info@fpinnovations.ca
www.fpinnovations.ca

FOREST BRIDGE CAPACITY SIGNAGE

A TECHNICAL REVIEW OF BRIDGE LOAD RATING

Allan Bradley, R.P.F., P.Eng., Research Lead, Roads and Infrastructure

September 2020

This report is unrestricted.

ABSTRACT:

This report was originally published in 2014 and described a technical review of forestry bridge load limits in B.C. and their application to road network ratings (the road load rating concept developed by Forests, Lands, Natural Resource Operations and Rural Development). The report included a discussion of load factors and other assumptions that went into calculating these load limits. Potential issues that might arise from adopting the various load limits were highlighted. The report detailed survey results from a poll of forest industry representatives about the road load rating concept. A brief discussion about communicating the new load limits was included, also.

Recently, FPInnovations revised this report to include three additional B.C. forest bridge designs and, after consulting with bridge experts, revised the analysis methodology and results accordingly. As a result of this latest review, substantial changes were made to the derivation of gross vehicle weight and axle load limits for all the bridge designs.

301013564
TECHNICAL REPORT NO. 16 (2020)
ACKNOWLEDGEMENTS
This project was financially supported by the B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) under its provincial agreement with FPInnovations.

The author would like to thank Brian Chow (FLNRORD), Gary McClelland (SNT Engineering), Julien Henley (Associated Engineering), Darrel Gagnon (COWI North America), Gary Farnden and Mark Frew (TRAN), and Tyson Lambert (T-Mar Industries) for their valuable contributions to this project.

APPROVER CONTACT INFORMATION
James Sinnett, Manager, Transportation
James.Sinnett@fpinnovations.ca

REVIEWERS
Brian Chow, PEng, Chief Engineer, FLNRORD

Julien Henley, PEng, Manager Municipal Bridges, Associated Engineering

Darrel Gagnon, PEng, Vice President, COWI North America

Jamie Rupar Gilliat, P.Eng., Senior Structures & Roads Engineer (TA), FLNRORD

AUTHOR CONTACT INFORMATION
Allan Bradley, RPF, PEng
Research Lead, Roads and Infrastructure
(604) 222-5667
allan.bradley@fpinnovations.ca

TABLE OF CONTENTS

EXECUTIVE SUMMARY....2
INTRODUCTION....3
Project Objectives....4
RESULTS AND DISCUSSION....5
Load Adjustment Factors Used in This Analysis....5
Load Factors....5
DLA and Distribution Factor....8
Technical Check of Bridge Load Limit Values....9
BCFS Bridge Design GVW and Axle Load Limits....9
LOH and HOH Bridge Design GVW and Axle Load Limits....10
CL-625 and BCL-625 Bridge Design GVW and Axle Load Limits....12
Short-truck Load Limits....12
Tracked Equipment Load Limits....15
Recommended Load Limits for B.C. Forest Bridges....18
Professional Engineer's Load Rating of Existing Forest Bridges....20
Communicating Bridge Load Limits....20
Load Limit Sign Formats....21
Signs for Posting Bridge Design Vehicle Load Limits....22
Special Case: L-45 Bridges....23
Special Case: Downrated Bridges....24
Evaluation of the Road Load Rating Concept....25
Stakeholder Survey....25
Considerations for Culvert Ratings in Road Load Limits....27
Adding Road Load Ratings to Road Use Permits....27
CONCLUSIONS....29
REFERENCES....31
APPENDIX 1: GO/NO GO GUIDE FOR 29 ARTICULATED ROCK TRUCKS....32
APPENDIX 2: LIVE LOAD ADJUSTMENT FACTORS for evaluating girder force effects....34
APPENDIX 3: TRACKED FORESTRY EQUIPMENT DATA....35
APPENDIX 4: BCFS BRIDGE DESIGN VEHICLES....38
APPENDIX 5: ADDITIONAL FOREST BRIDGE DESIGN VEHICLES....41

LIST OF FIGURES

Figure 1. LOH design vehicle. GVW: 72 375 kg (710 kN). 11
Figure 2. HOH design vehicle. GVW: 114 200 kg (1 120 kN). 11
Figure 3. Articulated rock truck ("short" truck) 13
Figure 4. Comparison of maximum factored shear forces from an L-75 design vehicle and a 54-tonne tracked equipment on 2-girder, single span, L-75 forest bridges. 17
Figure 5. Comparison of maximum factored bending moments from an L-75 design vehicle and a 54-tonne tracked equipment on 2-girder, single span, L-75 forest bridges. 17
Figure 6. Highway bridge capacity sign formats (axle load limits, GVW limit, triple GVW posting). 22
Figure 7. Proposed full road load sign for posting an L-100–rated road network (the same sign format applies to L-60, CL-625, BCL-625, L-75, LOH, L-90, L-120, HOH, L-150, and L-165 road networks). 23
Figure 8. Suggested L-45 road network load limit sign based on the load limit of the short truck........ 24
Figure 9. Simple sign formats for downrated bridges. 25

LIST OF TABLES

Table 1. Design life and safety reliability index [Henley (2003)], updated with information from [CSA (2006) and [Associated Engineering (2009)] 5
Table 2. Load factors associated with an annual reliability index of 3.75 (used in new designs) 6
Table 3. Load factors associated with a target reliability index of 3.25 used for load-rating existing structures 6
Table 4. Recommended posted limits of various forest road industrial traffic types (McClelland, 2013) 9
Table 5. Factored axle loads for 29 models of articulated rock truck 14
Table 6. Operating weights and key dimensions of tracked forestry equipment used in B.C. 16
Table 7. Recommended load limits for B.C. forest bridges [a] 19
Table 8. Road load ratings based on more than one bridge design 21
Table 9. Addition of road load limit information to table in schedule A of road use permit 28
Table 10. Example of table with road load limit information 28

EXECUTIVE SUMMARY

Overloading of forest bridges is a concern to the B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) because of the unacceptable increase in risk to human safety and environmental integrity, and because of reduced design service life and maintenance costs. Bridge capacity signage for forest bridges has become outdated and needs to be changed to reflect evolving truck populations. Non-forestry sectors are increasingly utilizing forest service roads (FSRs), and these industries employ a wide range of vehicle configurations that may exceed forest bridge design limits if loaded for off-highway travel. FLNRORD is taking action to rectify this situation. One step is to develop improved signage that posts bridge load limits in terms of gross vehicle weight (GVW) and axle-group limits so that road users can more easily determine the sufficiency of a bridge for their specific truck configuration. Another step is to inform all holders of road use permits on FSRs about the load limits of FSR bridges.

Buckland & Taylor Ltd. (now COWI North America) and SNT Engineering Ltd. were contracted to determine the GVW and axle load limits of current and new (light off-highway and heavy off-highway) forest bridge designs. In addition, SNT Engineering was commissioned to determine GVW load limits for concentrated loadings created by short trucks (i.e., 4-axle gravel and 3-axle articulated rock trucks) and tracked forestry equipment. Various existing bridge capacity sign formats were considered, and new formats proposed. The question remained: *How best to inform road users about the load limits?* Rather than posting the capacity of every bridge, FLNRORD proposed a road load rating concept, in which a single minimum bridge capacity would be posted for each FSR network, and only bridges that have been downrated would be individually posted.

In 2013, FPInnovations was asked to review the load limits and the assumptions that went into calculating the load limits. FPInnovations also was asked to consider and recommend formats for bridge capacity signs that would be understandable and easily read, and to gather feedback from its member forest companies and other stakeholders about operational concerns that might arise with the implementation of new signage and road load rating.

This report presented the results of the technical review of the load limits proposed by Buckland & Taylor and SNT Engineering and included a discussion of load factors and other assumptions that went into calculating these load limits. Potential issues that might arise from adopting the various load limits were highlighted. Specific recommendations were made that could improve the accuracy of the load limit analysis and resolve some of the identified issues. A brief discussion about communicating the new load limits was included.

From 2017 to 2020, FPInnovations revisited and revised the project report to include three additional B.C. forest bridge designs (CL-625, L-90, and L-120), reviewed the results with bridge experts, added an analysis of concentrated loads from rock trucks, and revised the analysis methodology and results accordingly. As a result of this latest review, substantial changes were made to the derivation of GVW and axle load limits for all the bridge designs.

Options for the formats for bridge capacity signs are summarized, and two formats are recommended for use with the various bridge designs. Multiple stakeholders were contacted and solicited for feedback on the road load rating concept. Feedback generally supported the concept; however, some potential issues were identified. In some cases, potential solutions to the issues are discussed, also. Finally, changes to road use permits are recommended that would detail road load limits.

INTRODUCTION

The B.C. Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) is responsible for bridge and major culvert designs on forest service roads (FSRs) and their structural inspections. Bridge overloading is a source of concern because of the unacceptable increase in risk to human safety and environmental integrity, and because of maintenance costs and reduced design service life.

When there was a relatively narrow range of vehicle configurations used on forest roads, FSR bridge capacity signs were based on 5-axle tractor/tandem pole trailer design vehicles. Forest licensees and their contract truckers understood and generally adhered to the terms and conditions of the road use permit. Further, the bridge design vehicles [5-axle British Columbia Forest Service (BCFS) truck configurations] resembled the truck population. The BCFS highway load configurations evolved from L-45 to L-60 and the relatively recent adoption of BCL-625 for consistency with the Ministry of Transportation and Infrastructure (TRAN).

Currently, the forest industry employs as many as 23 different tractor-trailer configurations to haul short-log and tree-length timber (e.g., 5-axle to 9-axle combinations). Bridge signage based on the BCFS truck configurations is outdated and needs to be changed to reflect the current truck populations (McClelland, 2012). As well, it is common practice for tracked vehicles (e.g., yarders, loaders, and excavators) to be walked across bridges when making short moves in industrial locations.

Non-forest industry sectors (e.g., oil and gas, mining, independent power projects) are increasingly utilizing FSRs; however, these road users may not understand or adhere to the terms and conditions of the road use permit or even know there is one. These industries employ a wide range of vehicle configurations that may exceed forest bridge design limits if loaded for off-highway travel. FLNRORD is taking steps to rectify this situation: One step is to inform all FSR users about the capacities of FSR bridges and, thereby, address overloading issues caused by a lack of knowledge or understanding about the FSR infrastructure.

Where FSR bridge capacity has been posted, it usually has been with just a gross vehicle weight (GVW) load limit. That GVW load limit applies to many but not all vehicles—notably not to short trucks and tracked machines because their mass is concentrated, which generates force effects in excess of the design vehicle loaded to a comparable GVW. The lack of understanding of concentrated loads may have contributed to some isolated bridge failures in which road users misunderstood what kind of loads the bridge could carry and, therefore, overestimated the actual bridge capacity (Ministry of Forests and Range, 2009). Improved forest bridge load limit signage is needed to address all types of heavy vehicles likely to use FSR infrastructure now and in the future (McClelland, 2012).

Load limit signage for TRAN roads generally only appears on bridges that have been downrated. The postings can be in different formats, ranging from single GVW to GVW with maximum single-, tandem-, and tridem-axle loads. Given the range of the types of loads travelling on resource roads and the varying allowances for loads between roads constructed for on-highway versus off-highway use, the work of this initiative focused on developing a general posting approach that would provide useful information to resource road users. Similar in format to TRAN signs, resource road load limit signs depict GVW, and maximum single-, tandem-, and tridem-axle loads. Given the nature of common industrial loadings, resource road signage was expanded to include short-truck and tracked-equipment maximums also.

In the early 2000s, FLNRORD commissioned a study to determine whether the BCFS bridge design vehicles were "*reasonably representative of B.C. log hauling truck loadings and whether these configurations were appropriate for use with the load factors in CHBDC [Canadian Standards Association, 2000]. The findings* *indicated that, for the current populations of trucks transiting forestry bridges, the existing BCFS design vehicles produced variable levels of design safety depending on the bridge span."* (Gagnon, 2004)

It was recommended that the existing BCFS design vehicles be modified for use with the design provisions of the Canadian Highway Bridge Design Code (CHBDC). Gagnon (2004) proposed three new design vehicles for use in the design of B.C. forest bridges:

- CL-625 – for forest bridges subject to on-highway (legally loaded) log-hauling trucks with GVW up to 63.5 t.
- Light off-highway (LOH) – for bridges subject to all off-highway log-hauling trucks with GVW up to 72.4 t.
- Heavy off-highway (HOH) – for bridges subject to all off-highway log-hauling trucks with GVW up to 114.2 t.

FLNRORD asked Buckland & Taylor Ltd. (now COWI North America) and SNT Engineering Ltd. to determine the load limits of the current BCFS and new (BCL-625, LOH, and HOH) forest bridge design vehicles in terms of tractor-trailer GVW and axle weights (Gagnon, 2012), and in terms of GVW of short trucks and tracked equipment (McClelland, 2013).

The next question was how best to express the load limits. It was deemed impracticable, too costly, and unworkable to sign each forest bridge and develop numerous different sign formats. FLNRORD proposed the road load rating concept to allow for rating all bridges in a road network and posting this rating on a sign at a road network entry point(s). The rating would be based on the lowest bridge capacity in the network. Conceptually, individual bridge signs would be posted only for bridges with substandard load ratings, like the TRAN practice of posting only bridges that have been downrated.

In 2013, FPInnovations was asked to review the short-truck and tracked-equipment load limits proposed by Gagnon (2012) and McClelland (2013); they were also asked to review current bridge capacity sign formats and recommend a sign format(s) that would allow the presentation of key load limit information in a way that was understandable and easily read. Last, FPInnovations was asked to gather feedback from its member forest companies regarding operational concerns that might arise from implementing a road load rating system.

From 2017 to 2019, FPInnovations reviewed and revised the analysis methodology and results to include assumptions based on discussions with additional bridge experts, and to include three additional bridge designs (CL-625, L-90, and L-120). This report provides an updated summary of the results of this analysis.

Project Objectives

- Conduct a technical review of the engineering method and calculated load limits for all FSR bridge designs.
- Consider and recommend bridge capacity sign formats and capacity information for road use permits that would be understandable and easily read.
- Gather industry feedback about options for informing road users about FSR bridge capacities.

RESULTS AND DISCUSSION

Load Adjustment Factors Used in This Analysis

In its evaluation of CAN/CSA-S6-00 as a design approach for B.C. forestry bridges, Associated Engineering Ltd. provided details about bridge design life and reliability index (Table 1) (Henley, 2003). Table 1 was updated with information from CAN/CSA-S6-06 (Canadian Standards Association [CSA], 2006), and given that CAN/CSA-S6-14 made no changes to load factors, this information remains unchanged today. Although the *Forest Service Bridge Design and Construction Manual* published by the Ministry of Forests, Lands and Natural Resource Operations (FLNRO) (1999) did not specifically estimate a target reliability index, it was implied that the authors were trying to be consistent with CAN/CSA-S6-88, so their annual and design life reliability indices are assumed to be the same.

The annual reliability index (denoted as β in the CHBDC) is an important design variable because it is used to define the appropriate live load factor. Reliability is generally insensitive, however, to small changes in design life duration (i.e., 45- to 75-year design lives get a similar lifetime β).

Table 1. Design life and safety reliability index [Henley (2003)], updated with information from [CSA (2006) and [Associated Engineering (2009)]

Code	Design life (years)	Target reliability Index (β)	
		Annual	Over the design life
CAN/CSA-S6-06	75	3.75	3.5
CAN/CSA-S6-00	75	3.75	3.5
CAN/CSA-S6-88 [a]	50	3.75	3.5
Forest Service Bridge Design and Construction Manual [b]	45	3.75	3.5

[a] CAN/CSA-S6-88 was based on a 50-year design life (β) of 3.5. This is roughly equal to an annual β of 3.75. The difference in going from an annual β to either a 50-year or 75-year β is small for most vehicle populations (personal communication Darrel Gagnon of COWI North America).

[b] FLNRO, 1999.

Load Factors

Using the design life and annual reliability index, the load factors and load combinations have been calibrated to a uniform level of reliability. At the ultimate limit state, using the load factors in CAN/CSA-S6-14, CAN/CSA-S6-06, and CAN/CSA-S6-00 (Clause 3.5.1) results in a probability of approximately 1% that the design load will be exceeded during the 75-year design life of the structure. The live load factors have been calibrated to reflect variability of truck traffic on public highways. Should the factors be applied to other live loads, such as the BCFS design trucks, a different safety level will be attained.

Table 2 summarizes the load factors associated with load effects and bridge design code. It must be noted that these factors cannot be viewed in isolation, as other parameters [dynamic load allowance (DLA), live load distribution, resistance model, and resistance factor] also directly affect the design.

Although the individual weights of the overall population of loaded highway trucks can vary widely, the mean weight of the loaded truck population is typically about 10% to 15% below the posted load limits. This represents the general level of adherence of the truck population to the posted load limits with typical load limit enforcement measures in place. (Gagnon, 2012, contained in McClelland, 2013)

The values defined in CAN/CSA-S6-06 provide a prescribed uniform level of reliability based on an acceptable probability that the factored loads will exceed the factored resistance during a specific period for typical highway bridges, subject to the specified design loads.

Table 2. Load factors associated with an annual reliability index of 3.75 (used in new designs)

Load effect	Load factor		
	CAN/CSA-S6-06	CAN/CSA-S6-00	CAN/CSA-S6-88
Live load	1.70	1.70	1.60
Dead load (manufactured components including pre-cast concrete and steel girders but excluding wood)	1.1	1.1	1.2
Dead load (wearing surfaces, based on nominal or specified thicknesses)	1.5	1.5	1.6

Using the CAN/CSA-S6-06 Section 14 provisions for reducing target reliability, Associated Engineering evaluated the force effects of 7-axle and 8-axle log-hauling trucks, on the basis of their conformance with the load variability of the normal (alternative loading) and permit annual (PA) traffic categories (Associated Engineering, 2009). Vehicles classified as normal traffic are assumed to have high GVW variability and are, therefore, assigned higher live load factors. Vehicles classified as PA traffic typically have practices in place to control the vehicle weights and limit the probability that the actual GVW will be greater than that assumed during the evaluation. Table 3 illustrates the range of load factors that were used in that evaluation.

Table 3. Load factors associated with a target reliability index of 3.25 used for load-rating existing structures

Traffic type	Span length [a]	Live load	Dead load
Normal	Short	2.10	1.08
	Other	1.56	1.08
PA	Short	1.59	1.08
	Other	1.42	1.08

[a] Based on Clause 14.13.13.1 in CSA (2006), short spans were defined as ≤6 m long for evaluating shear but ≤10 m long for evaluating bending moment.

Earlier traffic studies [Gagnon (2004)] showed that the load variability for B.C. log-hauling traffic was less than that of the general truck population. According to Gagnon (2012), this reduced load variability of log-hauling traffic may support reducing design live load factors of 1.7 (for HOH, LOH, and BCL-625 design vehicles) or 1.6 (for L-75 to L-165 BCFS design vehicles) to 1.5. Although no traffic data was available, Gagnon (2012) postulated that the live load factor for the L-45, L-60, and CL-625 (logging truck) designs also could be reduced to 1.5 if it was shown that they had similar loading statistics to the BCFS design vehicles. Gagnon used this logic to suggest increasing the HOH, LOH, and BCL-625 GVW load limits by 13.3% (= 1.7 / 1.5) and the BCFS design GVW load limits by 6.7% (= 1.6 / 1.5). Note that the increase in design vehicle GVW is contingent on the live load factor being reduced to 1.5, and the total factored loading stays the same. Vehicles other than log-hauling trucks (e.g., equipment transports and non-forestry industrial trucks) also use FSRs. It may not be justified, without further study, to assume that these vehicles have closely controlled axle weights (i.e., that they conform to loading variability for annual permit (PA) traffic).

Population studies conducted by Buckland & Taylor Ltd., and FERIC [Gagnon (2004)], indicated that axle loads are more variable than GVW. BCFS tandem-axle design loads must be decreased by 20% to be able to use the same live load factor used with GVW. BCFS vehicles are defined as having a maximum tandem-axle load of 46% of the GVW. Gagnon (2012) recommended, therefore, that the tandem-axle load limit for BCFS design vehicles be calculated as (GVW x 46%) x 80% = GVW x 37%. Gagnon (2012) recommended that load limits for tridem axles, owing to their improved ability to distribute load, especially on short spans, be slightly higher than the load limits for tandem axles (i.e., 110% of tandem load limits). Finally, Gagnon (2012) concluded that the same live load factor applied if single-axle load limits were equal to 53% of tandem-axle load limits.

McClelland (2013) noted that forest bridges have been designed over the years with various design codes and methodologies; therefore, there is no one standard live load factor that can be used for all structures. For example, the L-45 design vehicle was popular in the 1980s. The L-60 design vehicle was popular in the 1990s. CL-625 (for highway-legal vehicles) and L-75 (for off-highway vehicles) designs were popular in the late 1990s to 2000s, and BCL-625 replaced CL-625 in the late 2000s. During this period, four consecutive editions of the CHBDC were issued for use (1978, 1988, 2000, and 2006).

McClelland (2013) selected 1.6 as the live load factor for short-truck load limit calculations because there were no population studies to justify a live load factor of 1.5. He postulated that this was reasonable given the consistency of short-truck (i.e., 3- and 4-axle gravel or rock truck) loading and axle configurations. Unlike the analysis illustrated in Table 3, the CL3-W short truck used by SNT Engineering to model short-truck load limits was calibrated to use live loads that don't require any special attention to short spans.

McClelland (2013) specified a relatively conservative live load factor of 2.0 when evaluating the live load demands of tracked equipment because of the lack of population studies of GVW and because the operator could change the left–right load distribution by rotating the cab. This decision resulted in GVW load limits for tracked equipment that were lower than the GVW of common forestry tracked equipment [e.g., a 38.2 t Cat 235 excavator exceeded the 35 t capacity of L-75 bridges; all of the heaviest grapple yarders (90 to 115 t) exceeded the 85 t load limit estimated for L-165 bridges]. This situation was of concern because some in the forest industry may disregard the proposed GVW load limits on the basis that these bridges apparently were able to support these loads in the past.

The GVW of tracked equipment are believed to be relatively predictable given that this equipment carries no payload and manufacturers typically list an estimated operating weight (e.g., shipping weight plus weight of wire rope, fuel, oil, operator, etc.). After discussion with forest bridge experts, a live load factor of 1.3 was selected and the load limits were re-evaluated.[1] This resulted in higher estimates of bridge load limits for tracked vehicles. In addition, because concrete slab and gravel-over-log-stringer bridges sometimes are used in remote industrial locations, coinciding with where tracked equipment may be walked across bridges, load limits were also evaluated for these types of bridges.

[1] Teleconference discussion with Darrel Gagnon (COWI North America), Julien Henley (Associated Engineering), Brian Chow (FLNRORD), and Gary McClelland (SNT Engineering) on August 19, 2014.

Provincial guidance in the matter of defining traffic type for vehicle load limits is lacking, and a consistent approach for load rating is needed. Such an approach should consider the type of traffic anticipated to use the bridge during its design life and the effectiveness of enforcement efforts to control truck GVW.

Recommendation: *Higher allowable loads would be justifiable if a PA traffic classification is applicable to non-log–hauling vehicles using FSRs [e.g., equipment transports, non-forest industry trucks (including short trucks)]. FPInnovations recommends that FLNRORD commissions a study of non-log–truck traffic on FSRs to determine whether a single reduced live load factor is applicable for posting BCFS bridges.*

DLA and Distribution Factor

CAN/CSA-S6-88 defined DLA (dynamic load allowance) as a function of first flexural frequency (as a function of span length). CAN/CSA-S6-00 revised this definition, resulting in DLA being a function of the axle configuration causing the load effect that is being evaluated. This helps to account for the impact of overloaded axles. One problem with this definition is that DLA varies with load effect, span length, and location where the force effect is being considered. Given the complexity in choosing the appropriate DLA, Henley (2003) suggested that DLA be based on span length based on the following simple rules:

- For spans <10 m, DLA = 30%.
- For spans ≥10 m, DLA = 25%.
- Where only a single axle is used, the value of 40%, as required by CAN/CSA-S6-00, should be adopted. [Where using a tandem axle for deck design, Henley (2003) recommended a value of 40% be applied to both axles.).

The *Forest Service Bridge Design and Construction Manual* (FLNRO, 1999) requires that DLA equals 30% for all bridges and, thus, would be appropriate for all span lengths.

Gagnon (2012) did not utilize DLA or distribution factor (DF) when stating the maximum GVW of the bridge load limits. This was done for simplicity and assumed that the same DLA and DF values would be used for both the bridge design vehicle and the demand vehicle(s) being compared. McClelland (2013) made similar assumptions for the short-truck evaluation. The DF for short trucks was taken to be the same as for the bridge design trucks; however, this is likely somewhat conservative given that rock trucks are equipped with wide tires that limit eccentric tracking. Because short trucks, like the bridge design vehicles, are assumed to interact with a bridge in the same way, and there was no DLA data available for them, McClelland assumed their DLA to be 30%.

In lieu of having actual data on DF, McClelland (2013) used a DF for tracked vehicles of 0.55. This value assumed that the tracked equipment created very balanced loading of the bridge beams by staying aligned with the bridge centreline, not carrying payload, and not stopping to do work while on the bridge (i.e., rotating its cab and boom). The wide undercarriage of tracked equipment is expected to limit potential eccentricity also.

(McClelland, 2013) assumed a DF value of 0.23 for use with concrete slab and gravel-over-log-stringer bridges.

In the absence of published data, a DLA for tracked equipment was selected.[2] Given the slow travel speed, short spans typically involved, and lack of individual axles, it was judged to be appropriate to use some value less than 30%. A DLA of 24%, therefore, was selected for the analysis.

***Recommendation**: FPInnovations recommends that FLNRORD conducts further research to improve confidence in selecting DF and DLA for tracked equipment.*

Technical Check of Bridge Load Limit Values

Table 4 presents the load limits calculated for each bridge design and the accompanying notes (McClelland, 2013). FPInnovations reviewed and checked these values for arithmetic correctness. The sections that follow discuss the recommended changes to the values in Table 4.

Table 4. Recommended posted limits of various forest road industrial traffic types (McClelland, 2013)

Bridge design vehicle	GVW limit (t) [a]	Single-axle load limit (t)	Tandem-axle load limit (t)	Tridem-axle load limit (t) [b]	Short truck GVW limit (t)	Tracked equipment GVW limit (t)
L-45	43.5	8.5	16.1	17.7	25.5	25
L-60	58.1	11.4	21.5	23.6	28	27.5
BCL-625 [c]	63.5	9.1	17	24	33.2	33
L-75	72.6	14.3	26.9	29.6	35.8	35
LOH	83.2	20.3	38.3	42.1	46.4	44
L-100	96.7	19	35.8	39.4	46.9	44
HOH	129.4	31.5	49.5	n/a	71.4	67
L-150	145.2	28.5	53.7	n/a	69.9	66
L-165	159.6	31.3	59.1	n/a	89.8	85

[a] GVW load limits of the BCFS design trucks have been increased to reflect the reduced variability in loading expected with log-hauling trucks.

[b] Maximum tridem-axle values were not provided for HOH, L-150, and L-165 designs as we are of the belief that there are no trucks with tridem axles for those traffic categories.

[c] BCL-625 GVW and axle load limits are governed by B.C.'s Commercial Transport Act.

BCFS Bridge Design GVW and Axle Load Limits

Many BCFS design bridges were built before 2000 using a live load factor of 1.6. However, as weigh scale data indicated that log-hauling load variability conforms to PA traffic, Gagnon (2012) determined that a live load factor of 1.5 would be justified for BCFS bridge designs. Accordingly, Gagnon (2012) recommended increasing historical GVW load limits for these bridges by 6.7% (i.e., 1.6 / 1.5). Gagnon (2012) did not account for other types of non-forestry trucks using FSRs, however, and before a general reduction in live load factor is applied, the load variability of other populations of trucks using resource roads should be studied further. Until such a study is completed, FPInnovations does not recommend using a live load factor of 1.5 for posting forest bridges.

[2] The very limited data that COWI North America has located in the past indicates that DLA for tracked vehicles is somewhat higher than for typical highway vehicles (personal communication, Darrel Gagnon, COWI North America).

To apply the same live load factor to both GVW and axle loadings of log trucks, Gagnon (2012) specified that the design vehicle heavy axle load should be reduced by 20% to account for its greater variability. The design vehicle tandem-axle load limits, therefore, were calculated as the maximum tandem-axle loading, defined as (46% of the GVW) x 80% = 37% of the GVW load limit. Per Gagnon (2012), the single- and tridem-axle load limits were taken to be 53% and 110% of the tandem-axle load limit, respectively. Alternatively, the BCFS single-, tandem-, and tridem-axle load limits can be expressed as 19%, 37%, and 40% of GVW, respectively.

The axle loadings for the BCFS L-60 bridge design appear sufficient for many log-hauling truck configurations, except for the tridem-axle load limit (23.6 t). The tridem-axle load limit is not high enough to accommodate legal tridem loading on log-hauling configurations with winter log-hauling tolerances (i.e., 25.5 t for tridem axles on tractor/semi-trailers and 26.5 t for tridem axles on truck/pole trailers). If needed to carry log-hauling truck configurations with tridem axles, an L-60 bridge could be load-rated individually, which may produce a more favourable load limit. The L-60 bridge design is of limited usefulness for today's truck operating weights, and the construction of new L-60 bridges is not recommended.

The GVW and axle load limits for the BCFS L-45 design vehicle in Table 4 are too small to accommodate most legally loaded log-hauling trucks but would suffice for various short trucks, tracked equipment, and light non-forestry trucks. Therefore, the bridge is of limited usefulness for resource roads, and the construction of new L-45 bridges is not recommended. McClelland (2013) notes that road users are likely to ignore the posted limit of these bridges or not haul over them at all.

It is anticipated that in-service L-45 and L-60 bridges will need to be individually load-rated and posted accordingly, in which case the load limits may increase by 9% (with a reliability index of 3.25). Further, many of these bridges were over-built and detailed load ratings will identify this.

It is the author’s understanding that FLNRORD is no longer specifying new L-45 or L-60 bridges because they are not capable of handling the current allowable public highway loads. There are, however, numerous existing legacy bridges that were designed to L-45 and L-60 that need to be considered with a load rating approach.

The analysis of Buckland & Taylor that provides the ability to consider logging trucks as PA traffic was limited to logging-truck data. As such, the assumptions justifying the use of reduced live load factors are limited to being applied to logging-truck configurations. It is not known whether the non-log–truck traffic has similar characteristics that would allow for reduced live load factors and, thus, greater load allowances.

LOH and HOH Bridge Design GVW and Axle Load Limits

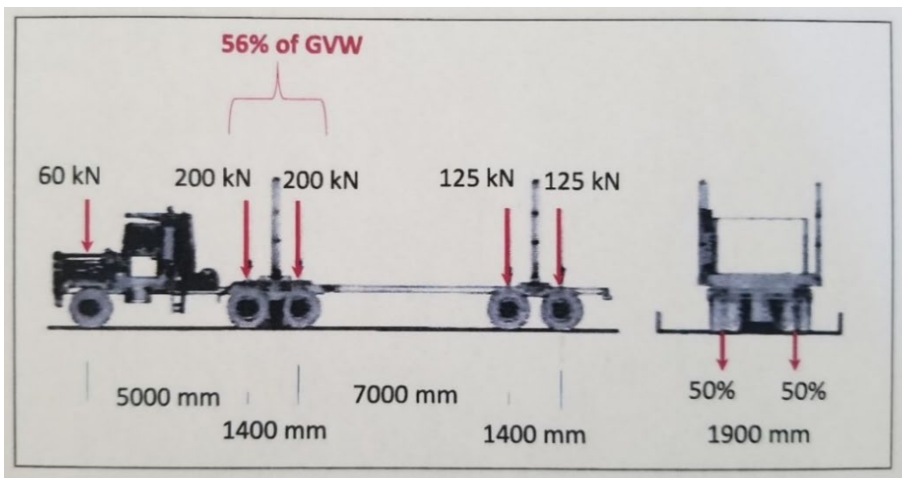
Gagnon (2012) derived the live load factor of 1.5 to provide a truck model better matched to current log hauling truck GVW. Gagnon calculated GVW load limits for the LOH and HOH bridge design trucks by multiplying the design vehicle GVW by the ratio of live load factors 1.7 / 1.5 (= 1.133). As with the BCFS designs, however, further study of the load variability of other populations of trucks using resource roads should be undertaken before a general reduction in live load factor (i.e., general increase in GVW load limit) is applied. Until such a study is completed, FPInnovations does not recommend using a live load factor of 1.5 for posting forest bridges.

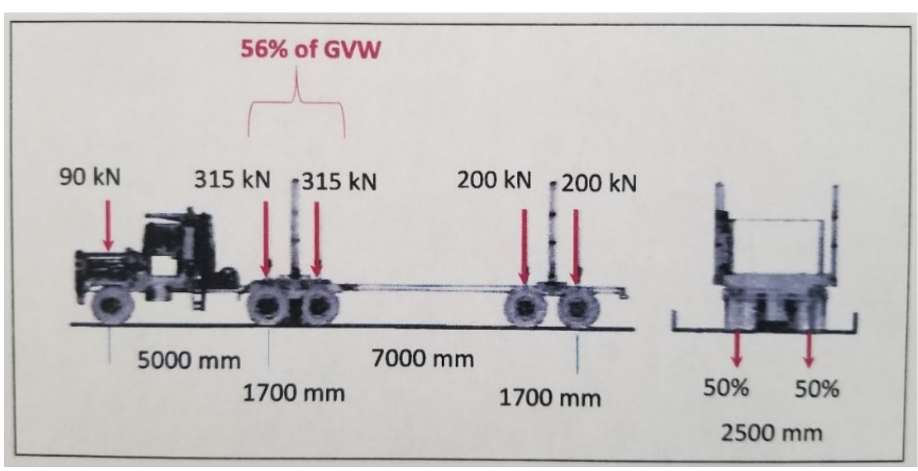
To apply the same live load factor to both GVW and axle loadings of log trucks, Gagnon (2012) specified that the heaviest axle load limits should be reduced by 20%. The design vehicle tandem-axle load limits, therefore, were calculated as the maximum tandem-axle loading, defined as (56% of the GVW) x 80% = 46% of the GVW load limit. Per Gagnon (2012), the single- and tridem-axle load limits were taken to be 53% and 110% of the tandem-axle load limit, respectively. The LOH- and HOH-axle load limits were developed separately (Gagnon, 2004) and are 24%, 46%, and 51% of the GVW for the single, tandem, and tridem axles, respectively.

The GVW load limits for the LOH and HOH design vehicles in Table 4 were checked and found to be incorrectly calculated, albeit only by a small amount. The reason for this is that the calculation of GVW and axle load limits were based on the original design vehicle GVW rather than the vehicles that FLNRORD currently uses (Ministry of Forests and Range, 2016). The new definitions of the LOH and HOH vehicles were developed by Gagnon and published in 2009 (Associated Engineering, 2009). The new definitions feature a 50%–50% load imbalance (to be consistent with CAN/CSA-S6-06), different axle spacing and axle widths, and slightly different axle loads (Figures 1 and 2). The current GVW values of the LOH and HOH design vehicles are 72.375 t (710 kN) and 114.200 t (1120 kN), respectively.

Figure 1. LOH design vehicle. GVW: 72 375 kg (710 kN).

Figure 2. HOH design vehicle. GVW: 114 200 kg (1 120 kN).





Recommendation: *FPInnovations recommends that the LOH and HOH load limits be based on the latest defined configurations (as noted in Figures 1 and 2) for these bridge design vehicles.*

CL-625 and BCL-625 Bridge Design GVW and Axle Load Limits

The GVW and axle load limits for the CL-625 and BCL-625 design vehicles were as specified in the Commercial Transport Act (Regulation 30/76 Sec 7.26) and not derived as part of these studies. This was because these bridges tend to be used on resource roads that lead directly to public highways. The values in Table 4 are the specified limitations for travel on public highways. As a result, the GVW and axle load limits for these bridges appear to be understated and may be closer to the L-75 load limits, given that they are governed by the same GVW limits as tracked equipment.

Gagnon (2012) recommended BCL-625 axle load limits that were constrained to highway-legal loads. However, it was noted that these did not allow for heavier log-truck axle loadings that result when winter log-hauling tolerances are applied by TRAN. Therefore, these axle load limits were increased to include maximum (winter) axle load tolerances for log-hauling trucks (no tolerance is applied to the GVW). With the winter tolerances applied and values rounded to the nearest one-half tonne, the posted axle load limits are 9.5 t, 18.5 t, and 26.5 t for single axles (not steering axles), tandem axles, and tridem axles, respectively. Load limits for CL-625 bridges were developed using the same methodology and assumptions as BCL-625 design vehicles. Thus, the CL-625 and BCL-625 bridge load limits, as shown in Table 7, will support all B.C. log-hauling trucks that carry legal loads during the winter.

<u>Recommendation</u>: *Given that CL-625 and BCL-625 bridge designs are commonly implemented for B.C. resource roads utilized by highway traffic, FPInnovations recommends that GVW and axle load limits of these designs be constrained to highway-legal limits plus applicable winter log-hauling tolerances, as captured in Table 7.*

Short-truck Load Limits

Articulated rock trucks and gravel trucks are a special vehicle configuration that apply heavy, concentrated axle loads onto resource road bridges and are believed to cause increased rates of damage to deck systems. The models of articulated rock trucks used on resource roads typically have 2 or 3 axles and can weigh as much as 100 t. The models of gravel trucks typically found on resource roads have 3 or 4 axles and may weigh 45 t or more. The concentrated axle loadings of these trucks create higher force effects in bridges than conventional trucks and, therefore, load limits were developed specifically for them.

The maximum bending moment and shear resistance was calculated for each bridge design for a range of common forest bridge simple span lengths (5 to 36 m). The resistances were compared to the demand from a CL3-W short truck having the maximum GVW reported in McClelland (2013). McClelland (2013) calculated maximum shear force as occurring 1 m from the end of the simple span, whereas FPInnovations' software estimates maximum shear at the end of the span. As a result, the calculated maximum shear forces differed by a small amount between the McClelland and FPInnovations calculations. Being a relative force effects comparison; however, the same short-truck load limits were found. Live load factors were not applied to either the design load or the short truck because the same three live load adjustment factors were used in all cases and they would cancel each other out if included. Similarly, dead loads were not included in the calculation of relative force effects. The live load factors used for evaluating short trucks are summarized in Appendix 2.

McClelland (2013) also proposed short-truck load limits based on the sum of the single-axle load limit plus the tandem-axle load limit. For example, the short-truck limit for L-75 bridges was calculated using the force effects approach above to be 35.8 t; however, the sum of the single- and tandem-axle load limits was 41.2 t. In 2018, FLNRORD and FPInnovations, in consultation with Associated Engineering, decided not to use a CL3-W to represent heavy short trucks, and instead, adopted McClelland's method of estimating short truck GVW as the sum of single and dual- or tridem-axle load limits.[3]

FPInnovations analyzed manufacturer specifications for 29 articulated rock trucks and found that their GVW ranged from 43.7 to 99 t, and all had three axles (Figure 3). Given that even the lightest articulated rock truck (the Bell B25E, at 44 t GVW) substantially exceeded the sum of single- and tandem-axle load limits for L-75 and lighter bridge designs, it was judged that the short-truck GVW for these lighter bridge designs should be based on tridem-drive gravel trucks. That is, the GVW for the L-75, BCL-625, CL-625, L-60, and L-45 bridge designs should be taken to be the sum of single- plus tridem-axle load limits. Conversely, the GVW for LOH and heavier bridge designs should be taken to be the sum of single- plus tandem-axle load limits. Inherent in this approach is the adoption of the same live load factor used to calculate the axle-group load limits—that is, a live load factor of 1.6 for BCFS designs and 1.7 for CL-625, BCL-625, LOH, and HOH designs. The resulting general load limits for short trucks are given in Table 7.

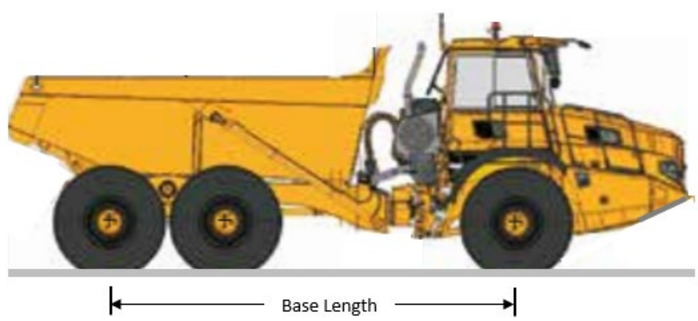


Figure 3. Articulated rock truck ("short" truck)

<u>Recommendation</u>: *FPInnovations recommends that short-truck GVW load limits be taken to be the sum of single- plus tandem-axle load limits for LOH and heavier forest bridge designs, and the sum of single- plus tridem-axle load limits for L-75 and lighter bridge designs.*

[3] The CL3-W design vehicle was intended only for legal highway axle loads and GVW of up to about 33 t (personal communication, Julien Henley, Associated Engineering).

Bridge girder evaluations for 29 articulated rock trucks

In addition to the general analysis of short truck load limits a secondary analysis was conducted to evaluate the girder capacity of each bridge design versus the maximum force effects from each of 29 articulated rock trucks. For each span length between 5 and 36 m, the bridge girder capacity (i.e., the maximum factored force effects from the bridge design vehicle) were compared to the corresponding demands (i.e., the maximum factored force effects) from each articulated rock truck.

The calculation of each rock truck's force effects considered the manufacturer-specified axle spacing, out-to-out tire width, and axle loading. The load factors used for the rock trucks comprised a live load factor of 1.7, a DLA of 0.4, and a DF based on a 50-50 load imbalance and the maximum eccentricity allowed by the bridge deck width and truck width. The load factors used for the bridge design vehicles are detailed in Appendix 2.

Bridge deck system evaluations for 29 articulated rock trucks

The concentrated loading of articulated rock trucks can be problematic for forestry bridge deck components and systems. In order to investigate the impacts of short trucks on bridge decks a comparison was made of the maximum factored axle load(s) from each of the 29 short trucks versus the maximum factored axle load from each of the bridge design vehicles. It is believed to be common practice to maximize the loading of short trucks when off-highway so the articulated rock truck GVW were taken to be their manufacturer-specified heaped capacity, and conservative values for the live load factor and DLA were selected for factoring the axle loads (1.7 and 0.4, respectively). Side-to-side load axle load distribution was taken to be 50%-50%. The GVW at heaped capacity and factored axle loads for each of the 29 articulated rock trucks are presented in Table 5.

Table 5. Factored axle loads for 29 models of articulated rock truck

	GVW at heaped capacity (tonnes)	Factored steering axle load (kN)	Factored second axle load (kN)	Factored third axle load (kN)	Maximum factored single axle load (kN)
Bell B25E	43.7	150	**180**	**180**	**180**
JD 260E	46.7	**185**	180	180	**185**
Cat 725 C2	47.0	**198**	177	174	**198**
Volvo A 25 G	47.5	174	**190**	**190**	**190**
Bell B30E	48.2	158	**203**	202	**203**
Terex TA250	48.3	**197**	187	180	**197**
JD 310E	51.0	177	**209**	**209**	**209**
Doosan DA 30	51.5	195	**203**	**203**	**203**
Cat 730	51.5	**208**	198	196	**208**
Terex TA300	51.9	**213**	198	195	**213**
Volvo A 30 G	52.3	182	**214**	**214**	**214**
Cat 730C EJ	53.3	185	**220**	217	**220**
Komatsu HM 300-5	53.5	192	**225**	207	**225**
Bell B40D	66.9	229	**278**	273	**278**
Terex TA 400	68.3	251	**279**	277	**279**
Cat 740 GC	68.7	214	**292**	**292**	**292**

Volvo A 40 G	68.9	236	**284**	**284**	**284**
JD 410 E	69.1	263	**271**	268	**271**
Doosan DA 40 - 5	70.3	260	**280**	**280**	**280**
Bell B40E	70.8	256	**289**	282	**289**
Volvo A 45 G	71.1	240	**295**	**295**	**295**
Bell B45E	72.9	258	**300**	293	**300**
Cat 740 EJ	73.7	257	**303**	300	**303**
JD 460 E	74.0	263	**302**	300	**302**
Cat 745	74.4	**299**	286	283	**299**
Komatsu HM 400-5	75.1	267	**314**	296	**314**
Bell B50D	79.9	274	329	**330**	**330**
Bell B50 E	81.1	283	**333**	331	**333**
Volvo A 60 H	98.4	335	**407**	**407**	**407**

To provide useful guidance to articulated rock truck operators, FPInnovations developed a GO/NO GO guide for these 29 rock trucks based on both girder force effects and the deck analysis above. The results were expressed in a table as either **GO** (the bridge design capacity and deck system can support the rock truck) or **NO GO** (the rock truck should not cross because its force effect(s) and(or) axle load(s) exceed the bridge design capacity). The GO/ NO GO guide applies to all simply supported, single span bridges between 5 to 36 m long. The GO/ NO GO table is presented in Appendix 1.

The short truck load limits in Table 7 are general in nature and, therefore, conservative. The GO/ NO GO table in Appendix 1 offers guidance for specific articulated rock trucks and these results support the use of higher GVW and axle loads with these trucks than allowed using Table 7. If the GO/ NO GO table indicates a truck-bridge combination is a NO GO, a higher load limit than in Table 7 may still be possible by consulting a bridge engineer for a load rating of the bridge (using the specific weights and dimensions of the bridge and the articulated rock truck).

Tracked Equipment Load Limits

It is not uncommon for tracked equipment to be moved under its own power on resource roads, instead of with equipment transport trucks. Tracked equipment constitutes concentrated loads, and traditional load limit signage does not safely capture the limits for crossing of bridge infrastructure.

The load limits in Table 4 for tracked equipment were checked by calculating the maximum bending moment and shear for tracked equipment assuming a uniform load 4 m long and a maximum GVW, as specified in Table 4. Subsequently, a review of the specifications of 104 types of tracked forestry and resource road building equipment revealed that their track contact lengths ranged from 2.6 to 5.5 m (3.8 m, on average), while 14 models of heavy tracked yarders and line loaders (over 50 t operating weight) had contact lengths ranging from 4.2 to 5.5 m (4.8 m, on average).[4] Table 6 summarizes the findings of this equipment weight and dimension survey. Given the findings of this equipment review, the 4 m-long contract track length used by McClelland (2013) for analyzing most types of tracked forestry equipment appears to be appropriate.

[4] In general, manufacturers were the source of all equipment information. Little information exists online for older model Coastal yarding and line loaders, however, and estimates of machine operating weights and some dimensions were graciously provided by the staff and management of T-Mar Industries in Campbell River, B.C.

However, assuming a 4 m-long track contact length for heavy coastal bridge designs appears overly conservative given the actual dimensions of large coastal equipment. FPInnovations recommends, therefore, that the contact length for Coastal bridge designs assume a 4.5 m-long track contact length.

Table 6. Operating weights and key dimensions of tracked forestry equipment used in B.C.

Equipment type	Estimated operating weight (t)		Track contact length (m)		Undercarriage width (m)	
	Average	Maximum	Average	Maximum	Average	Maximum
Feller bunchers & harvesters	35	42	3.9	4.3	3.4	3.6
Road building excavators	33	47	3.9	4.5	3.4	4.0
Road building bulldozers	28	40	3.2	3.5	3.4	3.9
Log loaders	39	49	4.0	5.1	3.6	4.0
Large yarders & cable log loaders	51	115	4.1	5.5	3.5	4.7

FPInnovations conducted a preliminary analysis of distribution factor to substantiate McClelland's choice of 0.55. Based on the equipment survey data, lighter forestry tracked equipment had an average operating weight of 34 tonnes and an average width of 3.4 m. The maximum eccentricity possible with this undercarriage width on 4.28 m-wide deck bridges was only 229 mm. This resulted in an average distribution factor of 0.57 for this equipment. Heavy yarders and line loaders govern bridge design on the B.C. coast and require the use of very strong designs (e.g., L-150 and L-165) and 4.878 m-wide decks. The 14 largest tracked machines (a subset of the 20 originally reviewed) had an average operating weight of 80 tonnes, an average undercarriage width of 3.9 m, and an average maximum eccentricity of only 183 mm. This resulted in an average distribution factor of 0.55 on 4.878 m-wide deck bridges. A complete listing of estimated operating weights, track contact lengths, and undercarriage widths is given in Appendix 3.

A general analysis of bridge force effects was conducted for tracked equipment. Maximum shear and flexure demand from a representative piece of tracked equipment of a given GVW was compared with the shear and flexure resistances of each bridge design. This force effects comparison of bridge resistance versus the force demands from the tracked vehicles was computed for both conventional two-girder forestry bridges and for gravel-over-log-stringer and concrete slab bridges. Only single, simply supported, bridges with clear spans of 5 to 36 m were evaluated because this covers that majority of B.C. forestry bridges. GVW was incrementally increased until one of the demands equaled the corresponding resistance. The GVW at which the demand first equaled a resistance was taken to be the load limit for that bridge design and compared with the results presented in McClelland (2013). McClelland (2013) calculated maximum shear force as occurring 1 m from the end of the simple span, whereas FPInnovations' software estimates maximum shear at the end of the span. As a result, the calculated maximum shear forces differed by a small amount between the McClelland and the FPInnovations analyses, but being a relative force effects comparison, the same load limits were produced. Dead loads were not considered in the comparison of relative live load force effects.

The tracked equipment load limits were re-calculated for forest bridges using a lower live load factor than that used in McClelland (2013). That is, the FPInnovations analysis used a live load factor of 1.3 versus the live load factor of 2.0 originally used in McClelland (2013)]. As in (McClelland (2013), FPInnovations used a distribution factor of 0.55 and a track contact length of 4.0 for evaluating equipment loads for most bridge designs. However, FPInnovations used a contact track length of 4.5 m for evaluating tracked equipment loads for four bridge designs commonly used on the coast (i.e., L-120, HOH, L-150, and L-165 bridge designs). This increased load limits by 53% - 67% compared with those in McClelland (2013). Tracked-equipment load limits also were calculated for concrete slab and gravel-over-log-stringer bridges using the same live load factor (1.30), but smaller DLA and DF (0.24 and 0.23, respectively). The load factors used for evaluating tracked equipment are summarized in Appendix 2. Figures 4 and 5 illustrate the factored force effects of a 54 t GVW piece of tracked equipment versus the L-75 design vehicle for 5 to 36 m span 2-girder forest bridges. The tracked-equipment load limit was governed by bending moment rather than shear, and the two bending moment curves were approximately equal at a clear span of 9 m. Note that deck capacity was anticipated to have the same design rating as the rest of the bridge and, therefore, would not need to evaluated separately.

The load limits for tracked vehicles calculated in McClelland (2013) are anticipated to be a concern because in the past, these bridges were considered strong enough to support the heaviest class of yarders (60 to 115 t GVW). After discussion with local forest bridge experts, however, lower live load factors were found to be justified, and these resulted in 2-girder bridge load limits in excess of the heaviest tracked equipment for the L-165 and L-150 designs. The calculation of load limits for concrete slab or gravel-over-log-stringer bridges found design load limits that were between 12% and 18% lower than the corresponding 2-girder forest bridges. The highest load limit for concrete slab and gravel-over-log-stringer bridges was 114 t for L-165 bridges; this is enough to accommodate almost all yarding equipment. Existing bridges also can be individually load rated and this will likely produce even higher load limits.

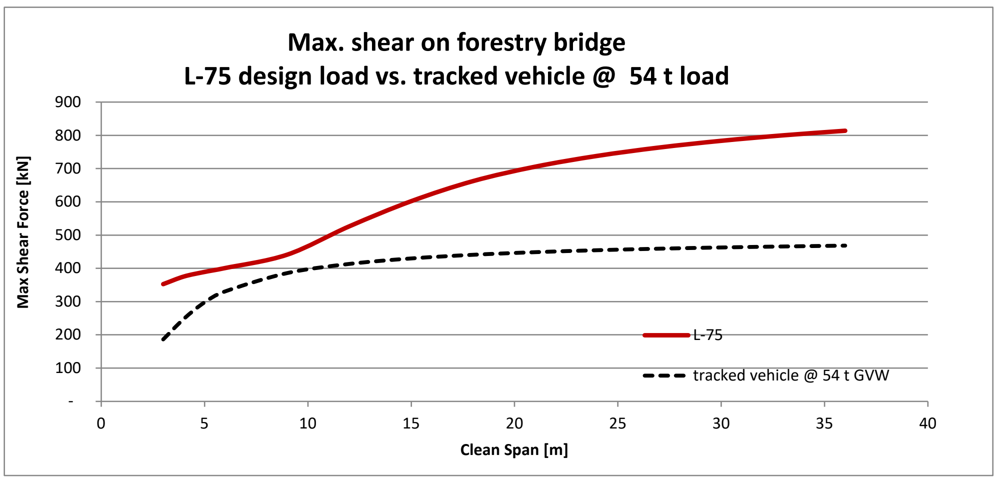


Figure 4. Comparison of maximum factored shear forces from an L-75 design vehicle and a 54-tonne tracked equipment on 2-girder, single span, L-75 forest bridges.

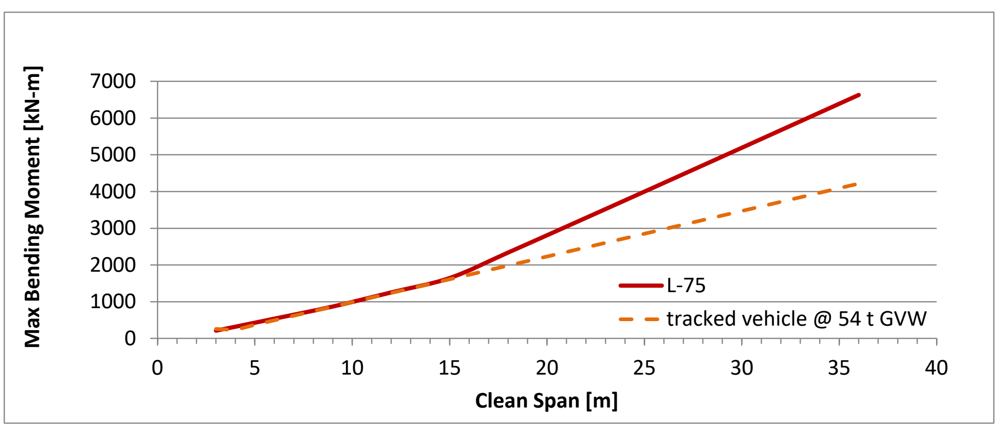


Figure 5. Comparison of maximum factored bending moments from an L-75 design vehicle and a 54-tonne tracked equipment on 2-girder, single span, L-75 forest bridges.

Recommendation*: FPInnovations recommends that road networks be posted for the lesser of the two tracked-equipment load limits (i.e., for concrete slab and gravel-over-log-stringer bridges) when posting road load limits. Bridge designers should be informed about the higher load limits that apply **ONLY** to 2-girder forestry bridges, however, so that these load limits can be used on road networks with no concrete slab or gravel-over-log-stringer bridges, or where existing bridges of this type have been individually posted.*

Recommended Load Limits for B.C. Forest Bridges

Table 7 presents the recommended GVW and axle load limits for posting new or existing B.C. forestry bridges and (or) associated road networks. This table was prepared as a convenient tool for rapidly selecting bridge load limits based on the original design vehicle configuration for the bridge infrastructure; however, these load limits were conservatively estimated. Specific bridges will likely have higher load limits if evaluated individually using a more rigorous analysis. Before selecting load limits from the table, the reader should review this report and the notes to the table and should understand the limitations of the analysis and the information.

The live load factors, DLA, and DF used to calculate the load limits in Table 7 are summarized in Appendix 2. The BCFS bridge design vehicles are defined in FLNRO (1999) and illustrated in Appendix 4. Additional forest bridge design vehicles considered in this project are illustrated in Appendix 5.

Table 7. Recommended load limits for B.C. forest bridges [a]

Bridge design vehicle	GVW limit (t) [b]	Single-axle limit (t) [c]	Tandem-axle limit (t) [c]	Tridem-axle limit (t) [c]	Short-truck GVW limit (t) [b, e]	Tracked equipment GVW limit (t)[b, f]	
						2-girder bridge	Concrete slab or gravel-over-log-stringer bridge
L-45	41	8.0	15.0	16.5	25	39	33
L-60	55	10.5	20.0	22.0	33	43	36
CL-625[d]	64	9.5	18.5	26.5	36	50	41
BCL-625[d]	64	9.5	18.5	26.5	36	55	45
L-75	68	13.0	25.0	27.5	41	54	45
LOH	72	18	34	37	51	73	61
L-90	82	16	30	33	46	66	55
L-100	91	18	33	37	51	69	57
L-120	109	21	40	44	61	83	69
L-150	136	27	50	55	77	104	88
HOH	114	28	53	58	80	110	96
L-165	150	29	55	61	84	130	114

[a] The calculated load limits assume that the bridge was appropriately designed, constructed, and maintained, and has no structural deterioration that would reduce the capacity of the bridge. This table is for simply supported, one-lane, single-span bridges carrying one vehicle at a time. Load limits apply to the range of spans from 5 to 36 m but are conservative for all except the governing span length. These load limits apply to conventional 2-girder B.C. forest bridges except for the tracked vehicle GVW limits on concrete slab and gravel-over-log-stringer-bridges.
A more detailed evaluation of a specific bridge could yield higher allowable load limits. For unusual or specialty equipment, the bridge owner should consult with a bridge engineer. Definitions of design vehicles may change over time. These load limits are based on the most recent (i.e., 2019) definitions. Load limits apply to the original design vehicle and not to any subsequent uprating unless justified by structural upgrades.

[b] GVW limits for all bridge designs are rounded to the nearest tonne.

[c] Axle load limits for lighter designs (L-45 to L-75) are rounded to the nearest one-half tonne, and heavier designs are rounded to the nearest tonne (LOH to L-165).

[d] Axle load limits are B.C. highway-legal loadings plus maximum log-hauling axle weight tolerances (0.5 t for non-steering single axles and 1.5 t for tandem and tridem axles). The tridem-axle legal loading in B.C. is 25 t (for pole trailer configurations).

[e] Short-truck GVW limits for L-45, L-60, CL-625, BCL-625, and L-75 designs are the sum of the single-axle plus tridem-axle load limits. Short-truck GVW limits for higher-capacity designs (LOH and higher) are the sum of the single-axle plus tandem-axle load limits. These load limits assume the rock truck tracks off centreline with the same eccentricity as the corresponding bridge design vehicle (i.e., by 400 to 619 mm).

[f] Tracked equipment load limits assume a 4 m-long contact track length for the L-45 to L-120 designs and a 4.5 m-long contact length for the L-150, HOH, and L-165 designs. Tracked equipment should be carefully driven down the bridge centreline when crossing, and the boom or gantry should not be rotated, or the machine stopped to do work while on the bridge. The load limits for conventional forestry bridges were calculated using a live load factor of 1.3, a DLA of 0.3, and a DF of 0.55 (which assumes the track edge is touching the curb). The load limits for gravel-over-log-stringer & concrete slab bridges were calculated using a live load factor of 1.3, a DLA of 0.24, and a DF of 0.23.

Professional Engineer's Load Rating of Existing Forest Bridges

Section 14 of the CHBDC provides guidance to bridge engineers conducting a load rating of an existing bridge. Knowing details about the traffic loading and the as-built bridge condition, the engineer can exercise judgement to adopting smaller live load factors and DLA for the determination of bridge capacity as appropriate. Smaller live load factors can result in considerably higher GVW and axle load limits than shown in Table 7 may be appropriate for the bridge.

Higher load limits also may occur if a bridge has been over-designed and its components are capable of higher loadings than the nominal bridge design limits. This would be identified through a more rigorous and detailed load-rating process.

Communicating Bridge Load Limits

The load limits in Table 7 offer a way of clarifying the capacity of forest bridges in B.C. This new information and the reasons for it need to be communicated to road use permit holders and other resource road users. This may best be done through an engineering bulletin posted on the FLNRORD's engineering branch website, letters sent to road use permit holders, trade magazine articles, and presentations given to road safety committees around the province.

This load limit initiative provides an opportunity for FLNRORD to update its bridge load rating policy. McClelland (2013) states that "essentially [FLNRORD] could use the proposed load limits values as default bridge design load ratings but could allow engineers to increase the loadings for specific truck styles on designated roads provided the requirements of Section 14 of [the current CHBDC (CAN/CSA-S6-14)] are met." This initiative also provides a process to introduce the LOH and HOH design vehicles to forest bridge designers and resource road users.

A useful approach might be to post a road load rating sign at the commencement of an FSR. This sign would show the bridge load limitations found on the FSR and the connecting road network. This signage would be based on the bridge capacity used on the network and would reflect the proposed load limits in Table 7.

In the case that a mix of bridge designs was used on the FSR network, then the posting should consider all of these and base the road load limit on the minimum load limits for GVW and axles. For example, a network with multiple L-100 and LOH bridges should be posted with the L-100 design axle load limits, short truck GVW limit and tracked equipment GVW limit but with the GVW limit from the LOH design because it is lower than the GVW limit from the L-100 design (Table 8). In this example, it was assumed that both 2-girder forest bridges and concrete slab or gravel-over-log-stringer forest bridges will be used on the FSR network in the future, so the smaller of the tracked-equipment load limits (57 t for concrete slab and gravel-over-log-stringer L-100 bridges) should be posted.

Bridge and road load limit signage can contain only a limited amount of information; the specifics upon which the load limits are based should be communicated to road users and those responsible for bridge maintenance also. With respect to the notes for Table 7, it will be important to let users know that vehicles should cross the bridge one at a time and tracked equipment should be walked down the centreline of the bridge without stopping or rotating the cab.

Table 8. Road load ratings based on more than one bridge design

Bridge design vehicle	GVW limit (t)	Single-axle load limit (t)	Tandem-axle load limit (t)	Tridem-axle load limit (t)	Short truck GVW limit (t)	Tracked equipment GVW limit (t)
LOH	**72**	**18**	**34**	**37**	**51**	61
L-100	91	**18**	**33**	**37**	**51**	**57**

Note: a network with multiple L-100 and LOH bridges should be posted with the load limits from the L-100 design for axle groups, short truck GVW, and tracked-equipment GVW but with the GVW limit from the LOH design because it is lower than the GVW limit from the L-100 design.

Anyone planning bridge capacity signage should consider its application. Road load rating does not necessarily need to be the same as the posting of a bridge that has been identified as having substandard capacity. If a bridge near the start of a mainline (FSR) is downrated and all traffic must cross that bridge to access the FSR network, the road load rating for the entire network should be reduced to be the same as the downrated bridge. If a bridge is downrated but does not restrict access to most of the FSR network (e.g., it is located on a spur road or there is a bypass route), then the load road rating for the network could be higher, and the load limits for the spur road with the downrated bridge need to be signed separately.

Load Limit Sign Formats

Bridge capacity signage quantifies the load limits of the structure. Road users must be able to read and understand the sign to be able to compare their vehicle's loading with the stated network bridge capacity, and to assess the risks of proceeding. To not adhere to the posted load limits is a violation of the Forest and Range Practices Act. Despite this, vehicle operators may choose to ignore bridge capacity signs for various reasons, including:

- The sign is confusing or ambiguous; for example, the sign does not appear to include information about the operator's vehicle type.
- The load limits are less than the weight of the operator's vehicle, but the operator judges that there is a low risk of bridge failure, and the costs of complying with the posted load limits are greater than the perceived cost of crossing the bridge.
- The load limit is judged to be too restrictive or conservative. For example, the L-165 load limit of 85 t given in Table 4 is lower than the yarder GVWs that commonly crossed the same bridge in the past.
- The operator does not know their vehicle's GVW or axle weights. This is especially likely with off-highway vehicles not equipped with on-board weigh scales. Also, it may occur with highway trucks that do not commonly cross highway weigh scales or those not equipped with on-board weigh scales. Note that most log-hauling and equipment transport vehicles in B.C. are equipped with on-board weigh scales that display axle weights.

To make a bridge capacity sign understandable and easy to read, it is recommended that universal symbols be used rather than words, where appropriate. Guidance on the size, shape, colour, materials, and font format is provided in FLNRORD's Engineering Manual (FLNRORD, 2018). CAN/CSA-S6-06 (CSA, 2006) offers several applicable standard sign layouts; these are illustrated in Figure 6.

Figure 6. Highway bridge capacity sign formats (axle load limits, GVW limit, triple GVW posting).

Signs for Posting Bridge Design Vehicle Load Limits

In 2018, FLNRORD adopted the full-sign format, as seen in Figure 7, for posting load limits of bridges and roads (https://www2.gov.bc.ca/gov/content/industry/natural-resource-use/resource-roads/engineering-standards-guidelines/forest-service-road-signs). This standard signage for load limits was developed with the objective of creating a sign format that is unambiguous and can be used to represent all current and anticipated future vehicle configurations on FSRs.

The bridge capacity for L-60 to L-165 bridges should be represented with a full posting format (load limits for truck GVW and axle groups, short-truck GVW, and tracked-equipment GVW) based on the appropriate load limits (refer to Table 7). The sign format could be as shown in Figure 7, provided that the posting is for 2-girder forest bridges. If the road network contains both 2-girder bridges and concrete slab or gravel-over-log-stringer bridges, then only the lower of the two load limits for tracked equipment should be included on the sign.

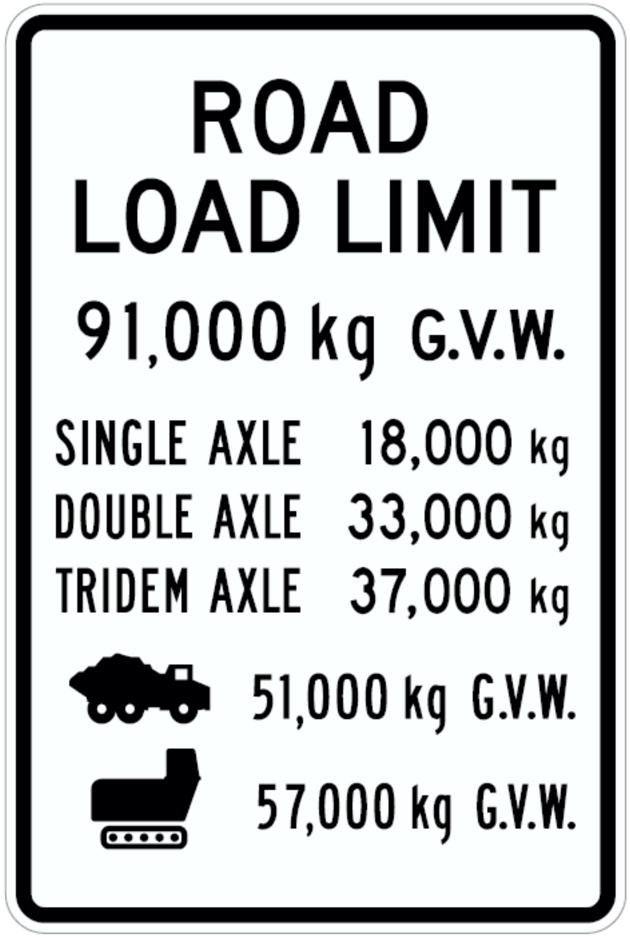


Figure 7. Proposed full road load sign for posting an L-100–rated road network (the same sign format applies to L-60, CL-625, BCL-625, L-75, LOH, L-90, L-120, HOH, L-150, and L-165 road networks).

Special Case: L-45 Bridges

As mentioned in the preceding discussion, the L-45 bridge load limits in Table 7 are too small to accommodate most legally loaded log-hauling trucks but would suffice for various short trucks, tracked vehicles, and light commercial trucks. Rather than show load limits that are less than legal limits, it may be preferable to show a single bridge GVW limit based on the 25-t short-truck GVW (Figure 8). Because 25 t is much less than the GVW of any loaded log-hauling configuration, this should discourage all log-hauling trucks from using the bridge.

It is anticipated that many L-45 bridges will have undergone a detailed load limit analysis and may feature higher load limits than the proposed load limits in Table 7. If the load rating of a bridge meets or exceeds the B.C. single, tandem, and tridem legal axle weights, then the full posting format can be used (Figure 7).

Figure 8. Suggested L-45 road network load limit sign based on the load limit of the short truck.

Special Case: Downrated Bridges

Bridges that cannot support common truck configurations with legal highway loadings should be posted more simply so that drivers are not confused or frustrated when their trucks are partially but not fully compliant. An example of this is an L-45 bridge, which is unable to support trucks with legally loaded tandem or tridem axles (Table 7).

Some forest companies report a practice of posting bridges to 5 t that have been load-rated to 50 t or less (i.e., insufficient for most log-hauling configurations). This practice, however, unfairly prevents bridge use by short trucks, tracked equipment, and light commercial trucks under 50 t GVW. Excluded commercial vehicles would include 40 t 5-axle tractor/tandem semi-trailers and 49 t 6-axle tractor/tri-axle trailers.

The chief consideration when choosing to use a simple sign for a substandard design or downrated bridge should be whether the capacity precludes the use of legal axle weights by road users. If it does, post the bridge with a simple GVW limit sign reflecting the short truck load limit (such as that shown in Figure 8). *Engineering Bulletin* Number 2 (Ministry of Forests and Range, 2010) specifies sign formats for downrated bridges that may be acceptable also (Figure 9).

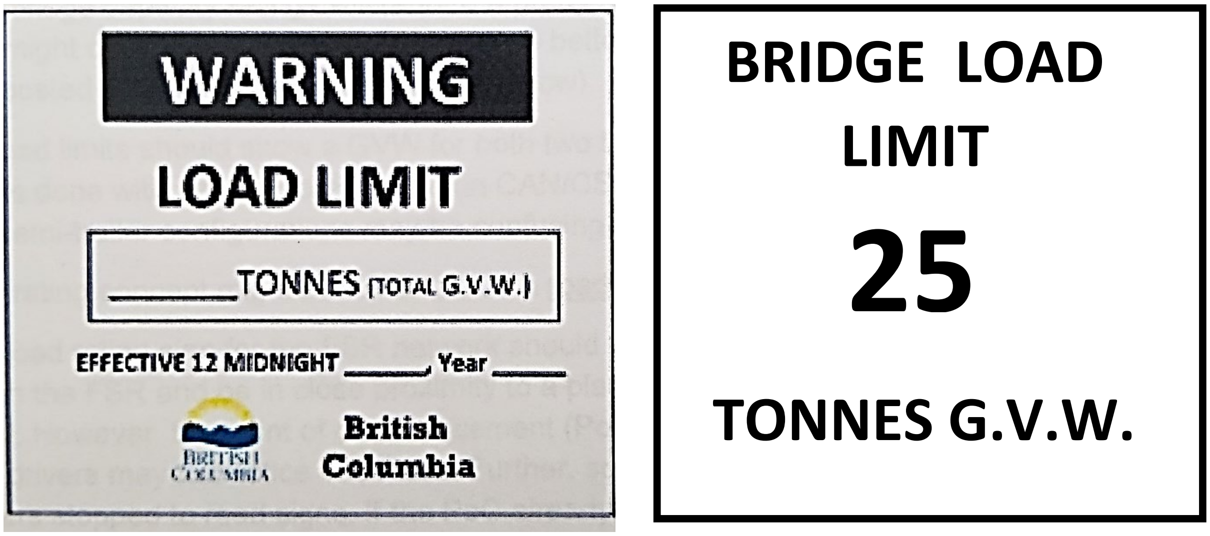


Figure 9. Simple sign formats for downrated bridges.

Evaluation of the Road Load Rating Concept

Stakeholder Survey

FPInnovations solicited feedback on the road load rating concept from various stakeholders: five forest bridge design consultants [Associated Engineering (B.C.) Ltd., StoneCroft Project Engineering, Allnorth Engineering, Onsite Engineering Ltd., and Caliber Bridge and Design Ltd.), the B.C. Forest Safety Council, TRAN, the five largest B.C. forest licensees [West Fraser Mills, Canfor, Tolko Industries, Western Forest Products, and Mosaic (formerly TimberWest)), FPInnovations B.C. extension officers, a transportation consultant working for Aero Transport, and several trucking contractors with the Log Truck Technical Advisory Committee.

Summary of feedback from surveys

The following list summarizes the key responses from surveyed stakeholders:

- The road load rating concept makes sense and is a timely idea given the impending rapid industrial development projects intending to utilize FSRs.
- Has there been an increase in forest bridge failures, and is this concern quantifiable? Is the bridge overloading concern widespread or limited to a just few areas of the province? Does the road load rating initiative address the root issues of overloading? Is it necessary to add a process as a one-off when the Natural Resource Road Act is being developed to handle resource road use, in general?
- This additional process will mean extra costs for maintaining signs but isn't likely to change most overloading behaviour. Anyone who truly cares will check on the bridges in the network if they have an unusually large load before they start. The rest will use the road regardless of the sign.
- Explaining bridge capacity ratings will require a pretty elaborate sign. The sign may change by season or might cause mass confusion. It may be better to put a default rating on all bridges unless otherwise posted (like the TRAN approach for highways).

- The road load limits should show a GVW for both two-trailer semi-trailers and one-trailer semi-trailers as is done with a triple posting sign (as in CAN/CSA-S6-06). Listing one GVW that applies to all tractor semi-trailer configurations may be confusing.
- The road load rating concept might better be called a “road network load rating” concept.
- A general load rating sign for the FSR network should be located before the truck commits to travelling on the FSR and should be near a place where trucks exceeding the rating can turn around. The points of commencement (POCs) of many FSRs are already filled with signs, and drivers may not notice one more. Further, some safety incidents have occurred at POCs when drivers stop to read signs. If the POC already has numerous signs, consider locating the sign on its own somewhere farther along the FSR and near a turnaround opportunity.
- It may be challenging and costly to post signs at all entrances to an FSR network. Some networks have multiple connections to adjacent roads or road networks. This interconnectedness is especially prevalent in the B.C. Interior.
- It is sometimes difficult to know where FSRs end and other tenure roads commence. It needs to be clearly signed which parts of the road the road load ratings apply to. It would be useful to delineate this in the road use permit agreement and share it with the road safety committee.
- If the road load limit is restricted after some distance up an FSR, consider making the road network load rating sign state that the first _x_ km of the FSR has _y__ capacity and beyond that the FSR has __z__ (reduced) capacity. A sign with the reduced road network load limit also should be located at a turnaround opportunity before the first restricted bridge. This information should be included in the road use permit agreement and shared with the road safety committee.
- If only applied to FSRs, this initiative will be straightforward. If applied to all the other tenure roads, the initiative may become more complicated.
- When adding information to a road use permit agreement, it may be preferable to say merely that “all bridges are built to (the minimum rating, such as L-75) unless otherwise posted.” Avoid giving specifics for individual bridges as this would not achieve all the objectives that the initiative is looking for.
- It is doubtful whether all drivers will know their axle weights on all trips. Some on-highway and off-highway vehicles using FSRs are not equipped with on-board weigh scales and may not cross a weigh scale prior to travelling on the FSR.

Based on the feedback received, FPInnovations believes that the FLNRORD concept of posting each FSR network according to its minimum bridge load limit is workable and logical. The concept is like that used for public highways, in that all highway infrastructure is designed to meet or exceed a minimum structural capacity, and rather than posting each structure, highway regulators control vehicle impacts to infrastructure through weight and dimension regulations. Exceptions to this include when a bridge is downrated, or when higher-than-normal capacity infrastructure has been constructed (e.g., to create heavy-haul routes).

Where there are numerous entrances to an FSR network, the district manager should determine whether the neighbouring networks and roads have the same road load rating as the subject FSR network. If so, it may not be necessary to post all possible entrances to the subject FSR network. This should be discussed with the local road safety committee(s).

Considerations for Culvert Ratings in Road Load Limits

The design load rating of major (engineered) structures also should be respected when selecting a road load limit. The drawings on file should provide the design load rating of an engineered structure; however, if records do not exist or are incomplete, it may be possible to estimate a load rating for the major structure by gathering dimensional information for the structure (e.g., corrugation profile, wall thickness, cover depth) and then consulting with the culvert manufacturer's engineering support services and the associated culvert design tables, or alternatively have a qualified engineer perform a load rating evaluation of the buried structure.

Recommendation: *Given that road load limits will impact both bridges and buried structures, it is recommended that FLNRORD conduct research into setting load limits for buried structures.*

Adding Road Load Ratings to Road Use Permits

The road use permit may provide a useful way to inform road users about bridge capacities (the road load limit) of each FSR. FLNRORD should not rely, however, on this document alone to inform road users. Not all vehicle operators will be aware that there is a road use permit agreement, let alone what it contains. Some industrial users are not subject to the Forests and Range Practices Act. These road users should be informed about the road load limits through other means (e.g., cutting permits, construction contracts, BC Timber Sales bidding information, road signage, and local road safety committees).

Road use permit agreements specify vehicle weight and size limitations when necessary, and, therefore, are an appropriate place to provide permit holders and other road users with information about a road load limit.

Information about the road load limit could be included in Section 2.00, Conditions of Use. A road load rating clause might read something like:

> This FSR and its branch roads as listed in Schedule A have a minimum culvert and bridge capacity (road load limits) unless specifically noted otherwise. The specific load limits for this FSR and named branch roads are listed in Schedule A. The permittee or other road users may apply to the district manager for an overload permit to move a vehicle exceeding this road load limit.

In Schedule A, make the following additions: In the first table of Schedule A, add a column to the right of the column with the FSR branch number (highlighted in yellow in Table 9), and in this column, indicate the road load limit on a kilometre-to-kilometre basis.

Table 9. Addition of road load limit information to table in schedule A of road use permit

FSR name/ project number	FSR branch number	Road load limit (refer to the load limit table in additional clause section for further details and exceptions)	Section to be used		If off-highway loading, indicate vehicle size A, B, or C from next section	FLNRORD USE ONLY. Name/telephone number of road use permit holder required by district manager to maintain the FSR
			km to km			
Greenwater		68 t GVW	0	45		
Greenwater	1000	68 t GVW	0	4		
Greenwater	1000	38 t GVW – short truck	4	22		

A table of road load limits and any exceptions could be included as an additional clause to Schedule A (see Table 10).

Table 10. Example of table with road load limit information

Design vehicle	GVW limit (t)	Single-axle load limit (t)	Tandem-axle load limit (t)	Tridem-axle load limit (t)	Short truck GVW limit (t)	Tracked equipment GVW limit (t)	
						2-girder forest bridge	Concrete slab or gravel-over- log-stringer bridge
L-75	68	13	25	27.5	41	54	45

Exceptional bridges: One bridge within the Greenwater FSR network is currently downrated to less than the road load limit. The bridge is a single lane at 4 km on the 1000 Road. It has been downrated by FLNRORD bridge engineers to a load limit of 38 t.

CONCLUSIONS

FPInnovations conducted a technical check of B.C. forest bridge design load limits that were proposed to FLNRORD by COWI North America (formerly Buckland & Taylor Ltd.) and SNT Engineering Ltd. These load limits were found to be correctly calculated, in general; however, the load limits for tracked vehicles were found to be based on overly conservative assumptions. After consultation with bridge design experts, less conservative live load factors were adopted; load limits for tracked vehicles walking over concrete slab or gravel-over-log-stringer bridges were added, also.

The methodology for estimating load limits involved assuming appropriate values for live load factor, dynamic load allowance (DLA), and distribution factor (DF). This analysis investigated these assumptions and generally found them to be reasonable, but further research is recommended. A COWI North America statistical analysis of log-hauling truck GVW data concluded that a live load factor of 1.5 appeared to be justified for posting resource bridges. Using this value as a live load factor would result in load limits 6% to 13% higher than those currently used. FPInnovations recommends further study, however, of non-log–truck heavy vehicles on FSRs (e.g., equipment transport trucks and non-forest industry trucks) before applying reduced live load factors to forest bridge designs.

The load limits proposed for each forest bridge design (Table 7) were evaluated considering current log-hauling truck configurations. The L-45 and L-60 bridge designs have limited utility for today's log-hauling configurations, and the construction of new bridges with these designs should be discouraged. Further, it is recommended that L-45 bridges be posted only in terms of their 25-t short-truck load limit. CL-625 and BCL-625 bridge designs are typically employed on resource roads from which log hauling proceeds directly onto public highways. Accordingly, CL-625 and BCL-625 bridge design GVW and axle load limits were constrained to B.C. highway legal weights for log trucks plus the applicable B.C. winter log-hauling axle weight tolerances. To compliment the table of load limits for posting forestry bridges a GO/ NO GO table (Appendix 1) was included for 29 specific models of articulated rock trucks and may prove to be a useful guide for industry.

Adopting the proposed bridge design load limits will clarify GVW and axle load limits for B.C. resource roads. These changes and the reasons for them need to be communicated to road use permit holders and other resource road users. This load rating initiative also presents an opportunity for FLNRORD to update its bridge rating methodology and introduce the LOH and HOH design vehicles to forest bridge designers. This project was intended to give general guidance for posting load limits on forest roads and bridges. Given the general approach used for determining the load limits (i.e., the same limit is applied to a range of bridge span lengths), higher load limits may be feasible for an individual bridge through a professional engineer's load rating based on the specific span length of the bridge and its components.

To make a bridge capacity sign understandable and easy to read, FPInnovations recommends that standard layouts for highway bridge signs be used; the signs should be patterned after the size, shape, colour, materials, and font formats defined in FLNRORD's *Engineering Manual (FLNRORD 2018),* and universal symbols should be used instead of words, where appropriate. A simplified sign format is recommended for L-45 bridges (and downrated bridges), while a general full posting sign is recommended for the other forest bridge designs.

A stakeholder survey was conducted to ascertain the acceptance of the road load rating concept and identify potential barriers to its use. The survey found that the concept was generally acceptable. A few operational issues were identified (e.g., road load signs need to be located near turnarounds), and potential solutions were offered. Based on the stakeholder feedback and project discussions, FPInnovations believes that

FLNRORD’s concept of posting each FSR network according to its minimum bridge load limit is workable and logical.

FLNRORD should develop a communication strategy for introducing the road load rating concept to FSR users. Part of the communication strategy should include adding specifics to each road use permit. Road users could be informed about the initiative through an engineering bulletin posted on the FLNRORD’s engineering branch website, letters sent to road use permit holders, trade magazine articles, and presentations given to road safety committees around the province.

REFERENCES

Associated Engineering. (2009). *Review of development and implementation of the new design vehicles for the design of bridges*. Prepared for B.C. Ministry of Forests and Range.

Canadian Standards Association. (2000). *Canadian highway bridge design code* (CAN/CSA-S6-00). Ottawa, ON.

Canadian Standards Association. (2006). *Canadian highway bridge design code* (CAN/CSA-S6-06). Ottawa, ON.

Gagnon, D. (2004). *Design vehicle configuration analysis and CSA-S6-00 implication evaluation. Phase III* (File reference: 1579-RPT-GEN-000-1). Prepared for the B.C. Ministry of Forests. Buckland & Taylor Ltd. North Vancouver, B.C.

Gagnon. D. (2012). *Logging truck target values report* (File reference: 1579-mof-001-dpg). Prepared for the Engineering Branch, Ministry of Forests, Lands and Natural Resource Operations. Buckland & Taylor Ltd. North Vancouver, B.C. [Contained in McClelland (2013) Road Load Rating Project report.]

Henley. J. (2003). *Evaluation of CAN/CSA-S6-00 (2000 Canadian highway bridge design code)*. Prepared for the Engineering Branch, Ministry of Forests, Lands and Natural Resource Operations. Associated Engineering (B.C.) Ltd. Burnaby, B.C. Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/resource-roads/eval-of-can-csa-s6-00-assoc-eng-jan-03.pdf

McClelland, G. (2012). *Road load rating project 2011–12. Project update*. Presentation for the Ministry of Forests, Lands and Natural Resource Operations. SNT Engineering Ltd. Nelson, B.C.

McClelland, G. (2013). *Road load rating project report*. Prepared for the Engineering Branch, FLNRO. SNT Engineering Ltd. Nelson, B.C. Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/resource-roads/road-load-rating-project-rev-may-2013-snt-eng-ltd.pdf

Ministry of Forests and Range. (1999). *Forest service bridge design and construction manual.* Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/resource-roads/bridge-design-construction/bridge_manual.pdf

Ministry of Forests and Range. (2009, 24 September). Clarification of GVW as applicable to bridge load rating. *Engineering Bulletin* (Number 1).

Ministry of Forests and Range. (2010, 31 May). FSR bridge inspections and load rating posting responsibility. *Engineering Bulletin* (Number 2).

Ministry of Forests and Range (2016). *Cattleguard notes and standard details* (Drawing No. STD-ECAT-010-01). Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/resource-roads/mfr_cattleguard_drawingsapril22-2016.pdf

APPENDIX 1: GO/NO GO GUIDE FOR 29 ARTICULATED ROCK TRUCKS

Articulated rock truck	GVW (tonnes)	The bridge design capacity is sufficient (GO) or the bridge design capacity is not sufficient (NO GO)											
		L-45 (40.9)	L-60 (54.5)	CL-625 (63.7)	BCL-625 (63.7)	L-75 (68.2)	LOH (72.4)	L-90 (81.8)	L-100 (90.9)	L-120 (109.1)	HOH (114.2)	L-150 (136.4)	L-165 (150.0)
Bell B25E	43.7	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
John Deere 260E	46.7	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO	GO	GO
Cat 725 C2	47.0	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Volvo A25G	47.5	NO GO	NO GO	NO GO	GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Bell B30E	48.2	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Terex TA250	48.3	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
John Deere 310E	51.0	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Doosan DA 30	51.5	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Terex TA300	51.5	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Cat 730	51.9	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Volvo A30G	52.3	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Cat 730 EJ	53.3	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO	GO
Komatsu HM 300-5	53.5	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO	GO	GO	GO
Bell B40D	66.9	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Terex TA400	68.3	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Cat 740 GC	68.7	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Volvo A40G	68.9	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
John Deere 410E	69.1	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Doosan DA40-5	70.3	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Bell B40E	70.8	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Volvo A45G	71.1	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Bell B45E	72.9	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Cat 740 EJ	73.7	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
John Deere 460E	74.0	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Cat 745	74.4	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Komatsu HM 400-5	75.1	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Bell B50D	79.9	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Bell B50E	81.1	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	GO	GO	GO
Volvo A60H	98.4	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO	NO GO

Notes:

- **“GO”** indicates that the bridge design is strong enough to support the articulated rock truck at up to the stated GVW.
- **“NO GO”** indicates that the rock truck should not cross the bridge because its force effects and(or) wheel loads exceed the design capacity of the structure.
- The table considers both factored girder force effects and factored single axle loads (for deck systems).
- Factored single axle loads used to evaluate deck system capacity were calculated assuming no truck eccentricity; and, rock truck side-to-side load imbalance was assumed to be 50%-50%.
- Factored force effects used to evaluate girder capacity were calculated using the live load factors listed in Appendix 2.
- The bridge approaches are assumed to be relatively smooth.
- Only one vehicle is assumed to cross the bridge at a time.
- The bridge is of a common forestry type, with 2 girders; simply supported, single span; clear span length of 5 to 36 m.
- L-45 to L-120 bridges are assumed to have a 4.3 m (14’) -wide deck and two girders spaced at 3.05 m (10’).
- HOH, L-150, and L-165 bridges are assumed to have a 4.9 m (16’) -wide deck and two girders spaced at 3.6 m (12’).

APPENDIX 2: LIVE LOAD ADJUSTMENT FACTORS FOR EVALUATING GIRDER FORCE EFFECTS

Bridge design vehicle [a]	Live load factor	DLA (%)	DF [truck eccentricity (mm)]	Centre of duals-to-curb (mm) [deck width (mm)]
L-45	1.6	30	0.691 [400]	819 [4276]
L-60	1.6	30	0.691 [400]	819 [4276]
CL-625	1.7	30	0.703 [619]	600 [4276]
BCL-625	1.7	30	0.703 [619]	600 [4276]
L-75	1.6	30	0.696 [400]	744 [4276]
LOH	1.7	30	0.692 [584]	600 [4276]
L-90	1.6	30	0.696 [400]	744 [4276]
L-100	1.6	30	0.696 [400]	744 [4276]
L-120	1.6	30	0.696 [400]	744 [4276]
HOH [b]	1.7	30	0.661 [589]	600 [4878]
L-150 [b]	1.6	30	0.682 [400]	709 [4878]
L-165 [b]	1.6	30	0.659 [450]	659 [4878]
Short truck (3-axle articulated rock truck or 4-axle dump truck)	per bridge design vehicle	30	per bridge design vehicle	n/a
Tracked equipment on 2-girder forest bridge	1.3	30	0.55	n/a
Tracked equipment on concrete slab bridge or gravel-over-log stringer forest bridge	1.3	24	0.23	n/a
Articulated rock trucks	1.7	40	0.535 – 0.565 (on 4276 mm decks) 0.537 – 0.559 (on 4878 mm decks)	

a. Only CL-625, BCL-625, LOH, and HOH design vehicles are defined using a distance from curb rather than using the eccentricity of the truck's centreline from bridge centreline. Although not currently used for the other bridge design vehicle definitions, the distance from the centre of the dual assembly to the curb is included for all designs for completeness.
b. Tracked equipment was assumed to have a 4.5 m track contact length (L-120 and lighter designs were assumed to have a 4.0 m track contact length).

APPENDIX 3: TRACKED FORESTRY EQUIPMENT DATA

	Make	Type	Model	Undercarriage width (m)	Contact length (m)	Estimated operating weight (t)
Feller bunchers and harvesters						
1	Komatsu	Feller buncher	XT430-3	3.2	3.6	29.63
2	Komatsu	Feller buncher	XT430L-3	3.2	3.7	30.64
3	Komatsu	Feller buncher	XT430-5	3.1	3.9	31.50
4	Komatsu	Feller buncher	XT445L-5	3.1	3.7	34.10
5	Komatsu	Feller buncher	XT465L-5	3.2	3.8	35.20
6	John Deere	Feller buncher	803MH	3.6	3.6	33.05
7	John Deere	Feller buncher	853M	3.6	3.8	35.62
8	John Deere	Feller buncher	859M	3.4	3.9	40.08
9	John Deere	Feller buncher	903M	3.6	3.8	31.69
10	John Deere	Feller buncher	953M	3.6	3.8	33.78
11	John Deere	Feller buncher	959M	3.4	3.8	38.26
12	Tigercat	Feller buncher	822D	3.4	3.9	31.15
13	Tigercat	Feller buncher	L822D	3.4	4.1	36.64
14	Tigercat	Feller buncher	LX830D	3.4	3.6	35.73
15	Tigercat	Feller buncher	845E	3.4	4.1	29.56
16	Tigercat	Feller buncher	L845E	3.4	4.1	36.89
17	Tigercat	Feller buncher	855E	3.4	3.9	33.65
18	Tigercat	Feller buncher	L855E	3.4	4.3	41.58
19	Tigercat	Feller buncher	X870D	3.4	3.5	36.37
20	Tigercat	Feller buncher	LX870D	3.4	4.3	39.48
21	Tigercat	Feller buncher	860C	3.4	4.0	32.06
22	Tigercat	Feller buncher	870C	3.4	4.0	34.10
23	Tigercat	Feller buncher	L870C	3.4	4.0	38.40
24	Tigercat	Feller buncher	LX870C	3.4	4.0	38.40
25	Cat	FB / Tracked Harvester	501HD	2.8	3.0	22.20
26	Cat	FB / Tracked Harvester	521B	3.2	4.0	31.20
27	Cat	FB / Tracked Harvester	522B	3.5	4.0	36.20
28	Cat	FB / Tracked Harvester	541 Series 2 (long felling linkage)	3.6	4.0	35.30
29	Cat	FB / Tracked Harvester	552 Series 2 (long felling linkage)	3.6	4.0	40.30
30	Cat	Danglehead Processor	538	3.5	3.7	33.37
31	Cat	Danglehead Processor	548	3.5	4.0	38.49
32	Cat	Excavator swing yarder	325C Escoliner	3.0	3.8	28.6
33	John Deere	Feller buncher	859M	3.4	3.8	40.06
34	John Deere	Feller buncher	903M	3.6	3.8	34.96
35	John Deere	Feller buncher	953M	3.6	3.8	36.99
36	John Deere	Feller buncher	959M	3.4	3.8	41.42
37	Tanguay	Tracked feller buncher	TG970	3.5	3.5	37.50
38	Tanguay	Tracked feller buncher	TG975	3.5	3.5	37.50
39	Tanguay	Tracked feller buncher	TG770	3.6	3.7	32.25
40	Tanguay	Tracked feller buncher	TG770HD	3.6	3.7	32.25
41	Tigercat	Tracked Harvester	H822D	3.4	3.9	30.80
42	Tigercat	Tracked Harvester	LH822D	3.4	4.1	36.25
43	Tigercat	Tracked Harvester	H845E	3.4	4.1	29.21

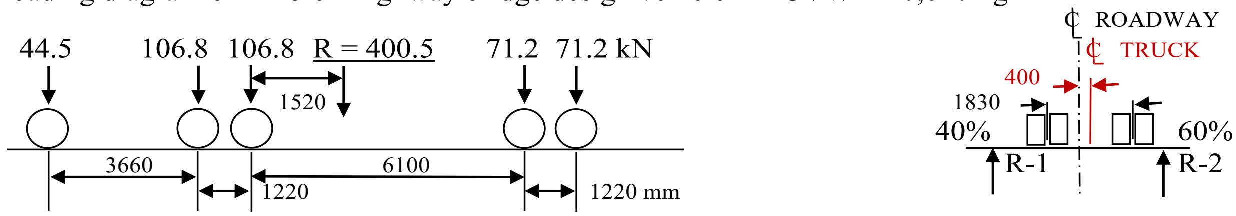
44	Tigercat	Tracked Harvester	LH845E	3.4	4.1	37.38
45	Tigercat	Tracked Harvester	H855E	3.4	3.9	33.30
46	Tigercat	Tracked Harvester	LH855E	3.4	4.3	41.23
47	Tigercat	Danglehead Processor	850	3.4	4.1	34.43
48	Tigercat	Danglehead Processor	H850D Processor	3.4	3.6	28.85
49	Volvo	Harvester/ processor	FC2121C	3.1	3.7	27.00
50	Volvo	Harvester/ processor	FC2421C	3.3	3.7	29.62
51	Volvo	Loader/ processor	FC294C	3.3	3.7	35.47
52	Volvo	Loader/ processor	FC3329C	3.5	4.0	39.15
			maximum	3.6	4.3	41.6
			average	3.4	3.9	34.6
Large yarders and cable log loaders						
1	Cypress	Grapple swing yarder	6280	4.2	4.2	67.2
2	Cypress	Grapple swing yarder	7280B	4.2	5.5	79.6
3	Cypress	Grapple swing yarder	7280C	4.2	5.5	92.7
4	Cypress	Large line loader	7230C	4.2	4.3	88.7
5	Madill	Mobile Tower	071	3.7	3.7	38.8
6	Madill	Large tower yarder	171	2.4	3.9	46.3
7	Madill	Large tower yarder	172	3.8	4.4	54.8
8	Madill	Swing grapple yarder	044	4.7	5.1	95.9
9	Madill	Swing grapple yarder	143	4.0	5.2	106.7
10	Madill	Swing grapple yarder	144	4.6	4.4	115.3
11	Madill	Swing yarder	120	3.4	3.8	47.6
12	Madill	Swing yarder	122	3.7	4.3	58.7
13	Madill	Swing yarder	123	4.3	4.5	63.0
14	Madill	Swing yarder	124	3.6	4.3	65.9
15	Madill	Large line loader	075	3.2	4.5	96.7
16	T-mar Industries	Grapple swing yarder	Log Champ 550	3.5	3.8	47.7
17	T-mar Industries	Grapple swing yarder	Log Champ 650	3.6	4.2	70.5
18	Thunderbird	Swing yarder	TSY6255 and variants	3.7	4.5	61.0
19	Thunderbird	Swing yarder	TSY155			45.5
20	Washington	Grapple swing yarder	super 88 Mark II	3.2	3.7	42.6
			maximum	4.7	5.5	115.3
			average	3.8	4.4	50.8
Tracked log loaders						
1	Barko	Tracked log loader	495B CRL	3.5	3.5	22.00
2	Barko	Tracked log loader	595B CRL	3.5	4.0	28.35
3	Cat	Tracked log loader	558 / 558 LL	3.6	5.1	39.66
4	Cat	Tracked log loader	568 (butt & top)	3.7	4.4	49.30
5	Cat	Tracked log loader	538 LL	3.5	3.7	31.23
6	Komatsu	Tracked log loader	PC210LL-10	3.3	3.8	31.11
7	Komatsu	Tracked log loader	PC240LL-10	3.7	4.0	38.10
8	Komatsu	Tracked log loader	PC290LL-11	3.5	4.0	40.70
9	Komatsu	Tracked log loader	PC390LL-10	3.8	4.0	48.50
10	Madill	Tracked log loader	3000	3.6	4.3	43.18
11	Madill	Tracked log loader	4000	3.8	4.5	48.18
12	Madill	Tracked butt & top loader	3800C	3.8	4.1	45.45
13	Tigercat	Tracked log loader	T250D (butt & top)	3.4	3.0	26.45
14	Tigercat	Tracked log loader	875 Logger	3.5	4.2	36.69

15	Tigercat	Tracked log loader	880D Logger	3.5	4.2	43.64
16	Tigercat	Tracked log loader	890 Logger	3.6	4.7	48.40
17	Volvo	loader/processor	FC2924C	4.0	3.5	38.00
18	Volvo	loader/ excavator	FC3329C	4.0	3.5	41.20
			maximum	4.0	5.1	49.3
			average	3.6	4.0	38.9
Road building bulldozers						
1	Cat	Bulldozer	D8T (LGP)	3.3	3.2	38.00
2	Cat	Bulldozer	D8T	3.1	3.2	39.80
3	Cat	Bulldozer	D7 (LGP)	3.4	3.5	27.10
4	Cat	Bulldozer	D7	2.9	3.0	24.96
5	Cat	Bulldozer	D7E (LGP)	3.4	3.5	28.53
6	Cat	Bulldozer	D7E	2.9	3.0	26.06
7	John Deere	Bulldozer	950K	3.2	3.2	29.94
8	John Deere	Bulldozer	950K LGP	3.6	3.4	31.50
9	John Deere	Bulldozer	850L XLT	3.4	3.3	22.13
10	John Deere	Bulldozer	850L WLT	3.6	3.3	22.74
11	John Deere	Bulldozer	850L LGP	3.9	3.3	22.83
12	John Deere	Bulldozer	750K	3.0	2.6	15.68
13	Komatsu	Bulldozer	D85EX-18	3.6	3.1	30.98
14	Komatsu	Bulldozer	D85PX-18	3.8	3.5	28.94
			maximum	3.9	3.5	39.8
			average	3.4	3.2	27.8
Road Building Excavators						
1	Cat	Excavator (mid-size)	320 GC	3.2	3.7	21.90
2	Cat	Excavator (mid-size)	320	3.0	3.7	22.80
3	Cat	Excavator (mid-size)	323	3.2	3.7	25.50
4	Cat	Excavator (mid-size)	325	3.2	3.6	22.50
5	Cat	Excavator (mid-size)	326	3.2	3.8	25.90
6	Cat	Excavator (mid-size)	330 GC	3.2	4.0	30.70
7	Cat	Excavator (mid-size)	330	3.4	4.0	30.90
8	Cat	Excavator (large)	335 F L	3.4	4.0	38.02
9	Cat	Excavator (large)	336 GC	3.4	4.0	36.50
10	Cat	Excavator (large)	336D L	3.4	4.0	30.50
11	Hitachi	Excavator (large)	ZX300NC-6	3.4	4.1	29.45
12	Hitachi	Excavator (large)	ZX330LC	3.4	3.7	33.34
13	Hitachi	Excavator (large)	ZX350LC-5	3.4	4.1	36.43
14	Hitachi	Excavator (large)	ZX380LC-5	3.4	4.1	37.06
15	Hitachi	Excavator (large)	ZAXIS450LC	3.3	4.5	46.20
16	Komatsu	Excavator (mid-size)	PC210LL-10	3.3	3.8	29.54
17	Komatsu	Excavator (mid-size)	PC240LL-10	3.7	4.0	36.17
18	Komatsu	Excavator (mid-size)	PC290LL-11	3.5	4.0	37.30
19	Komatsu	Excavator (large)	PC390LL-10	3.8	4.0	46.90
20	Volvo	loader/ excavator	FC3329C	4.0	3.5	38.10
			maximum	4.0	4.5	46.9
			average	3.4	3.9	32.8

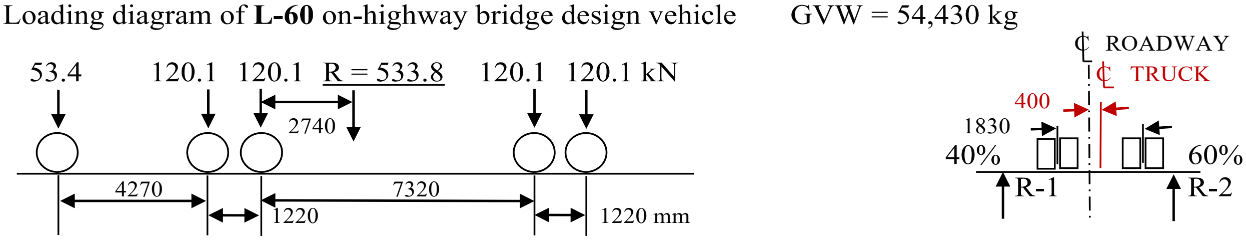
APPENDIX 4: BCFS BRIDGE DESIGN VEHICLES

Logging truck axle and wheel loads used in the design of forest road bridges

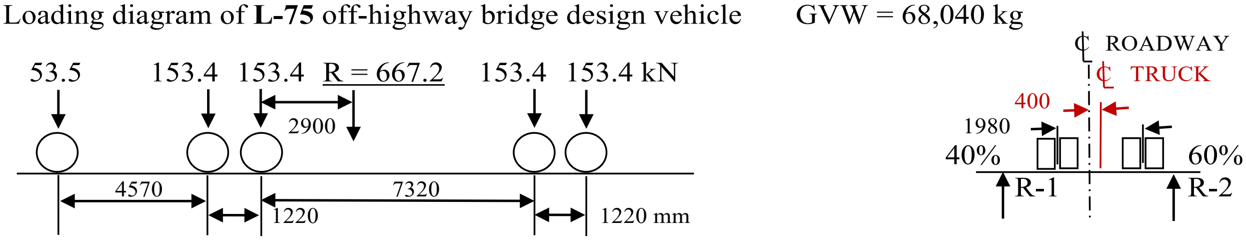
Loading diagram of **L-45** on-highway bridge design vehicle GVW = 40,840 kg



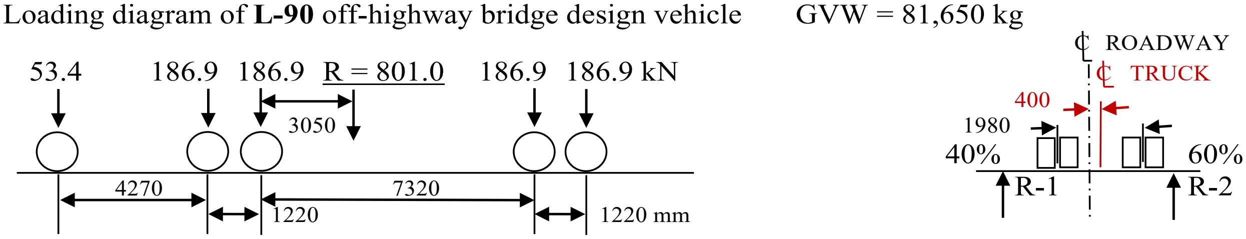
Loading diagram of **L-60** on-highway bridge design vehicle GVW = 54,430 kg



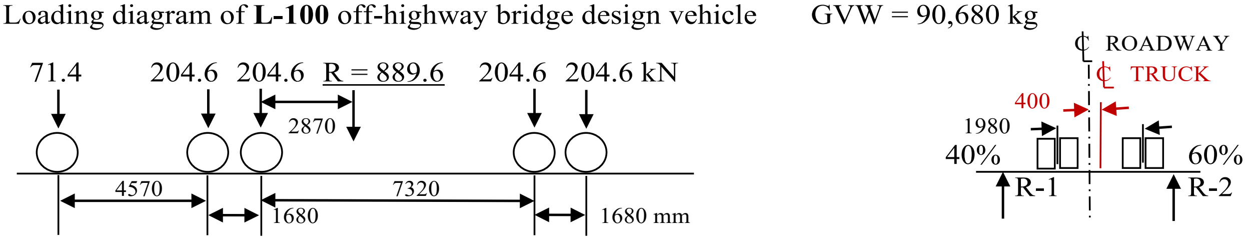
Loading diagram of **L-75** off-highway bridge design vehicle GVW = 68,040 kg



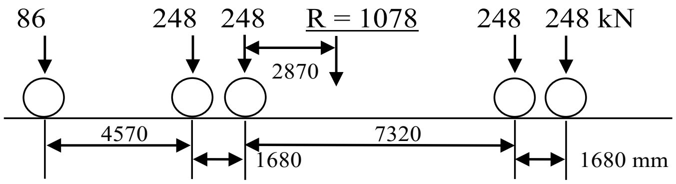
Loading diagram of **L-90** off-highway bridge design vehicle GVW = 81,650 kg

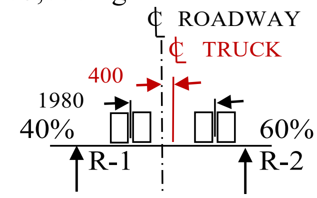


Loading diagram of **L-100** off-highway bridge design vehicle GVW = 90,680 kg

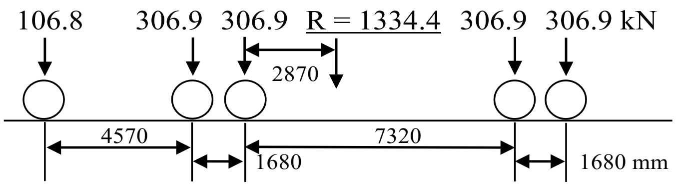


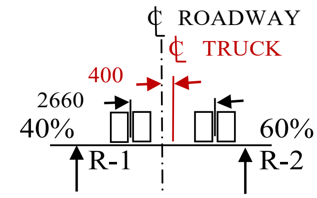
Loading diagram of **L-120** off-highway bridge design vehicle GVW = 107,800 kg



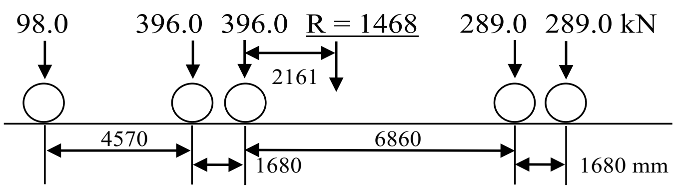


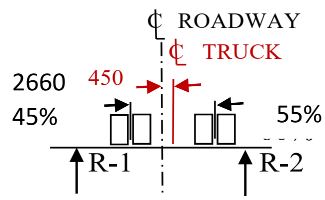
Loading diagram of **L-150** off-highway bridge design vehicle GVW = 136,680 kg





Loading diagram of **L-165** off-highway bridge design vehicle GVW = 90,680 kg

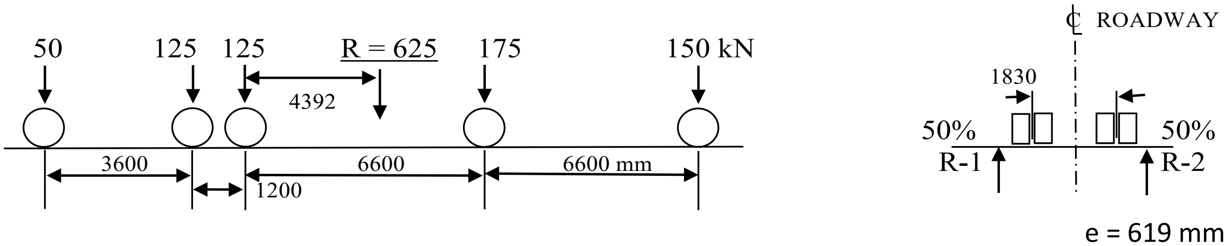




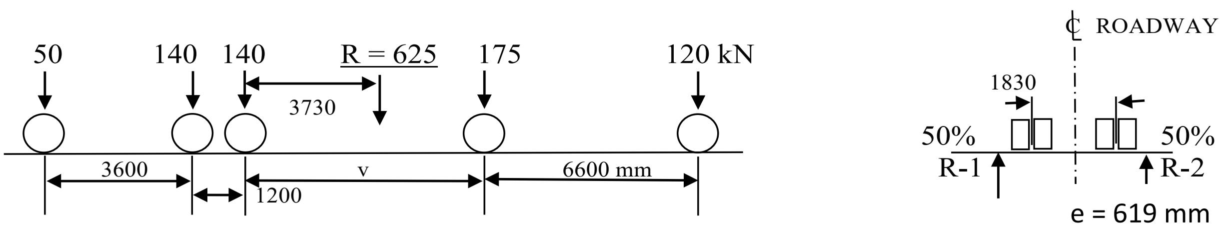
APPENDIX 5: ADDITIONAL FOREST BRIDGE DESIGN VEHICLES

Logging truck axle and wheel loads used in the design of forest road bridges

Loading diagram of **CL-625** off-highway bridge design vehicle GVW = 63,500 kg

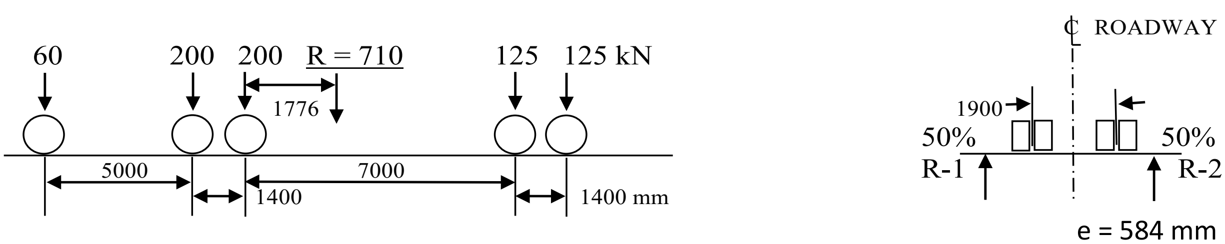


Loading diagram of **BCL-625** off-highway bridge design vehicle GVW = 63,500 kg

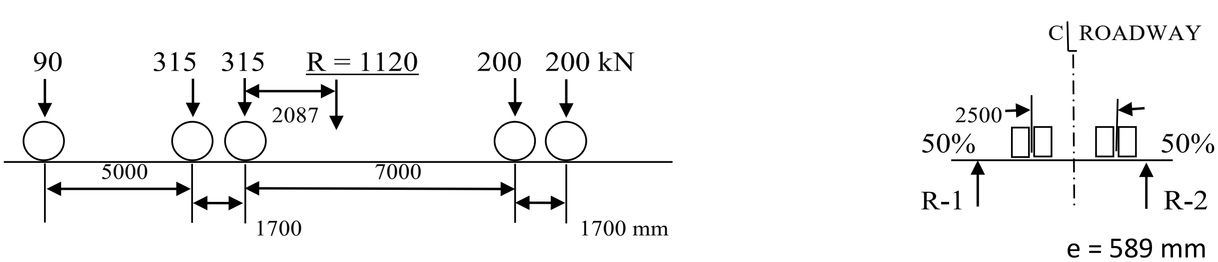


V = variable spacing – 6600 to 18000 mm inclusive. Spacing to be used is that which produces the maximum stresses.

Loading diagram of **Light Off-Highway (LOH)** bridge design vehicle GVW = 72,375 kg



Loading diagram of **Heavy Off-Highway (HOH)** bridge design vehicle GVW = 114,200 kg



info@fpinnovations.ca
www.fpinnovations.ca

OUR OFFICES

Pointe-Claire
570 Saint-Jean Blvd.
Pointe-Claire, QC
Canada H9R 3J9
(514) 630-4100

Vancouver
2665 East Mall
Vancouver, BC
Canada V6T 1Z4
(604) 224-3221

Québec
1055 rue du P.E.P.S.
Québec, QC
Canada G1V 4C7
(418) 659-2647