from the general public would make the use of creosote unacceptable. The treatment process for creosote requires a significant period of time with approximately two years from the time the timber is cut until the treated timber is ready for use.

Before treatment the cut timber must be properly stored for a minimum 6 month seasoning period. An inspection service checks the green stock, performs moisture content tests, culls out twists, checks, and any other pieces that fail to meet the current NLGA standards.

The timber is treated in pressure tanks with 100% creosote. In the past there was a mixture of 50% oil and 50% creosote in use, which is now discontinued. The success of this treatment was in the past tested by measuring the volume of creosote returned from the tank and relating this amount to the volume of timber in a given charge. This method was criticized by investigators as inadequate in that some items could be over-treated whereas other items of a charge were then under-treated. In response to this criticism an assay method was introduced to timber testing that has implications for on site inspection of timber bridges. Each charge of timbers is sampled, selected items are cored, and the cores subjected to an extraction test. This method yields accurate depth of penetration and application rates for each tested member. As well, an additional inspection is carried out on timbers just before the pressure treatment occurs so as to avoid treating potential rejects. At this time moisture content is also re-established.

Dimensional timber is incised approximately 9 mm (3/8") deep to allow for proper penetration of creosote treatment into its heartwood portion. Piling, which takes in the whole tree trunk and therefore is surrounded on the outside by sapwood, is not incised. It has been established in the past that the looser grain of the sapwood absorbs sufficient creosote without incising.

The pressure treatment currently in use involves vacuum treatment of the timbers in the treatment drum, heating, addition of creosote under vacuum to allow fluid to be sucked into pore spaces, and then pressurizing the vessel to force creosote even deeper into the matrix. Even with this very efficient treatment, only the outer shell of heavy timbers is treated and subsequent perforation of the shell will result in opening of an inroad for rot and other wood diseases. As a rule, timbers are not pre-cut or pre-drilled prior to treatment, and sizing in the field opens up timbers, requiring on site treatment with brush grade creosote to close the openings.

Creosote and other fungicides are hazardous to human health and all other animal life. Handling these materials requires certain safety precautions, like wearing of coveralls, rubber gloves, and breath protection. Because of its carcinogenic qualities, creosote has been banned in a number of States in USA, and the inspector should be very careful in handling timbers carrying these coatings.

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