12-16-2014 12:00 AM

Applying Probabilistic Methods to the NATO Military Load Classification System for Bridges

Andrew J. MacDonald
The University of Western Ontario

Supervisor
Dr. F.M. Bartlett
The University of Western Ontario

Graduate Program in Civil and Environmental Engineering
A thesis submitted in partial fulfillment of the requirements for the degree in Master of Engineering Science

Recommended Citation

MacDonald, Andrew J., "Applying Probabilistic Methods to the NATO Military Load Classification System for Bridges" (2014). *Electronic Thesis and Dissertation Repository*. 2570.
https://ir.lib.uwo.ca/etd/2570

APPLYING PROBABILISTIC METHODS TO THE NATO MILITARY LOAD CLASSIFICATION SYSTEM FOR BRIDGES

(Thesis format: Monograph)

by

Andrew J. MacDonald

Graduate Program in Civil and Environmental Engineering

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Engineering Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada
December 2014

Abstract

Military vehicles frequently use civilian bridges. The loading effects of military vehicles, both wheeled and tracked, are specific and different than those of civilian vehicles in normal traffic. Calibration to determine appropriate load factors for military loading of civilian bridges has not been fully performed and the corresponding levels of safety have not been quantified. This lack of calibration prevents the implementation of limit state design methods for military bridges and the evaluation bridges for military loading. This thesis quantifies probabilistically the single lane traffic load effects on interior girders of simply supported slab-on-girder bridges for three military vehicles in use by the Canadian Forces with corresponding load factors for design and evaluation. General categories of military vehicles are proposed with associated partial load factors for application in military bridge design and evaluation.

Keywords:

Bridge evaluation, Military vehicle, Live load, Load factors, Limit state design, Code calibration, Military engineering, Bridges, Simply-Supported Spans, Slab-on-Girder

For my Daughter Lucy.

From birth to a bouncing pre-schooler, you have grown up so much since the beginning of this.

Acknowledgments

I would like to acknowledge the help, guidance and knowledge from my supervisor, Dr. Bartlett, who graciously accepted me as a student (albeit with my infant daughter in tow for many of the early meetings), I am also grateful to the Royal Military College project sponsors, Dr. Wight and Dr. Tanovic, who identified me as an appropriate candidate to undertake this research. Their experience and insights have helped to direct the research and derive workable solutions for the challenges addressed in this document.

I would also like to thank the large number of Canadian Forces personnel and Department of National Defence employees who provided extremely valuable insight that helped direct the research focus. Within the Department of National Defence I would specifically like to thank the individuals with Air Movements and the National Movement and Distribution System Support Center for providing data, and answering questions about intermodal container weights.

I would like to thank the Canadian Department of National Defence for financial support, as well as access to technical information pertaining to this research. I am also grateful for financial support provided by the National Sciences and Engineering Research Council (NSERC).

Finally I would like to thank my wife, Linda, and my daughter, Lucy, for their support and perspective while working on this thesis.

Table of Contents

List of Tables

List of Figures

Nomenclature

Abbreviations

AHSVS-PLS	Armoured Heavy Support Vehicle System – Palletized Loading System
APC	Armoured Personnel Carrier
ARL	Acceptable Risk Level
ASD	Allowable Stress Design
CoV	Coefficient of Variation
CHBDC	Canadian Highway Bridge Design Code
CSA	Canadian Standards Association
DAF	Dynamic Amplification Factor
DLA	Dynamic Load Allowance
DND	Department of National Defence (Canada)
FEA	Finite-Element Analysis
GVW	Gross Vehicle Weight
LAV III-ISC	Light Armour Vehicle III – Infantry Section Carrier
LDF	Load Distribution Factor
LRFD	Load and Resistance Factor Design
LSD	Limit State Design
MLC	Military Load Classification System
MSR	Main Supply Route
NATO	North Atlantic Treaty Organization
STANAG	Standardization Agreement
UDL	Uniformly Distributed Load

Symbols

A	cross-sectional area; or analysis coefficient (mean value $\bar{A}$, bias δ_A, CoV V_A)
DAF	Dynamic Amplification Factor (mean value $\overline{DAF}$, CoV V_{DAF})
D_i	specified dead loads (mean value $\overline{D_i}$, bias δ_{D_i}, CoV V_{D_i})
DLA	Dynamic Load Allowance (mean value $\overline{DLA}$, bias δ_{DLA}, CoV V_{DLA})
E	Young’s modulus of elasticity
E_B	modulus of elasticity of the girder
E_D	modulus of elasticity of the deck

e	eccentricity (mean eccentricity $\bar{e}$, maximum eccentricity e_{max})
e_g	distance between the centers of gravity of the beam and deck
$F(x)$	cumulative probability
$F_A(x)$	cumulative probability for the maximum observed weight x in n observations
f_b	natural frequency of bridge
$F_E(x)$	cumulative probability at for event weight x
F_m	amplification factor for lateral load distribution
i	iteration number; or rank
I	moment of inertia
k	Weibull distribution dispersion parameter
K_g	longitudinal stiffness parameter
L	stringer, girder or span length; or nominal static live load (mean value $\bar{L}$, bias δ_L, CoV V_L)
L_1	nominal live load effect (mean value $\overline{L_1}$, bias δ_{L_1}, CoV V_{L_1})
m	mass of shipping container (mean mass of a single shipping container $\overline{m_1}$, mean mass of two shipping containers $\overline{m_2}$)
M_{D_f}	factored dead load moment per girder
M_g	design moment of a girder
$M_{g,avg}$	average design moment per girder
M_{l_0}	moment per design lane
M_{ref}	moment per girder
M_r	factored moment resistance per girder
M_T	maximum moment per design lane, CSA (2006a)
$\breve{m}_X$	Log-Normal distribution central tendency parameter
n	total number of vehicles; number of vehicles entering and leaving the road segment per year; number of observations; number of vehicles per year; or number of design lanes
N	number of girders in a slab-on-girder bridge
n_d	number of military fatalities in a conflict
n_i	number of vehicles for the for the reference population
n_{min}	the minimum number of vehicles required to cross a bridge
n_p	total number of military personnel involved in a conflict
p	probability of failure for each crossing
P_{d_1}	annual probability of death for travel along the road segment

P_f	probability of failure
P_{f0}	acceptable annual probability of military personnel fatality attributed to bridge failure
$P_{f_{ARL}}$	annual probability of death corresponding to the ARL
P_{f_T}	probability of death for the conflict
$P_{f_{yr}}$	annual probability of death
P_i	plotting position for the i^{th} observation
P_r	probability of death per vehicle-km
$P_Y(y)$	probability that y collapses happen in n_{min} trials
s	spacing between vehicle axles
S $\bar{S}$,	constant of proportionality, 0.025; girder spacing; or load effect (mean value bias δ_S, CoV V_S)
S_i	effects due to specified loads
R	resistance (mean value $\bar{R}$, bias δ_R, CoV V_R)
R_L	modification factor for multi-lane loading
T	duration under consideration in year
t_s	depth of concrete slab
W_c	nominal curb weight of the vehicle (mean value $\overline{W_c}$, bias δ_c, CoVV_c)
W_p	nominal payload (mean value $\overline{W_p}$, bias δ_P, CoV V_p)
W_V	nominal vehicle weight (mean value $\overline{W_V}$, bias δ_V, CoV V_V)
x	vehicle or intermodal shipping container "weight"
y	number of collapses

Greek Symbols

α	significance level for Kolmogorov-Smirnov (K-S) test
α^*	separation factor
α_D	dead load factor
α_i	load factors
α_{L_1}	live load factor
β	Gumbel distribution dispersion parameter; or target reliability index
β_1	Gumbel distribution parameter for the weight of a single shipping container

β_2	Gumbel dispersion parameter for two independent shipping containers
β_A	annual maximum weights Gumbel distribution dispersion parameter
γ	payload weight fraction
μ	central tendency parameter for Gumbel or Weibull distribution
μ_1	Gumbel central tendency parameter for the weight of a single shipping container
μ_2	Gumbel central tendency parameter for the sum of two independent shipping container weights
μ_A	Gumbel distribution central tendency parameter for annual maximum weight
σ	standard deviation
σ_1	standard deviation of the weight of a single shipping container
σ_2	standard deviation of the combined weight of two independent shipping
σ_p	standard deviation of the payload weight
σ_v	standard deviation of the vehicle weight
$\sigma_{\ln(X)}$	Log-Normal distribution dispersion parameter
ϕ	structural action resistance factor

Chapter 1

1 Introduction

Military vehicles frequently use civilian bridges in domestic, peacekeeping, stabilization and combat theatres of operation. The load effects of military vehicles, both wheeled and tracked, are unique and likely different than those of civilian vehicles in normal traffic. The probabilistic quantification of military vehicle bridge loading has not been fully performed. As such, calibration to determine appropriate load factors for military loading of bridges cannot be undertaken and the corresponding level safety is unknown. This lack of calibration prevents the proper implementation of Limit States methods in military bridge design and evaluation. Investigation of the appropriate life safety risk in bridges for the military has not taken place. Without a defined acceptable risk and quantification of military vehicle loads on bridges, Limit States design and evaluation methods will not be adopted for general military use.

1.1 Military Load Classification System

The Military Load Classification System, outlined in North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2021, (NATO, 2006) categorizes military vehicle loading and the capacity of bridges, ferries, and rafts. "The aim of this agreement is to standardize, for NATO forces, a method of computing the Military Load Classification (MLC) of bridges, ferries and rafts (including their landing stages) and vehicles" (NATO, 2006). Bridges are assigned an MLC based on the highest vehicle MLC that can safely traverse them. Thus, the Military Load Classification System is the basis of military bridge design and evaluation for NATO member countries and so allows better interoperability between NATO countries. STANAG 2021 (NATO, 2006), outlines the need for NATO countries to account for dynamic load effects and consider appropriate factors of safety when determining a bridge rating, but the definition and application of these values are the purview of each member country (NATO, 2006).

1.1.1 Vehicle Classification

According to NATO (2006), the means of classifying a vehicle is closely associated with the procedure for rating a bridge. This document specifies thirty-two hypothetical wheeled and tracked vehicles, as shown in Figure 1.1 for MLC 20 and 24 Wheeled vehicles and Figure 1.2 for MLC 20 and 24 Tracked vehicles. These thirty-two standard classes between MLC 4 and MLC 150 are used to derive maximum shear and moment tables and charts for these vehicles acting on simply supported reference spans from 1 m to 100 m with ground contact points between vehicles at 30.5 m apart (NATO, 2006). A sample chart for wheeled vehicles is shown in Figure 1.3. Each line in Figure 1.3 corresponds to one of the 16 standard-class wheeled vehicles. The numbers in the vertical column, on the right side of the figure are the corresponding MLCs, spaced vertically to reflect their relative position.

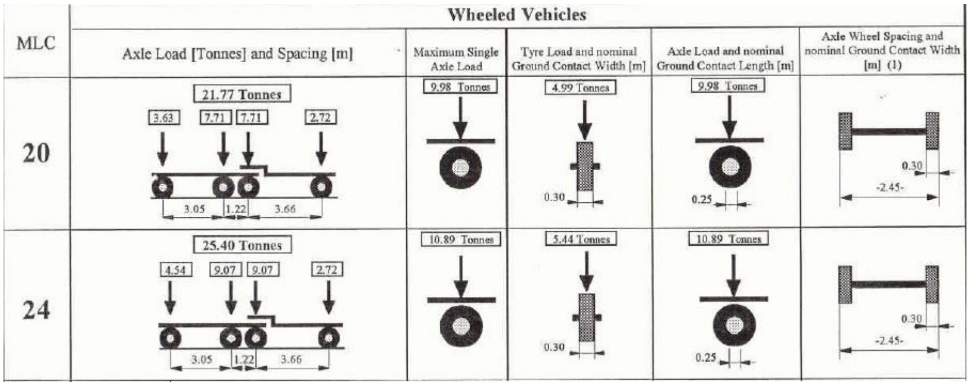


Figure 1.1 – Hypothetical standard class vehicles – Wheeled, (NATO, 2006)

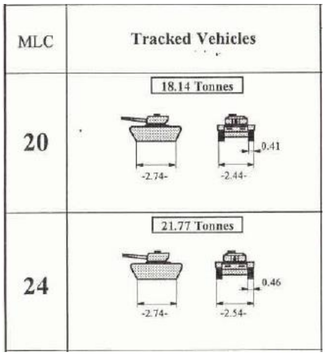
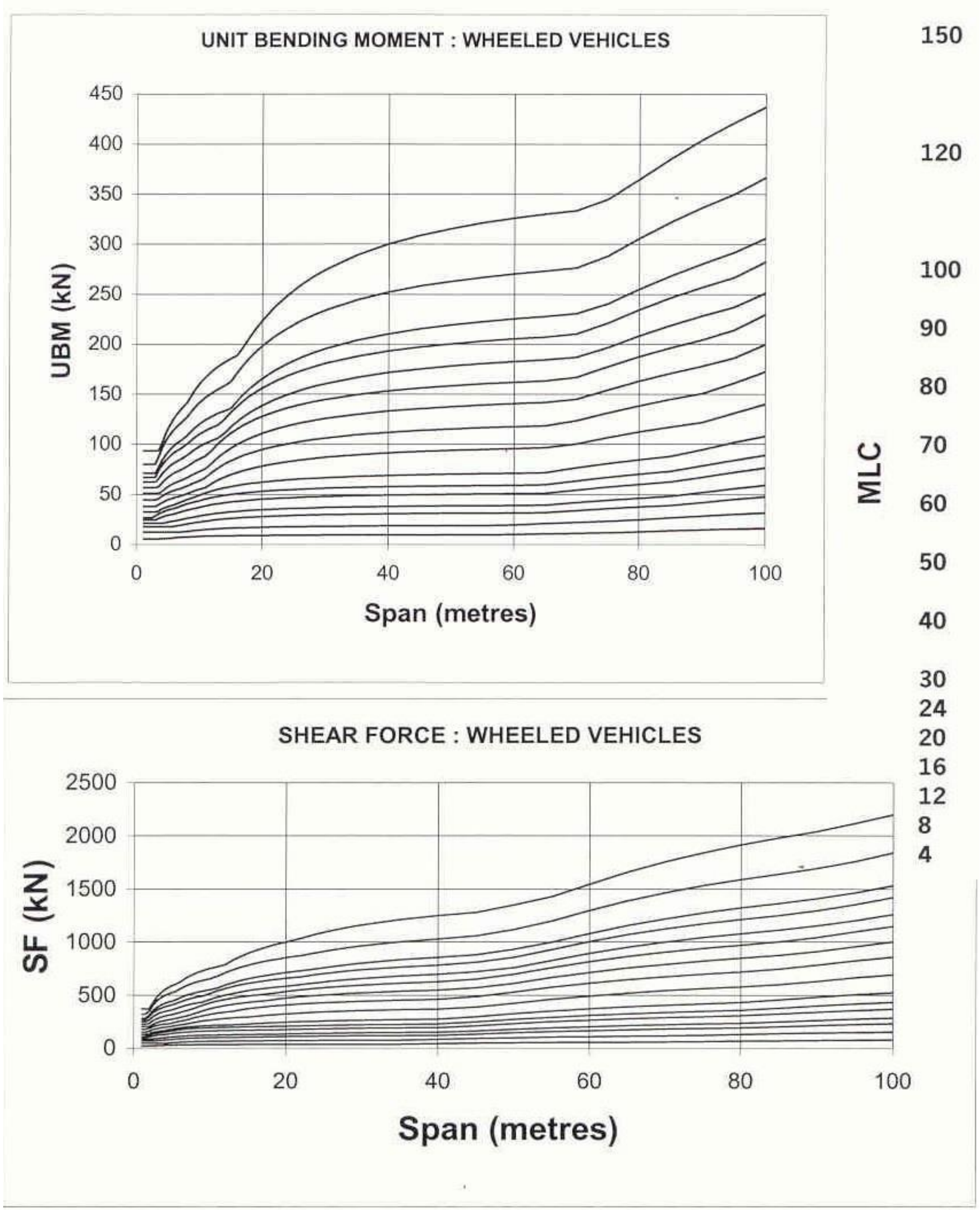


Figure 1.2 – Hypothetical standard class vehicles – Tracked, (NATO, 2006)



UNIT BENDING MOMENT : WHEELED VEHICLES

SHEAR FORCE : WHEELED VEHICLES

Figure 1.3 – Unit bending moment and shear force charts for MLC (Wheeled) vehicles (NATO, 2006)

To assign an MLC to a vehicle, first, the maximum bending moment and shear force due to its fully laden state is calculated for each span length in the tables. For each span length, the bending moment and shear force will be compared to the standard classes (using linear interpolation to assign an MLC when falling between standard classes). The MLC of a vehicle is for the span length which yields the highest MLC, in moment or shear. “At the end of calculations, the MLC as calculated shall be rounded off to the nearest whole figure” (NATO, 2006). It is beneficial to categorize a military vehicle in this manner, rather than its number of axles and Gross Vehicle Weight (GVW), because it allows each vehicle to be rated based on the nominal maximum load effects it causes on a simple span.

One shortfall of this MLC definition procedure is that it does not specifically address the expected, potential or observed variability of the load. The assigned MLC is generally assigned to the whole fleet, which may or may not account for the variability of the actual load effects of each vehicle within that fleet. Thus, two fleets with the same expected fully laden vehicle weight, one with a high variability and the other with a low variability, could receive the same MLC designation. Figure 1.4 indicates an example of such a comparison. The US Stryker – Infantry Carrier Vehicle and the US M813A1-5-ton Cargo Truck are both rated at MLC 20 Wheeled (US Department of the Army, 2008). Although both vehicles have the same MLC designation, the GVW of the M813A1 is mostly payload, transporting various types of cargo, whereas the role of the Stryker is limited to the transporting infantry without significant additional cargo. It is therefore likely that the M813A1-5-ton Cargo Truck would have much greater variability of load effects because it is much easier to overload the M813A1 than the Stryker. Yet they are given the same MLC rating.


M813A1-5-ton Cargo Truck

US Stryker - Infantry Carrier Vehicle

Figure 1.4 - Comparison of two MLC 20 (Wheeled) vehicles (Photos Left to Right: Army Trucks Inc. (2014), US Army (2014))

Although it would seem appropriate to quantify and account for the bias and variability of vehicle load effects in the vehicle and/or bridge MLC designation, this is not addressed in the minimum requirements outlined in NATO (2006). This can be problematic and inefficient for a vehicle that causes relatively low load-effect variability and will have a lower probability of failure than other vehicles with the same MLC that cause greater load-effect variability. Within one MLC designation, the bridge failure probability will therefore be different for each vehicle fleet. Although this may be desirable due to various factors (such as number of personnel that would be vulnerable during bridge collapse, the vehicle cost, the impact of mobility limitations has on achieving/maintaining battlespace advantage, the impact of loss of vehicle on military operations, etc.) this should be a conscientious decision where differences in risk are rationally accounted for.

1.1.2 Bridge Rating

For bridge design and evaluation, the allowable moment and shear resistance of the bridge span are compared to tables and charts in NATO (2006) such as the example shown in Figure 1.3. The bridge MLC rating is the minimum obtained from the moment and shear charts. How each nation defines the allowable moment and shear is their own prerogative. This can be done by Allowable Stress Design, limiting the allowable stress in structural members subjected to specified loads, or Limit States Design using load and resistance factors. Either approach is roughly based on of "the current civilian structural standards published in their respective countries" (Lenner, Keuser, & Sykora, 2013) with slight modifications. Given that there is limited literature available on force effects due to military traffic on bridges (Kim (2012) and Kim, Tanovic and Wight (2010)) often the Allowable Stress Design method is used as the bridge design and evaluation methodology.

1.2 Limit States Design

Limit States Design (LSD) has generally been adopted by civilian standards for bridge design and evaluation in Canada (e.g. CSA, 2006a) and is similar to Load and Resistance Factor Design (LRFD) that is slowly being adopted in the United States (e.g., AASHTO, 2012). Given that most NATO members are countries that have adopted or are in the process of adopting LSD or LRFD for their bridge evaluation and design standards, it is a logical progression that bridge design and evaluation standards for military traffic would follow suit. For the military, there are advantages in adopting LSD in their bridge standards; however, to do so requires the collection and quantification of statistical data on military traffic loading effects on bridges.

1.2.1 Allowable Stress Design Methods

Prior to the adoption of LSD methods, the predominate approach to structural design was Working Stress Design in Canada, which is similar to Allowable Stress Design (ASD) in the United States (US). ASD is still generally adopted when there is insufficient information available to employ LSD. "The ASD method establishes the … allowable stress for each construction material as a fraction (or percentage) of the material's load-carrying capacity, and requires that calculated or design stresses in the structure do not exceed the allowable stress" (DND 2007a). In its purest form, ASD does not consider, in a probabilistic sense, the contribution of the variability of loads and material strengths to the overall structural safety.

1.2.2 Limit States Design Methods

LSD is a more rational approach to structural design and evaluation because it accounts for the statistical variability of both the applied loads and resistance of the structure, as well as the consequences of a particular limit state occurring. In LSD, "[a] structure, or part of a structure, is considered unfit for use or to have failed when it exceeds a particular [limit] state… beyond which its performance or use is impaired" (CSA, 2011). The limit states of particular interest in bridge design and evaluation are:

- Ultimate limit states – "The ultimate limit states involve a loss of equilibrium that causes all or part of the structure to collapse" (CSA, 2011). This is generally associated with structural instability or loss of the capacity of structural components due to excessive demands.
- Fatigue limit state – "The fatigue limit state is associated with unstable crack growth under cyclic loading that potentially leads to fractures in service and, in turn, to full or partial collapse of the structure" (CSA, 2011). This limit state differs from ultimate limit state in that the behaviour the material, such as its capacity, will change due to cyclic loading and has a strong time/usage component in its derivation.
- Serviceability limit states – "The serviceability limit states restrict the normal use and occupancy of the structure" (CSA, 2011). Although exceeding a serviceability limit state does not result in structural failure it does render a structure non-functional for its intended use due to excessive deformations, localized damage or vibration.

1.2.3 Advantages of LSD

LSD has several advantages over ASD. Overall, risks accepted for the design, whether life-safety or economic, are conscious decisions. Some specific advantages of LSD over ASD are:

- in LSD, the factors used in design are tied to the probability of exceeding a limit state by the reliability index, "hence, the advantage of the calibrated

LRFD format from a reliability viewpoint is uniform safety indexes [sic] over different materials, spans, and load effects" (Transportation Research Board, 2001);

- LSD is able take into consideration each member failure mode differently, depending on its impact to life safety, and is better able to incorporate the realities of failure when determining appropriate levels of risk; and
- LSD can account for different variability of specific load types through load factor selection.

In the context of the military, some additional advantages of adopting LSD are:

- ability to quickly estimate and compare the level of life-safety risk being assumed in "risk crossings" as defined by NATO (2006); and
- potential to calibrate bridge life-safety risk to the life-safety risk of the associated military operation.

An impediment to the conversion of structural "design models to the LRFD format from the previous allowable stress design (ASD) practices [is] the lack of high-quality data to calibrate load and resistance factors" (Allen, Nowak, & Bathurst, 2005). This can be a substantial effort. However, the benefits of LSD/LRFD potentially warrant such effort.

1.2.4 Data Needed for Limit State Design of Military Bridge Design and Evaluation

To be able to implement LSD, both structural loads applied and resistances must be quantified in probabilistic terms.

1.2.4.1 Loads

Most bridge loads are able to be accurately described in probabilistic terms in Canada, the United States, and most Western European countries. Describing military vehicular loads in probabilistic terms is the greatest obstacle preventing the application LSD to military bridge design standards. Although there is information available on nominal weights of military vehicles, there are little data on the operational weights in terms of bias and variability with respect to the nominal weight. Probabilistic quantification of dynamic load effects caused by military vehicles is also lacking in available literature. Collection of this data is necessary to move military bridge design and evaluation from ASD to LSD.

1.2.4.2 Resistance

Structural resistances in most NATO countries are well documented and so can be used for the implementation of LSD for military use (e.g., CSA (2006a, 2006b)). Without some estimate of this behaviour it would be difficult to assign an MLC to a bridge using a LSD approach. Given that bridges will likely be subject to military vehicular loads for short periods of time, the effects of fatigue can likely be ignored.

1.3 Research Objectives

The overarching objective of this research is to quantify the probabilistic description of military vehicular loads on bridges and the associated structural reliability. This will facilitate the development of load factors related to military vehicle loads so that LSD methods can be adopted for use by the Canadian Forces with confidence. The related sub-objectives of this thesis are to:

- examine acceptable life-safety and optimal risks (both life-safety and economic)for bridges in the context of acceptable life-safety risk for military operations to formulate suitable target reliabilities;
- quantify the probabilistic load effects of three vehicles currently in use by the Canadian Forces:
  - Armoured Heavy Support Vehicle System – Palletized Loading System (AHSVS-PLS);
  - Light Armour Vehicle III – Infantry Section Carrier (LAV III-ISC); and
  - Leopard 2A4M tank.

- generalize the probabilistic load effects of these three vehicles for evaluation of other military vehicles;
- derive load factors specific to the AHSVS-PLS (transport), LAV III-ISC (armoured personnel carrier) and Leopard 2A4M tank, as well as, general load factors for categories of military vehicles; and
- describe methods to reconcile LSD methods with current Military Load Classification System.

1.4 Thesis Outline

To effectively use LSD, one must be able to reasonably quantify: probabilistic loads; probabilistic resistance; and target reliability (on the basis of acceptable life-safety risk). Specifically for Canada, loads (with the exception of military vehicles) and material properties are already well understood in this sense. Bridge acceptable risk in the context of military operations has not been previously explored. As such, bridge acceptable risk for military operations needs to be defined, and probabilistic military vehicle load effects need to be derived.

"Acceptable levels of risk attaining a limit state, to be used as targets in design, should be assessed with due regard to… criteria applicable to the structures under consideration" (CIRIA, 1977). Acceptable levels of risk for bridges in the context of military operations are discussed in Chapter 2, while factors to be considered in risk optimization, both life-safety and economic for bridges in use by the military are presented in Chapter 3. Different acceptable levels of risk are discussed; however, target reliabilities are only defined for circumstances similar to those given in CSA (2006a, 2006b).

Chapter 4 quantifies the probabilistic definitions of the Gross Vehicle Weight (GVW) for three military vehicles. Using these probabilistic definitions, Chapter 5 quantifies the load effects due to these three vehicles by exploiting previous research relating to the dynamic load effects and lateral load distribution of military vehicles.

Chapter 6 derives load factors calibrated to the load effects of the three vehicles from Chapter 5. Further to this, Chapter 6 proposes four Military Vehicle Categories with associated load factors that all military vehicles can be assigned to. Chapter 7 reconciles the proposed Military Vehicle Categories and load factors with the Military Load Classification System.

Chapter 8 summarizes research, presents the main conclusions and recommends follow-up research to further our understanding of military vehicle loads on bridges.

Chapter 2

2 Acceptable Risk for Military Bridges

Life-safety risk, defined in terms of probability of annual death unless otherwise stated, must account for some unique circumstances when evaluating bridges for military use. Given the unlimited liability expected of those in military service, the acceptable risk for military personnel may be higher than that for the civilian population they serve (Canadian Defence Academy, 2007). This chapter therefore seeks to define the maximum acceptable risk based solely on socially acceptable considerations, i.e., without considering economic factors or other benefits. This could be considered an upper risk limit for military bridge evaluation. Acceptable risk should account for "the proportionately greater public concern for multiple-death tragedies than for equivalent number of death caused singly by numerous accidents" (CSA, 1981). This aspect of acceptable risk, will not investigated in the context of acceptable risk for the military.

2.1 Acceptable Risk and Military Operations

Military operations inherently expose armed forces personnel to increased levels of acceptable risk due to: necessity for rapid execution of tasks, exposure to heavy specialized equipment, need to handle hazardous equipment and material (including lethal weapon systems whose intent is to maim or kill), enemy forces actions, and friendly forces actions, such as friendly fire (Armed Forces Epidemiological Board, 1996). It is deemed acceptable that military personnel assume these increased levels of acceptable risk due to the function they perform for the society they serve (Canadian Defence Academy, 2007). The purpose of a military fighting force is to impose the will and desire of the nation-state through the threat of force or the application of force up to and including the use of deadly force to achieve a political purpose. "By its very nature, the application of force will place individuals and resources in harm's way" (DND, 2007b).

2.1.1 Mission Planning Factors and Life Safety Risk

When conducting mission analysis, military planners must weigh the cost of putting personnel at risk of death or injury to the benefits of achieving the mission objective. At times this requires that some individuals assume disproportionally higher risks than others. In military operations, exposing a few individuals to very high risk levels can ensure reduced risk to all other personnel involved in the operation. Given the complexity of risk and the complexity of military operations, risk management tools are put in place "to provide a decision process that will aid planners in identifying, analyzing, evaluating and controlling all types of risk" (DND, 2007b). "[R]isk management is required in military planning to ensure that threats are fully considered, appropriate measures are taken to minimize their effects and that risk decisions are fully understood" (DND, 2007b). In general, this process involves (US Department of the Army, 1998):

1) identifying hazards;

2) determining impact these hazards have on mission accomplishment in terms of probability and severity;

3) developing controls to mitigate the risk associated with hazards;

4) developing-analyzing-comparing course of actions

5) deciding on a course of action;

6) implementation of risk mitigation controls during task execution;

7) supervision and re-evaluation during mission execution (which include adjusting to changes in the known situation); and

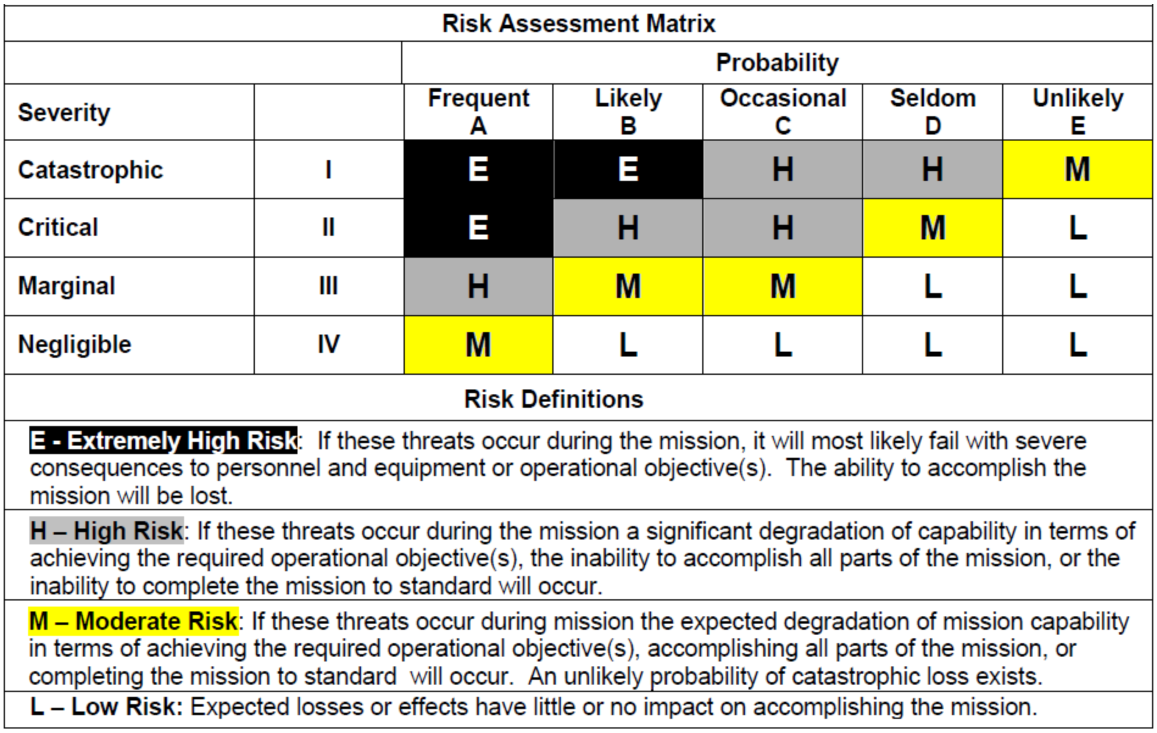
8) mission evaluation to summarize lessons learned for next risk analysis cycle.

A main tenant of this process is to ensure that unnecessary risks are not accepted, and that additional risk is only accepted "if the benefits outweigh the potential costs or losses" (US Department of the Army, 1998). In the risk management process, even after risk mitigating measures are in place, residual risk will always exist; it is left to the commander to "decide whether to accept the level of residual risk to accomplish the mission" (US Department of the Army, 1998). If the residual risk is greater than what has been deemed acceptable by higher command guidance, then subordinate commanders must "seek the higher commander's approval to accept risks" (US Department of the Army, 1998) or change the mission scope to reduce the residual risk to an acceptable level.

2.1.1.1 Mission Risk Assessment

Table 2.1 shows the risk assessment matrix used in the risk management process where risks are defined in the context of accomplishing the mission. Similar to CSA (2011), military mission risk is defined on the basis of consequences and its associated probability of occurrence. Although expected personnel loss (which is essentially life safety risk during the execution of the mission) is closely associated with the risk of not accomplishing the mission, defining mission risk does not categorically identify the acceptable life safety risk to personnel (Wight, 1997). Although the aim is to minimize losses to achieve the mission objective, it might be warranted to increase the risk of mission failure to lower the life safety risk to personnel or increase life safety risk to minimize risk of mission failure. This decision is based on other considerations such as "the public reaction to [personnel] loss against national, strategic, operational or tactical objects" (DND, 2007b) and the consequences of mission failure, where at its extreme when "a leader's survival or when a regime, political, religious, ideological, or economic system is at stake, virtually any level of [life safety] risk may be acceptable" (Wight, 1997).

Table 2.1 – Mission risk assessment matrix with risk definitions (DND, 2007b)



Risk Assessment Matrix						
		Probability				
Severity		**Frequent A**	**Likely B**	**Occasional C**	**Seldom D**	**Unlikely E**
Catastrophic	**I**	**E**	**E**	**H**	**H**	**M**
Critical	**II**	**E**	**H**	**H**	**M**	**L**
Marginal	**III**	**H**	**M**	**M**	**L**	**L**
Negligible	**IV**	**M**	**L**	**L**	**L**	**L**

Risk Definitions

E - Extremely High Risk: If these threats occur during the mission, it will most likely fail with severe consequences to personnel and equipment or operational objective(s). The ability to accomplish the mission will be lost.

H – High Risk: If these threats occur during the mission a significant degradation of capability in terms of achieving the required operational objective(s), the inability to accomplish all parts of the mission, or the inability to complete the mission to standard will occur.

M – Moderate Risk: If these threats occur during mission the expected degradation of mission capability in terms of achieving the required operational objective(s), accomplishing all parts of the mission, or completing the mission to standard will occur. An unlikely probability of catastrophic loss exists.

L – Low Risk: Expected losses or effects have little or no impact on accomplishing the mission.

2.1.1.2 Acceptable Life Safety Risk

In the context of evaluating mission risk, the commander must weigh the cost/benefit of having personnel assume additional risk to achieve the mission. To quantify the appropriate life safety risk to achieve the mission is a complicated procedure that uses incomplete situation information. It relies on personal experience and other human qualities (such as morale and esprit de corps) that are difficult to quantify in methodical terms. Regardless of how the commander determines the appropriate life safety risk for various sub-elements under their command, this information must be conveyed in a manner that is both reliable and easily understood. Wight (1997) describes life safety based on Acceptable Risk Levels (ARLs), shown in Table 2.2, that "would be a commander's directive to subordinates to shape further planning and execution decisions that specifies what level of potential losses is acceptable in order to achieve the mission objectives" (Wight, 1997). Theses ARLs, are appropriate for use for engineering systems since they can be quantified in terms of probability of death per year. Where the probability of death per year, $P_{f_{yr}}$, was not explicitly stated by Wight (1997), it was possible to compute this for each example battle or conflict used. Table 2.2 shows the $P_{f_{yr}}$ for these battles or conflicts, along with other more recent examples, as calculated using:

[2.1]
$$P_{f_{yr}} = 1 - \left(1 - \frac{n_d}{n_p}\right)^{\frac{1\,yr}{T}}$$

where n_d denotes the number of military fatalities in the conflict, n_p is the total number of military personnel involved in the conflict and T is the duration under consideration in years. Equation [2.1] is derived assuming that probability of death and total number of personnel remains constant over the duration of the conflict. The actual probability of death varies throughout the conflict.

Table 2.2 – Acceptable Risk Level (ARL) and associated annual probability of death for conflict or battle within ARL

ARL	Order of Magnitude of Probability of Death per Year (%)	Example within ARL	Probability of death per year (%)	
Negligible	0.01	This is general population rate of death for 20-24 year olds	All Causes	0.06[a]
			Non-Disease Related	0.04[a]
Low	0.10	Operation Iraqi Freedom 2003-2007 (US)	All Causes (All)	0.42[b]
			Combat Only (All)	0.34[b]
		Kandahar, Afghanistan 2006-2011 (Canada)	All Kandahar (All)	0.96[c][d]
			Inside Airfield (All)[e]	0.06[c][d]
Moderate	1.0		Outside Airfield (All)[e]	1.9[c][d]
		Vietnam War 1965-1974 (US)	All Causes (All)	2.2 [b]
			Combat Only (All)	1.8 [b]
High	10	Battle of the Bulge (US)	All Causes 16 Dec 1944 to 25 Jan 1945 (All)	25 [f]
			All Causes 19 Dec 1944 - 6 Jan 1945 (101st Airborne)	45[g]
		Battle of Britain WWII (Allied)	Combat Only (Pilots Only)	49[h]
Extreme	70 to Approaching 100	Kamikaze Missions WWII (Japan)	-	

[a] Table 2.3 – Annual deaths per 100,000 persons aged 20-24 years
[b] Goldberg (2010)
[c] icasualties.org (2013)
[d] canada.com (2013)
[e] Assumed half troops at airfield at all times. Average number of troops = 2,595, 141 fatalities outside the airfield, 5 fatalities inside the airfield
[f] Wikipedia.org (2014a), 610,000 US troops, 19,000 fatalities, duration of 40 days
[g] Wikipedia.org (2014b), 11,800 101st Airborne troops, 341 fatalities, duration of 18 days
[h] Vancata (2014), 2,367 allied pilots, 446 fatalities, duration of 113 days

2.2 Acceptable Risk for Military Personnel during Bridge Crossings

In military operations, a continuum of acceptable risk exists that depends on the conflict, operation, mission and individual. As such, it would be unreasonable to assign a single value to the acceptable risk for ancillary activities that military personnel participate in during military operations. In the context of military traffic, there should be a continuum of acceptable risk for bridges that is aligned with the Acceptable Risk Level (ARL) of the military operation. Although other factors must be accounted for to estimate the optimum level of risk, this acceptable risk represents the upper bound of risk allowed in bridge crossings. Military planners should also consider if civilian traffic (vehicular or pedestrian) will be present when military vehicles are traversing the bridge. In this case, the civilians would be exposed to the same risk as the military personnel, so the acceptable risk may be lowered from that corresponding to the ARL to that considered acceptable for civilians. This socially acceptable risk for civilians may vary with the situation.

The concept of differing risk levels for bridges based on the type of military operation is not new. During World War II, Britain developed a military-specific classification for roughly 40,000 bridges of importance throughout the country (Chettoe, 1948). In establishing allowable stresses to calculate bridge strengths, Chettoe (1948) states: “Clearly, when the country was in danger of invasion, the use of normal stresses would have laid too much restriction on military movements”. Such classification would be used during “…actual fighting or manoeurves – and it was felt that the stresses chosen should be as high as possible – subject to the proviso that a reasonable number of the heaviest loads allowable would not damage the bridges”. A higher allowable stress of 50 percent in excess of normal was used to assess and classify bridges. In some cases, dual classifications were given with the lower classification based on allowable stresses of 25 percent in excess of normal (Chettoe, 1948). In the case of “dual classifications, the military authorities were asked to use the lower or “routine” figure whenever possible” (Chettoe, 1948). For more extreme situations “…it was made clear to the military authorities that the assessment made did not represent the ultimate strength of the bridges, and that, if necessary in the course of actual fighting, loads perhaps twice as great could have been taken across without actual collapse, though the bridges might be irreparably damaged in so doing" (Chettoe, 1948). Given that a land invasion of Britain in World War II might have allowed for a HIGH or EXTREME ARL for Allied Forces in the conduct of warfighting, it is reasonable that greater risks of bridges failure were deemed acceptable following Chettoe's recommendations.

2.2.1 NATO Standardized Agreement 2021 - "Risk Crossing"

NATO Standardized Agreement 2021 (2006) specifies that if a vehicle with a specified MLC that "…is less than or equal to the MLC of the bridge..., the vehicle can cross the bridge…; otherwise it must be diverted" (NATO, 2006). However, "…under exceptional operational conditions, this prohibition may be lifted on special decision of the theatre commander in the operational zone, or on that of civil authorities in areas under their control" (NATO, 2006). These exceptions would be considered "risk crossings". Given that each mission within a military operation has an ARL that could allow for different levels of risk during bridge crossings, a crossing need not be considered a "risk crossing" that required theatre commander approval unless the probability of failure allowed for given the ARL of the mission was exceeded. There could be further restrictions for bridges along designated Main Supply Routes (MSRs), where a bridge collapse may result in strategic consequences. This would give lower levels of command the flexibility necessary to gain the initiative in higher risk missions. If mission risk analysis indicated that crossing a certain bridge was required for mission success, and this activity was a lower risk than the ARL of the operation, it would not require higher command approval since this risk is implicitly allowed given the ARL set by higher command.

2.2.2 Acceptable Risk Level and Maximum Allowable Probability of Bridge Failure

To determine the appropriate risk for bridges used by the military in the absence of civilians, a baseline acceptable risk should be established. The risk of bridge failure during a crossing should be lower than that of the associated military activities, which is the ARL or the expected losses of the military operation.

Acceptable risk in bridge design and evaluation for civilian application has been defined and used to calibrate civilian design standards based on Limit State Design methods. The annual risk of fatality associated with bridges in Canada is in the order of $0.1x10^{-6}$, which “has been associated with a satisfactory fatality rate for bridge users” (Allen, 1992). Railway lines have deemed that $1x10^{-6}$ is an acceptable annual risk of fatality (Cremona, 2011). In comparing the fatal accident rate of different activities, Menzies (1997) found that for short and medium span bridges the maximum annual “socially acceptable risk of accidental death to members of the public associated with normal highway bridge collapse [is $1x10^{-6}$]”. Menzies (1997) approached the problem using the fatal accident rate of driving by car of $150x10^{-6}$ as an upper bound and the background fatal accident rate at home of $10x10^{-6}$ as a lower bound. The “statistics for all types of accident suggest that a fatal accident rate of about [$20x10^{-6}$] would be an acceptable value relating to bridge collapse” (Menzies, 1997). This value was however lowered to $1x10^{-6}$ due to subjective attitudes associated with voluntary and involuntary exposure to risk, “on the basis that the risk of loss of life caused by bridge collapse is an involuntary one, the acceptable probability for such an event is in the region of $0.1x10^{-6}$ to $1x10^{-6}$” (Menzies, 1997).

Adopting Menzies’ perspective, it could be argued that, military activities in Canada, including bridge crossings, are voluntary. Thus under a NEGLIGIBLE ARL it would be deemed acceptable for military personnel to assume an annual risk of fatality of $20x10^{-6}$. However, given that the Canadian Department of National Defence (DND) under its Ammunition Safety Program suggests that “the organization must strive to meet high standards in terms of accident prevention” (DND, 2005) with annual probabilty of death due to an accident related to ammunitation of about $20x10^{-6}$ (22 deaths between 1983-2005, with the assumption of roughly 50,000 personnel) it would seem, under normal peacetime circumstances, necessary to lower the annual risk fatality to $1x10^{-6}$ as proposed by Menzies (1997).

Table 2.3 shows the annual death rates of Canadians due to various causes as reported by Statistics Canada (2012). The average annual probability of death for all causes, excluding disease, for Canadians aged between 20 and 24 years is 407x10^{-6} (or 0.04%). The societal acceptable annual risk of fatality for bridge crossings is 1x10^{-6} (or 0.0001%) or 1/400th of this value. Thus the risk of military fatalities for bridge crossings could reasonably be taken as 1/400th of the military ARL.

Table 2.3 – Annual deaths per 100,000 persons aged 20-24 years (Statistics Canada, 2012)

Cause of Death	Year					Average
	2005	2006	2007	2008	2009	
Disease	16.6	17.8	14.2	15.1	14.9	15.7
Intentional Self-Harm (Suicide)	13.2	11.7	12.8	11.2	11.9	12.2
Assault (Homicide)	3.8	3.4	4.0	4.5	3.9	3.9
Legal Intervention	0.1	0.1	0.0	0.1	0.0	0.1
Events of undetermined intent	1.3	1.9	1.9	2.0	1.4	1.7
Motor Vehicle Accidents	17.5	15.7	17.4	14.7	12.5	15.6
Other Transport Accidents	1.0	1.1	0.8	1.0	0.6	0.9
Accidental Drowning and Submersion	0.8	1.1	0.9	0.9	0.9	0.9
Other Non-transport Accidents	5.5	5.4	5.0	5.8	5.9	5.5
Sum Accidental Cause of Death	24.8	23.3	24.1	22.4	19.9	22.9
Sum Non-Disease Related Death	43.2	40.4	42.8	40.2	37.1	40.7
Sum All Causes of Death	59.8	58.2	57.0	55.3	52.0	56.5

Figure 2.1 shows a relationship between probability of bridge collapse and ARL. The annual risk of fatality is maintained at 1/400th the ARL, and so increases linearly with ARL for ARL greater than 0.04%. Thus:

$$P_{f0} = S \cdot P_{f_{ARL}} \quad [2.2]$$

where P_{f0} is the acceptable annual probability of military personnel death due to bridge failure, $P_{f_{ARL}}$ is annual probability of death corresponding to the ARL, and S is the constant of proportionality, 0.025. For $P_{fARL} < 0.04\%$, the civilian fatality risk limit of 1x10^{-6} (Menzies, 1997) governs. This relationship seems reasonable when the ARL is LOW or MODERATE, where the risk associated with bridge crossings is negligible compared to all other risks assumed by military personnel. At these ARLs it is expected that military units at the end of the operation or mission will remain fit for further combat (Wight, 1997).

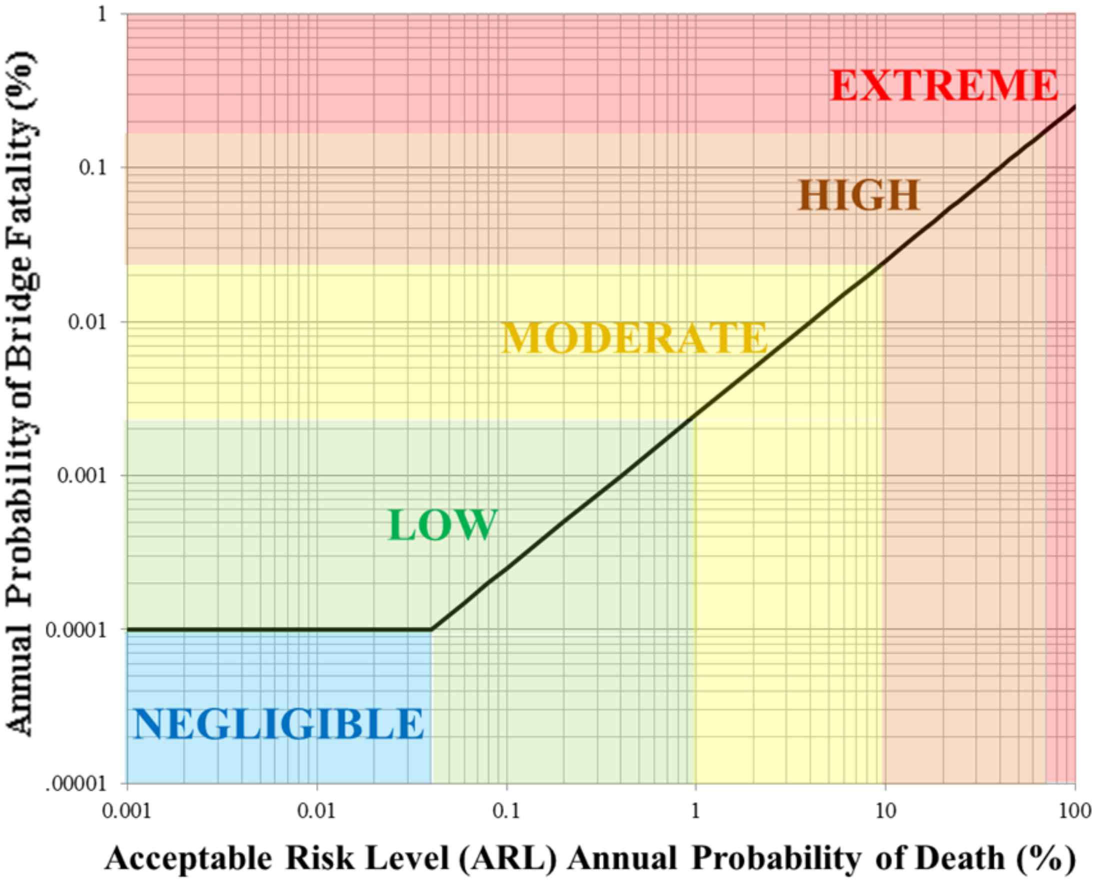


Figure 2.1 – Acceptable annual risk continuum for military bridging

In general, over the long-term, a conflict can be expected to take fatalities at an ARL of LOW or MODERATE, since the conflict would not continue at a sustained ARL of HIGH or EXTREME. Over the course of a conflict, individual military units in the conduct of the operation may be exposed to an ARL of HIGH or EXTREME for short periods of time (days to months) on individual missions, and would likely sustain losses that would render the units unfit for further combat. At these higher ARLs, the P_{f0} computed using Equation [2.2] could possibly be too conservative. This is best illustrated by looking at the EXTREME ARL, where “losses may result in complete force annihilation" (Wight, 1997). In its most simplistic sense, in military operations, bridges are obstacles between the current and desired locations of military assets required to complete the mission. Thus for a mission given the highest possible ARL (i.e. $P_{fARL} \rightarrow 100\%$), risks taken to get military assets where they are required, such as crossing bridges, should have an upper limit corresponding to the unit remaining combat effective after completing the crossing. A military unit is considered to be combat capable at 85% or greater strength (e.g., US Department of the Army & US Department of the Navy 2004, US Department of the Army 2003).

For example, assume that a single bridge needs to be traversed to engage the enemy. If the bridge collapses, any military vehicles that had not yet crossed could no longer support the mission. Although several bridges might need to be traversed, only one may contribute significantly to the risk. Thus, the goal of maintaining combat capability would require that 85% of the vehicles will successfully traverse the bridge with say, 99.75% probability, before it is rendered non-functional. The size and vehicle composition of the mechanized military unit, specifically the number of limiting vehicle types involved in the mission, must therefore be considered. For example, an armoured brigade typically includes main battle tanks, infantry fighting vehicles and support vehicles; the main battle tank causes the most severe load effects and so would be the limiting vehicle. The location of the limiting vehicles in the overall convoy (i.e., order of road movement) would also need to be considered in the planning stage because these vehicles are most likely to render the crossing unfit for use by the vehicles that follow.

To determine the acceptable event probability of failure the binomial mass function was used:

[2.3]

$$P_Y(y) = \left(\frac{n_{min}!}{y!\,n_{min}!}\right) p^y (1-p)^{n_{min}-y}$$

where p is the probability of failure for each crossing, n_{min} is the minimum number of vehicles required to cross (which would normally be taken as a percentage of total number of vehicles, n), y is the number collapses and $P_Y(y)$ is the probability that y number collapses happen in n_{min} trials. When $y = 0$, Equation [2.3] simplifies to:

[2.3a] $$P_Y(0) = (1 - p)^{n_{min}}$$

where $P_Y(0)$ is the probability that n_{min} vehicle can successfully cross prior to collapse. Equation [2.3a] can be rearranged to solve for p given n_{min} and $P_Y(0)$:

[2.4] $$p = 1 - P_Y(0)^{1/n_{min}}$$

Given that HIGH and EXTREME ARLs would be more likely employed for mission or situation-specific circumstances and so are not likely to be present for long periods of time, it is beneficial to quantify event risk for each vehicle crossing. Table 2.4 outlines the event risk for the crossing of n vehicles, where greater than n_{min} (taken as $0.85n$, rounded up to the nearest integer) vehicles must meet a minimum probability, $P_Y(0)$, that they will successfully traverse the bridge prior to a failure by overloading that renders the bridge non-functional for subsequent vehicles. $P_Y(0)$ at each ARL is taken such that when $n = 1$, the event risk does not exceed the annual risk given in Equation [2.2]. Table 2.4 does not relate specifically to annual risk since it is confined to the risk associated with a single bridge crossing by n vehicles for a particular mission. The event risk identified Table 2.4, is the maximum risk allowed to ensure a mission involving n vehicles has a sufficient probability of remaining combat capable after a bridge crossing. It is unknown how often HIGH or EXTREME ARL crossings would occur per year (if at all) due to the highly unpredictable nature of warfare.

Table 2.4 – Event risk for single bridge crossing by n vehicles

ARL Boundary	ARL annual risk of death	ARL daily risk of death	$P_Y(0)$ probability that 85% Vehicles Cross	Event Risk (%) for Number of Vehicles Crossing (n)				
				1	10	100	1,000	10,000
EXTREME	99.99 %	2.5%	99.75%	0.25	0.028	2.9E-3	2.9E-4	2.9E-5
HIGH/ EXTREME	70%	0.3%	99.825%	0.175	0.019	2.1E-3	2.1E-4	2.1E-5
MODERATE/ HIGH	10%	0.03%	99.975%	0.025	2.8E-3	2.9E-4	2.9E-5	2.9E-6
LOW/ MODERATE	1%	0.003 %	99.9975%	2.5E-3	2.8E-4	2.9E-5	2.9E-6	2.9E-7
NEGLIGIBLE /LOW	0.04%	0.0001 %	99.9999%	1E-4	1.1E-5	1.2E-6	1.2E-7	1.2E-8

Figure 2.1 and Table 2.4 can be used as guidance for determining the minimum level of reliability when evaluating bridges based on the ARL specified by a commander or conversely after an engineer has quantified the reliability of a bridge, a means to report the corresponding level of risk through the chain of command.

An example of this would be at the beginning of a combat mission. Early in the mission, the ARL for the theatre of operations is designated by the commander as MODERATE (1% to 10% probability of death). This was decided on the basis of the type of enemy forces, and need to gain military advantage to capture a high value target. Thus, military engineers rate the MLC of existing bridges in the theatre of operations for a MODERATE ARL using Figure 2.1 (probability of bridge fatality ranging from 0.0025% to 0.025%). During the combat mission, the location of a high value target is identified. Military planners estimate that 10 MLC 22 (Wheeled) vehicles would likely be sufficient to capture the high value target. However, they would need to cross an MLC 14 (Wheeled) bridge, rated for a MODERATE ARL. The proximity of the bridge to the high value target requires that the crossing be uncontrolled. Military engineers are requested to determine the reliability of the crossing. Based on the analysis of the bridge, it is found for this particular case to have an event crossing risk of fatality of 0.006%. From Table 2.4, this corresponds to an equivalent of a HIGH ARL crossing. With this information, the commander can decide to accept this level of risk in using the bridge, or consider alternative options.

2.3 Chapter Conclusions

In military operations varying levels of risk can be appropriate to achieve mission success. By conducting a risk assessment, a military commander may benefit from allowing personnel to assume greater risks in bridge crossings. The data shown in Figure 2.1 and Table 2.4 outline the maximum acceptable risk of bridge failure given the ARL of the associated military mission. This maximum acceptable risk is an upper bound of the optimal risk for bridges crossings by military vehicles.

Chapter 3

3 Optimal Risk for Military Bridges

Economic factors and constraints associated with military operations are fundamentally different than those in the civilian context. Factors associated with military conflict, such as ensuring military advantage in a battlespace, may warrant accepting much higher life-safety and economic risks in bridge crossings by military vehicles.

In Chapter 2 it was shown that the acceptable risk in bridges used by the military could exceed acceptable civilian risk. This, however, is not reason enough to substantiate the necessity to expose military personnel to greater risk when traversing bridges. It must be shown that there are benefits in accepting greater risk, both economic and life-safety, in bridge crossings than the probable cost of bridge failure. Thus requires a cost optimization involving other relevant factors.

3.1 Different Parameters in Cost Optimization Factors for Military Bridges

3.1.1 Ancillary Costs of Construction or Repair

In Canada, the construction costs of new military bridges are similar to those for civilian bridge construction. However, during combat operations, the bridge construction or repair costs would likely increase. It might be necessary, for example, to secure the construction site from enemy forces to allow construction to proceed unabated. If the construction of a new bridge is being undertaken, it is likely to serve a larger strategic purpose that could be associated with operations costing billions of dollars. The value of the bridge’s function to the strategic purpose is vastly greater than the monetary cost of construction. The cost of military operations can be significant; for example, the annual operating cost for each US soldier in Afghanistan was between $500,000 (Entous, 2009) and $1 million (Drew, 2009). The combination of the bridge construction cost and the cost of the operation it is intended to support is therefore likely much larger than the bridge material costs. In many cases, the active bridge construction is likely to be undertaken by Combat Engineers who may, at best, train in non-standard bridge construction every few years but are more likely to have been introduced to it only once during their initial training. Thus the construction cost of new military bridges will be much smaller than the total cost of emplacement (security, personnel, logistics, etc.) and because they will likely be constructed by unspecialized personnel it is expected, given logistics and material availability, that new non-standard military bridges may be oversized from the minimum standards to meet their usage requirements. This will ensure functionality of the bridge and reduce the likelihood of costly follow-on operations for repairs or upgrades. Primary focus of design should be the expediency of construction, ease of repair, and continued functionality if damaged (discussed further in Section 3.2.3).

The relationship between the military and the entity that covers cost of damage to the bridge is also important. In bridge evaluation, if the military or the government (or allied governments) it serves are the owners of the bridge, the cost of repairing damage or full bridge replacement would be considered in the computation of the appropriate economic risk. However, if military operations are conducted in enemy territory, the cost of replacement or damage repair may be of little concern since this cost would be incurred by the enemy during or after the conflict. Thus, the cost of bridge damage or failure may be neglected in the economic risk optimization depending on the circumstances.

3.1.2 Period of Consideration or Usage

With the exception of bridges on or near permanent military installations, in most cases the expected period when military traffic would be transiting a bridge would be much lower than its design life: it would typically be the length of the operation itself. Most bridges in Canada would be unlikely to be subjected to military traffic within their operational life. Exceptions would be domestic operations such as disaster relief or security operations, which are normally the purview of civil authorities unless they are extreme in nature. If a bridge is subjected to only military traffic during extreme emergencies, higher levels of life-safety risk might be acceptable (Sýkora, Holický, Lenner, & Maňas, 2013). In any case, military traffic might use a bridge for domestic operations for a period from several days to several months.

For military engagements, major conflicts that involved Western nations over the last century have ranged between 7 months (Persian Gulf War) to 14 years (Vietnam), with an average duration of interstate conflicts lasting 11 months (Bennett & Stam III, 1996) and civil wars on average last 7 years (Collier, Hoeffler, & Söderbom, 2004). As such, military traffic loads would likely be limited to the length of these conflicts.

Unless a bridge is regularly used by military vehicles due to its proximity to a military base, it should be assumed that a bridge will be in use by the military for a limited duration. It terms of risk optimization, both economic and life-safety, this limits both the period when damage costs can occur and magnitude of the extreme loading. This would allow for higher acceptable loads given target reliability.

3.1.3 Cost of Collateral Damage from Bridge Collapse

If a bridge collapse were to occur, the cost of collapse in terms of number of lives lost and damage to vehicles might be greater for the military than expected under civilian considerations. This is due to two major factors:

1) <u>Damage or Loss of Military Equipment</u>: If there is a failure, the cost of losing a military vehicle is much greater than a civilian vehicle. The unit cost of a Leopard 2A4 tank is $1 CDN million (Army Guide, n.d.). This would be a significant financial loss and would be compounded by the associated loss of the military's ability to conduct operations.
2) <u>Number of Persons on Bridge</u>. When military vehicles are used for troop transport, the number of persons at risk due bridge collapse is significantly increased. The 6.7 m long Medium Logistics Vehicle Wheeled (MLVW), can carry up to 20 personnel plus three personnel in the cab. In addition to this, many armoured personnel carriers carry about 10 persons, which is 5 to 10 times greater than the number of persons in most civilian 20 tonne vehicles.

Even for the heaviest military vehicles, tanks at 60 tonnes or greater, the crew is normally four.

3.1.3.1 Perceptions of Civilian Population

The success of most military operations, especially in the context of counter insurgency operations, requires the support of the civilian population. Where "…whatever else is done, the focus must remain on gaining and maintaining the support of the population. With their support, victory is assured; without it, [counter insurgency] efforts cannot succeed" (US Department of the Army, 2006). Bridges temporarily or indefinitely rendered unusable by military operations, could influence the opinion of the local population of the military personnel. In determining an appropriate level of damage or collapse risk, when evaluation an existing bridge that is used by the local population, it may be necessary to consider:

1) how the civilian population would weigh the cost of damaged infrastructure to the success of one's military forces' operations;
2) how damage to bridge infrastructure cause a negative perception of the military force responsible, and so inhibit the success of operations; and
3) how a negative perception of one's military could encourage the local population to aid enemy forces.

Any impact due to the perception of the civilian population is difficult to evaluate in quantitative terms, and would differ drastically given location and context. Even so, this would be an important consideration when assessing crossings with an ARL of MODERATE or greater.

3.1.4 Military Vehicle Operating Costs

There are several costs associated with limiting route network options due to specified maximum acceptable bridge failure risk. The cost of operating military equipment is high, so the additional operating costs may be incurred due to taking less direct routes. For example, the M1-A1 Abrams tank costs about $92 USD per km ($147 per mile) to operate (Greider, 1999), whereas an average tractor trailer for the US in 2011 would cost about $1.07 USD per km ($1.71 per mile) to operate (Fender & Pierce, 2012). This also increases the cost of bridge failure due to the cost of diverting military traffic while the structure is repaired or rebuilt. This cost consideration may lead to higher or lower optimal risk of failure levels, depending on the particular circumstances of each crossing. It may be more cost effective to upgrade a bridge to increase its capacity rather than have heavy vehicles use longer alternative routes. A lower risk of bridge failure may be optimal for routes that are constantly used by military vehicles with high operating costs, such as crossings near military bases.

3.2 Optimization Factors Unique to Military Bridges

There are some factors for economic, military-mission, and life-safety risk optimization that are unique to bridges used by the military. Limitations placed on bridge crossings can impact all types of risks associated with other military activities.

3.2.1 Main Supply Routes

In determining the appropriate risk of bridge collapse, the role of the bridge in the logistical support of the military operations is important. In particular interest are Main Supply Routes (MSRs), which are “routes designated within an operational area upon which the bulk of traffic flows in support of military operations” (NATO, 2008). Much like lifeline bridges in post-seismic events for emergency response operations, bridges along MSRs are essential to military operations. A bridge along an MSR would warrant a lower risk of collapse. The two major reasons are as follows:

1) the negative impact on the ability to conduct military operations should an MSR bridge collapse would be much greater than other bridges in a battlespace; and
2) the number of military vehicle crossings on a bridge along an MSR would be much greater than other bridges in a battlespace.

3.2.1.1 Impact on Military Operations

For each military operation the consequences of temporarily losing access to an MSR will vary. In road networks where there is a single MSR between transited points, the consequences of a bridge collapse is greater than for a network with many alternative supply routes. When there is only one viable MSR in a road network, it would warrant a lower target bridge failure risk than if there were many. The estimated time necessary to initiate use of an alternative route or repair an MSR bridge is also a factor; longer delay times would reduce the optimal bridge failure risk.

3.2.1.2 Highly Variable Annual Traffic Volumes

Depending on the nature of the military operation, MSRs may experience short durations of extremely high traffic rates. During Operation Desert Shield/Desert Storm in the first Gulf War "… at a major checkpoint along the [MSR], an average of eighteen vehicles passed every minute, twenty-four hours a day, seven days a week, for six weeks" (Clair, 1993). This equates to a roughly a million vehicles over the six week period. For such volumes, the consequence of an MSR being interrupted for even a short period of time could have a major impact on the overall operation. Even if the gap created by a bridge collapse was sufficiently narrow to facilitate employment of a rapidly emplaced bridge in 30 minutes, this would have delayed over 500 vehicles in Operation Desert Shield/Desert Storm from reaching their destination.

The likelihood that an extreme load will be observed in a timeframe increases as more vehicles cross a bridge in that specified timeframe. Although with further investigation annual traffic volumes of several thousand would be more likely for bridges on MSRs, an average assumed traffic volume may be applicable for evaluation or design. However, for major operations like Operation Desert Shield/Desert Storm, engineers should be aware that not accounting for traffic volumes much higher than average will result in lower levels of reliability.

3.2.1.3 Recommendations

Should Limit State Design be considered for military use, two different evaluation approaches are suggested; (1) bridges that are categorized as being part of an MSR should account for the expected level of military traffic they will be subject to during the military operation; and (2) for non-MSR bridges it might be appropriate to rate them based on a single crossing of the smallest packet of vehicles allowed to move autonomously within the theatre of operations (likely three or four vehicles) or the likely number of vehicles involved in a single major mission (likely 100 or less).

3.2.2 Consideration of Hazards Associated with Other Crossing Alternatives

In certain circumstances for mission success, it may be imperative that certain vehicles traverse a longitudinal obstacle such as a river or mountainous terrain. If during initial assessment the bridge capacity is not sufficient, given the acceptable risk, other options being considered to traverse the obstacle should be compared to the risk of using the bridge. For example, if a bridge cannot be traversed, the only other option might be fording a river, which can be very risky. If this risk of fording the river is greater than the risk of crossing the bridge, allowing for a greater than normal risk for the bridge crossing may be preferable.

3.2.3 Risk of Bridge Damage due to Conduct of War

In the context of war, bridges may be targeted for attack to limit the mobility of an opposition force. Bridges are also often choke points for mechanized militaries, so force engagements can take place in their vicinity. As such, bridges are often deliberately or collaterally damaged in the conduct of war. In designing rapidly emplaced assault bridges it has been proposed (Walker, Zintilis, & Bulson, 1991) that design could ensure an acceptable residual strength that received expected levels of damage. If this philosophy was adopted for design, it would increase the reliability of undamaged bridges.

3.2.4 Risks from Hazards due to Enemy Action

In the context of war fighting, gaining the advantage on an enemy force can reduce the risk due to the hazard of enemy actions. More road network options, which in effect allows for greater mobility, can provide some advantages over an enemy force by facilitating:

- greater unpredictability in road moves;
- quicker deployment of forces where they are most needed by using more direct routes;
- fewer choke-points for enemy to concentrate effort; and,
- resilience in logistics support through road network redundancy.

It may also be important to achieve a certain force concentration at a particular location to fend off an enemy offensive. Since bridges tend to be choke points for on-road or off-road vehicle maneuvers, additional bridges may facilitate reduced response times. The required response time may dictate what risk is appropriate. It is difficult to quantify these advantages in terms of probability of success against an enemy force or reduction of fatality risk to military personnel from enemy action. However, doctrine for mechanized warfare emphasizes the importance of mobility. “At the tactical level, superior mobility is critical to the success of the force. Mobility facilitates the momentum and freedom of movement and maneuver of forces by reducing or negating the effects of existing or reinforcing obstacles” (US Department of the Army, 2003). Given the importance of mobility in context of war, in most cases, it would be reasonable to allow the risk in bridge crossings to be increased beyond what would normally be acceptable.

3.3 Chapter Conclusions

Some factors that influence the optimal, economic and life-safety risk for military bridges are common to civilian bridges but others are different. In the context of domestic and non-combat operations, the factors that define the optimal risk for military and civilian bridges are common, albeit with somewhat different parameters. In the context of combat operations, a major factor that is unique to military bridge risk optimization is the direct consequence or cost of limiting mobility when conducting military operations against an enemy force or defending against enemy military operations.

The risk factors investigated within this chapter touch on several small aspects of this complicated problem in a highly simplified manner. Given the complicated and situation-specific interactions between factors, further work is necessary to define an optimal risk for military bridges in the context of combat operations. However, if risk optimization could be understood and simplified for use by military planners, it would be an important tool to manage bridge risk effectively without increasing the overall risk of military operations. In the context of military operations there is no single target risk or discrete target risk range that is optimal or acceptable. Each situation will present different risk factors and outcomes, some of which may not be readily quantifiable and will vary over time.

The research reported in this chapter indicates that in the context of combat operations, new bridges should be designed for a higher target reliability than civilian bridges in Canada. Conversely, when evaluating existing bridge infrastructure in the context of combat operations, with the exception of MSRs, a lower target reliability seems justifiable. Similarly, the design of new bridges subject to regular military loads in non-combat/domestic situations might be more appropriately designed to a higher reliability than similar civilian bridges; while in the context of emergency response-domestic military operations, given the short periods of use and consequences in delaying response time, a lower target reliability may be permitted.

Chapter 4

4 Quantification of Military Vehicle Loading

4.1 Estimation of Gross Vehicle Weight Variability

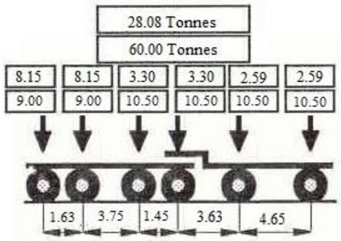
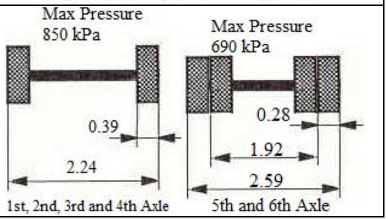
Three vehicles were investigated, specifically the Armoured Heavy Support Vehicle System – Palletized Loading System (AHSVS-PLS), Light Armour Vehicle III – Infantry Section Carrier (LAV III-ISC), and Leopard 2A4M tank. They were selected because they represent three distinct loading categories: they have either transport or fighting functions and are either wheeled or tracked. The total vehicle weight is the combination of the curb weight and the payload. The curb weight is the weight of the fuelled vehicle and, if uparmoured (which relates to vehicles that have optional armour kits to achieve different levels of protection), additional armour including mine protection. The combat weight, considered the maximum nominal weight of the vehicle, is the curb weight plus the payload weight that consists of cargo, crew, ammunition, communications equipment, consumables (i.e. extra fuel, water, food, etc.), secondary weapons, crew's personal equipment and mission-specific equipment.

4.1.1 AHSVS-PLS (Transport)

The Armoured Heavy Support Vehicle System (AHSVS) is a fleet of militarized Mercedes-Benz Actros trucks that fulfill various heavy logistics functions. The vehicle system was purchased to meet a shortfall in Canadian Forces capabilities for Operation ATHENA in Afghanistan (DND, 2007c). There are seven variants in this family of vehicles; the Cargo Gun Tractor (GT), Cargo with Material Handling Crane (MHC), Heavy Mobile Repair Team (HMRT), Palletized Loading System (PLS), Recovery Vehicle, Tractor 13.5 tonnes and Tractor 24 tonnes.

The vehicle load of the PLS variant, which was investigated in detail, is summarized in Table 4.1. The image shows an AHSVS-PLS and PLS trailer (without payload). The axle loads are given in kg for the curb "weight" (above) and combat “weight” (below) in the top right of the table. The MLC but differs slightly from the GVW since it is derived from force effects.

Table 4.1 – Nominal AHSVS-PLS with trailer axle loads

Image[a]		Axle Loads (Tonnes) and Spacing (m) [b][c]	
MLC[d] Empty/Full	26/54	Axle Track (m) [b][c]	

[a] Photo by Peacock, 2009
[b] DND (2011d)
[c] DND (1999)
[d] email from DND vehicle technical authority and verified with hand calculations

4.1.1.1 Quantification of AHSVS-PLS Payload - Intermodal Shipping Containers

The primary cargo for the AHSVS-PLS is 6.1 m (20 ft) long intermodal shipping containers. The weights of intermodal shipping containers flown by the Canadian Forces from Kandahar Afghanistan between 2006 and 2012 are assumed to be representative of intermodal shipping containers transported by the AHSVS-PLS. A query of the Department of National Defence (DND) National Material Distribution System (NMDS) for 6.1 m intermodal containers yielded 11,371 entries (National Movement and Distribution System Support Center, 2012) including many duplicate entries. There were instances where the stated “weight” were clearly erroneous: containers with weights lower than the “weight” of an empty container (roughly 2,200 kg), others between 2 to 3 times the weight of the maximum allowed weight (roughly 31,200 kg), and some whose description indicated “quadcan” (term used to describe containers roughly 3 m in length). After removing these spurious values from the data set, 3,723 unique intermodal containers were identified as summarized in Appendix A. The mean mass of these vetted containers entries is 6,880 kg with a Coefficient of Variation (CoV), defined as the standard deviation divided by the mean, of 0.415. To further quantify the data, they were ranked from smallest to largest and Weibull plotting positions were computed using:

[4.1] $$F(x) = P_i = \frac{i}{n+1}$$

where i is the rank from lowest ($i = 1$) to highest ($i = n$), n is the total number of observations, and P_i is plotting position for the i^{th} observation with sample cumulative probability $F(x)$ for the corresponding mass, x. Other plotting positions were not considered given the "theoretical attributes and the computational simplicity" (Ang & Tang, 1984) of Weibull plotting positions." Then Exponential (shifted), Normal, Log-normal, Gumbel, Weibull and Rayleigh (shifted) distributions were fit to the sample data. Table 4.2 summarizes the necessary mapping of the mass (x-axis) and probability (y-axis) data for the various distributions considered.

Table 4.2 – Necessary data mapping for determination of best-fit parameters

Distribution Type	x-axis	y-axis
Weibull	$\ln(x)$	$\ln\{-\ln[1-F(x)]\}$
Normal	x	$\Phi^{-1}[F(x)]$
Log-Normal	$\ln(x)$	$\Phi^{-1}\{\ln[F(x)]\}$
Exponential	x	$-\ln[1-F(x)]$
Gumbel	x	$-\ln\{-\ln[F(x)]\}$
Rayleigh	x	$\sqrt{-\ln[1-F(x)]}$

Linear regression of the transformed data was used to determine the best-fit slope and y-axis intercepts values, from which the parameters defining each distribution were computed. The fitted Log-Normal and Gumbel distributions were in closest agreement with the data. The Cumulative Distribution Function (CDF) for the Log-Normal distribution is:

[4.2] $$F(x) = \Phi\left(\frac{\ln(x/\breve{m}_X)}{\sigma_{\ln(X)}}\right)$$

where, $F(x)$ is the cumulative probability at x, $\breve{m}_X$ is a measure of the central tendency, and $\sigma_{\ln(X)}$ is a measure of the dispersion. The CDF for the Gumbel Distribution is:

[4.3] $$F(x) = \exp\left[-\exp\left(-\frac{(x-\mu)}{\beta}\right)\right]$$

where, μ is a measure of the central tendency, and β is a measure of the dispersion. Figure 4.1 shows the sample CDF values superimposed on the CDFs of these fitted distributions. The two corresponding root-mean-square errors are 0.0076 for the Log-Normal distribution and for the Gumbel distribution 0.0073 respectively. The Kolmogorov-Smirnov (K-S) test (Benjamin and Cornell, 1970) was used at a significance level 10% (e.g. α = 0.10) to determine which of the fitted CDFs agreed well with the data. Only the best-fit Log-Normal and Gumbel distributions passed this test. For ease of subsequent computations, the best-fit Gumbel distribution with $\beta = 2{,}247$ kg and $\mu = 5{,}583$ kg was selected to describe the "weight" of the intermodal shipping containers.

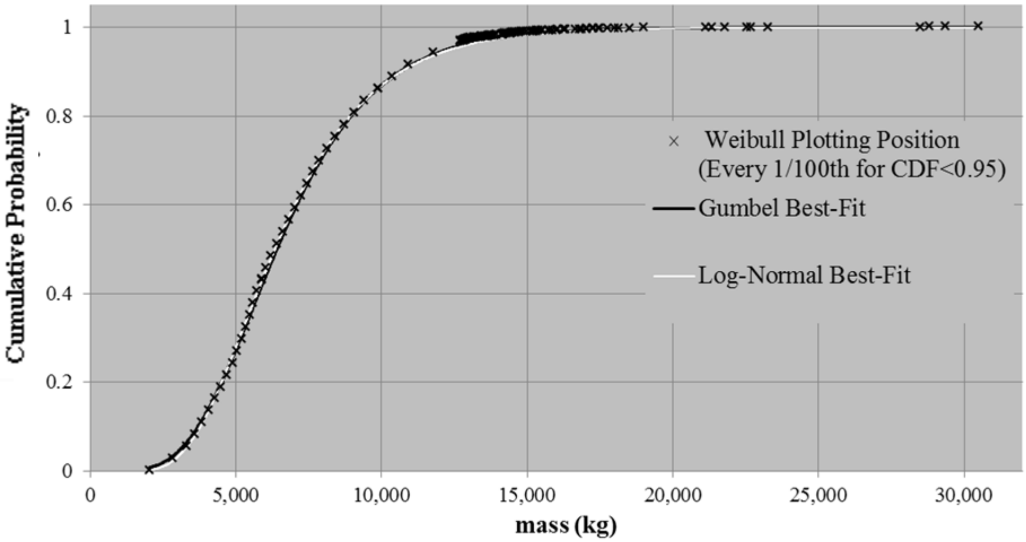


Figure 4.1 – Cumulative distribution for intermodal shipping container "weights"

It is necessary to account for any eccentricity of the shipping container center of gravity when computing axle loads from the intermodal shipping containers masses. These data were not available for the shipping containers listed in the DND NMDS database. It was assumed the eccentricities of shipping containers transported by the Canadian Forces would be the same as the general shipping container population. Through several lines of query, it was determined that most of the available data on the eccentricity of the resultant of shipping container weights is held by Bill Brassington of ETS Consulting, United Kingdom. Table 4.3 summarizes data made available by Mr. Brassington which is solved by mass category. The various columns present the number of containers where eccentricity exceeded 5% of the container length, the average eccentricity for this subpopulation expressed in metres or as a percentage of the overall container length, and the percentage of the total container population represented by each subpopulation. The total container population, which includes shipping containers with less than 5% eccentricity, consists of (1,223 $\div$ 17.17% $=$) 7,121 containers.

Table 4.3 – Intermodal shipping container average eccentricity (Brassington, 2014)

Mass Category	Number	Percentage of Total Lifts	Average Longitudinal Eccentricity	
			(m)	Percentage of total Length
< 5 tonne	307	4.31%	0.332	5.4%
5 - 10 tonne	149	2.09%	0.426	7.0%
10 - 15 tonne	67	0.94%	0.510	8.4%
15 - 20 tonne	146	2.05%	0.411	6.7%
20 - 25 tonne	242	3.40%	0.396	6.5%
25 - 30 tonne	282	3.96%	0.492	8.1%
30 + tonne	30	0.42%	0.652	10.7%
Overall	1,223	17.17%	0.420	6.9%

The statistical parameters for the mean eccentricity and its variability are desirable for the present study but were not provided by Mr. Brassington. Thus they have been approximately quantified using the following procedure:

1. Assume the fraction of the total population within each mass category is identical to that for a separate data set of 37,398 shipping containers provided by Mr. Brassington (shown in Appendix B).
2. Estimate the percentage of containers in each mass category that have weight eccentricities of 0.305 m (5%) or greater as the number obtained from Table 4.3 to the overall number of containers from step 1 (shown in Appendix B).
3. Estimate a cumulative probability distribution of the weight eccentricity for each mass category. This involves:

a. Recognizing that three sample CDF values are available:
   - CDF = 0 for 0% eccentricity;
   - CDF = value computed in step 2 for 0.305 m (5%) eccentricity; and
   - CDF = value obtained assuming triangular shape for the upper tail of the mass probability density function for the mean eccentricity shown in Table 4.3.

b. For the triangular upper tail shown in Figure 4.2, the distance from the 0.305 m (5%) eccentricity to the mean eccentricity, $\bar{e}$, is 1/3 times the distance from 0.305 m eccentricity to the maximum eccentricity, $e_{\max}$.

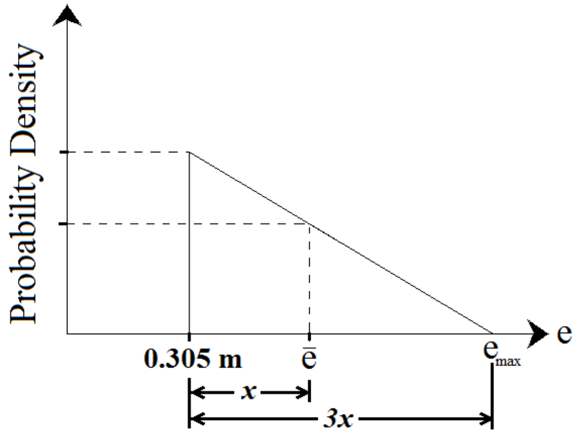


Figure 4.2 – Probability density for shipping container eccentricities ≥ 5%

The area, A_0, under the assumed Probability Density Function (PDF), $f(x)$, from the 0.305 m eccentricity to $e_{\max}$ is:

[4.4]
$$A_0 = 1 - F(0.305\text{ m}) = \frac{1}{2}(e_{\max} - 0.305\text{ m}) \cdot f(0.305\text{ m})$$

The area under the PDF from $\bar{e}$ to $e_{\max}$ is therefore:

$$= \frac{1}{2}\left[\frac{2}{3}(e_{\max} - 0.305\text{ m}) \cdot \frac{2}{3} f(0.305\text{ m})\right] = \frac{4}{9}A_0$$

Thus the CDF for eccentricity $e = \bar{e}$ is:

[4.5]

$$F(\bar{e}) = 1 - \frac{4}{9}[1 - F(0.305\text{ m})]$$

c. Using these three points, estimate CDF (shown in Appendix B).

Figure 4.3 shows the cumulative distribution and probability density functions for each mass category as obtained from this procedure. It is apparent that for shipping containers less than 30 tonnes, the eccentricities are closely approximated by a Half-Normal distribution with standard deviation, σ, of 0.226 m. For shipping containers greater than 30 tonnes, a Half-Normal distribution with σ, of 0.140 m is a better fit. Thus the variability of the eccentricity of the center of gravity is less for the heaviest shipping containers, perhaps because, for the heavily loaded containers there is little room available to load the container asymmetrically.

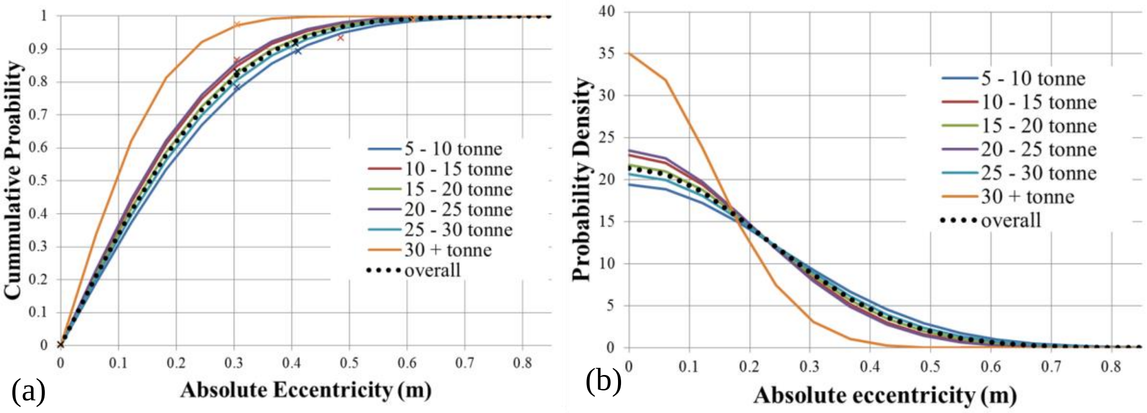


Figure 4.3 –Shipping container eccentricity for different mass categories:
(a) cumulative probability; (b) probability density

For payloads of intermodal shipping container it will therefore be assumed that the longitudinal eccentricity of the centre of gravity is normally distributed about the midpoint of the container. If the container mass is less than 30 tonnes, the standard deviation of the eccentricity will be taken as 0.226 m, otherwise it will be taken as 0.140 m.

4.1.1.2 AHSVS-PLS Static Load

The AHSVS-PLS facilitates loading/unloading of intermodal shipping container without the need of an external lift by using its Palletized Loading System (PLS). Often the AHSVS-PLS truck will tow a trailer to transport a second intermodal shipping container with a weight that could be uncorrelated or highly correlated to the weight of the first container. Three configurations must therefore be considered: AHSVS-PLS with no trailer; AHSVS-PLS with trailer (no correlation between intermodal container weights); and, AHSVS-PLS with trailer (fully correlated intermodal container weights).

To verify the curb weight bias coefficient and variability, a query of the NMDS database (summarized in Appendix C) yielded the weights of 30 AHSVS-PLS flown from Afghanistan to Canada. This data set included several entries that were as much as 6,000 kg heavier than the curb “weight” of 22,900 kg (DND, 2011d). These high values might be due to shipping containers being loaded on the AHSVS-PLS for air transport, although this cannot be confirmed through the NMDS query. Thus, the accuracy of the flown weights for the AHSVS-PLS could not be trusted. Two variants similar to the AHSVS-PLS were subsequently also queried, the AHSVS-Cargo and AHSVS-Cargo (Gun Tractor for M777). Both of these variants have the same nominal curb “weight" of 24,300 kg (DND, 2011a). With the removal of a single entry with an unreasonably low weight, the weights of the remaining 22 entries have a bias coefficient of 1.005 and a CoV of 0.023. The actual curb weight may have a lower bias coefficient and smaller CoV due to unknown vehicle conditions at the time of weighing, such as added stowage, and fuel volume. The actual curb weight for the AHSVS-PLS likely has a bias coefficient smaller than 1.005 and CoV smaller than 0.023. Thus, the bias coefficient and variability of the overall weight is quantified assuming curb “weight” to be deterministic, at 22,900 kg (DND, 2011d) and the trailer curb “weight” also deterministic, 5,020 kg (DND, 1999). Only the intermodal shipping container weights (i.e., the payload) were assumed to contribute to the overall vehicle weight variability.

With these assumptions, the best-fit Gumbel distribution for the event “weight” of the AHSVS-PLS and AHSVS-PLS and trailer with fully correlated container weights can be derived. For the AHSVS-PLS, β is as calculated for the intermodal shipping containers (e.g., $\beta =$ 2,247 kg), while μ is the sum of the curb “weight” and payload Gumbel distribution central tendency parameter (e.g. $\mu =$ 22,900 kg + 5,583 kg = 28,483 kg). For the AHSVS-PLS with fully correlated trailer, β is twice that of a single container (e.g., $\beta =$ 2 • 2,247 kg = 4,494 kg), and μ is twice that for a single intermodal container plus the curb “weight” of the vehicle (e.g. $\mu =$ 2 •5,583 kg + 22,900 kg + 5,020 kg = 39,246 kg).

For the AHSVS-PLS and trailer with uncorrelated container weights, the standard deviation the two independent shipping containers can be calculated by:

[4.6]
$$\sigma_2 = \sqrt{{\sigma_1}^2 + {\sigma_1}^2} = \sigma_1\sqrt{2}$$

where, σ_2 is the standard deviation of the combined mass of two independent shipping containers and σ_1 is the standard deviation of the mass of a single shipping container. Given that the shipping containers masses are assumed to follow a Gumbel distribution, the standard deviation of the mass of one container can be computed for a known β as:

[4.7]
$$\sigma_1 = \frac{\pi}{\sqrt{6}}\beta_1$$

where $\beta_1$is the Gumbel distribution parameter for the mass of a single shipping container. Substituting Equation [4.7] into Equation [4.6] and rearranging, the Gumbel dispersion parameter for two independent shipping containers, β_2, is:

[4.8]
$$\beta_2 = \beta_1 \cdot \sqrt{2}$$

The mean mass of two shipping containers, $\overline{m_2}$, is:

[4.9] $$\overline{m_2} = \overline{m_1} + \overline{m_1} = 2\overline{m_1}$$

where $\overline{m_1}$ is the mean mass of a single shipping container, this can be computed for known parameters β and μ as:

[4.10] $$\overline{m_1} \approx \mu_1 + 0.577\beta_1$$

where $\mu_1$is the Gumbel distribution parameter for the weight of a single shipping container. Substituting Equation [4.10] into Equation [4.9] and rearranging, the Gumbel central tendency parameter for two independent shipping containers, μ_2, is:

[4.11] $$\mu_2 = 2(\mu_1 + 0.577\beta_1) - 0.577\beta_2$$

For the AHSVS-PLS with uncorrelated trailer the Gumbel distribution parameters are $\beta = \beta_2$ as calculated in Equation [4.8], and μ as μ_2 calculated by Equation [4.11] increased by the curb weight of the vehicle and trailer.

Table 4.4 presents the central tendency and dispersion parameters, bias coefficients (defined as the mean value divided by the nominal combat weight) and CoV for the three AHSVS-PLS configurations considered. The statistics are presented for the event vehicle, which represents the overall population of AHSVS-PLS vehicles and for the maximum annual AHSVS-PLS vehicle "weight" corresponding to annual traffic volumes of 100, 1,000, 10,000 and 100,000 vehicles per year. As the event data are assumed to follow a Gumbel distribution, the maximum annual "weights" also follow Gumbel distributions with the dispersion parameter, β_A, given by:

[4.12] $$\beta_A = \beta$$

and the central tendency parameter, μ_A, given by:

[4.13] $$\mu_A = \beta \cdot \ln(n/n_i) + \mu$$

where β and μ are the dispersion and central tendency parameters of the event distribution, n is the number of vehicles per year and n_i is the number of vehicles for the for the reference population (in this case n_i = 1 for the event distribution).

Table 4.4 – AHSVS-PLS "weight" quantification

AHSVS-PLS Configuration Curb / Combat [a][b]	Gumbel Parameters	Event	Maximum Annual			
			100	1,000	10,000	100,000
No Trailer 22,900 kg / 39,000 kg	μ (kg)	28,483	38,831	44,005	49,179	54,353
	β (kg)	2,247	2,247	2,247	2,247	2,247
	Bias	0.764	1.029	1.162	1.294	1.427
	CoV	0.096	0.072	0.064	0.057	0.051
Correlated Trailer 28,080 kg / 60,000 kg	μ (kg)	39,246	59,942	70,289	80,637	90,985
	β (kg)	4,494	4,494	4,494	4,494	4,494
	Bias	0.697	1.042	1.215	1.387	1.560
	CoV	0.138	0.092	0.079	0.069	0.062
Un-correlated Trailer 28,080 kg / 60,000 kg	μ (kg)	40,005	54,640	61,957	69,275	76,593
	β (kg)	3,178	3,178	3,178	3,178	3,178
	Bias	0.697	0.941	1.063	1.185	1.307
	CoV	0.097	0.072	0.064	0.057	0.052

[a] DND (2011d)
[b] DND (1999)

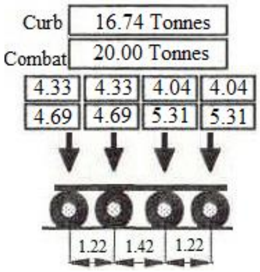
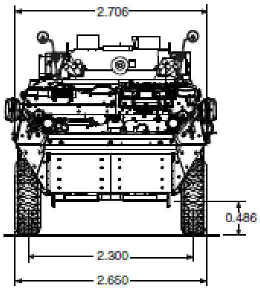
As the annual traffic volume increases, the bias coefficients for the maximum annual "weight" increase while the CoVs reduce. The bias coefficients and CoV for the truck-plus-trailer configuration with fully correlated container masses are more severe than for truck-plus-trailer configuration with uncorrelated container masses, which is expected since it is less likely that both containers will be exceedingly heavy if their weights are uncorrelated.

4.1.2 LAV III-ISC (Armoured Personnel Carrier)

Table 4.5 summarizes the uparmoured LAV III-ISC, a fighting vehicle that primarily serves as an Armoured Personnel Carrier (APC) for one infantry section but can also provide additional firepower. It is a variant within the LAV III family of vehicles, which is the Canadian Army's primary light armoured vehicle for mounted combat operations.

This vehicle therefore provides a very different function than the AHSVS-PLS. In Table 4.5, the axle loads are given in kg for the curb “weight” (above) and combat “weight” (below). The MLC differs slightly from the GVW since it is derived from force effects.

Table 4.5 – Uparmoured LAV III-ISC nominal axle loads prior to Afghanistan modifications

Image[a]	Axle Loads (Tonnes) and Spacing (m)[b]	MLC (fully laden)	Horizontal Axle Spacing(m)[d]
		1. 22[c]	

[a] Photo by Peacock 2009
[b] Assumed based on multiple phone conversations with DND and GDLS engineers
[c] MLC calculated as prescribed in NATO (2006)
[d] DND (2011c)

The nominal “weights” of the LAV III-ISC without uparmour according to the vehicle data summary are a curb “weight” of 13,702 kg and a GVW of 16,958 kg (DND, 2011c). “When uparmoured and fully loaded, the LAV III weighs 20 tonnes” (DND, 2003). Nominally, a fully laden LAV III-ISC consists of a curb “weight” of 13,702 kg, potentially an additional 3,042 kg of uparmour and a payload of 3,256 kg. In the latter portions of Canada’s military engagement in Afghanistan, the LAV III underwent many field modifications to better suit conditions faced during the mission there. Some of the modifications included improvised explosive device protection such as shields for turret crew, hanging seats, a parapet for air sentries and belly armour. The LAV Operational Requirements Integration Task (LORIT) program rationalized these ad hoc field improvements (Defense Industry Daily, 2013). The estimated curb “weight” for the LAV III-ISC after the LORIT program is 20,630 kg (WLAV Chassis Management Team Leader, Department of National Defence, 2014).

This wide range of possible curb “weights” for the LAV III-ISC is reflected in the “weights” of vehicles flown from Afghanistan as obtained from NMDS database (after vetting and removal of repeat entries and entries with descriptions indicating major parts, such as engines removed) These data are presented in Appendix D. A histogram of 77 LAV III-ISC flown “weights”, with bin widths of 250 kg is shown at Figure 4.4. Some inferences concerning points of particular interest in Figure 4.4 are as follows:

a. the single LAV III-ISC mass less than 12,500 kg likely corresponds to a vehicle with parts removed that were not specified in the shipping description and so was removed from the data set;
b. the grouping of LAV III-ISC masses between 13,250 kg and 14,250 kg reflect vehicles with no uparmour added (nominal mass of 13,702kg);
c. the concentration of LAV III-ISC masses between 16,500 kg and 16,750 kg reflect LAV III-ISC’s with uparmour (nominal mass of 16,744 kg) prior to LORIT modifications; and
d. LAV III-ISC masses greater than 16,750 kg might correspond to vehicles with differing levels of modification. These cannot be definitively categorized as LORIT modifications but no longer reflect the curb “weight” of unmodified LAV-III’s. They could also be LAV III’s upgraded under the LORIT program with some armour removed for transportation.

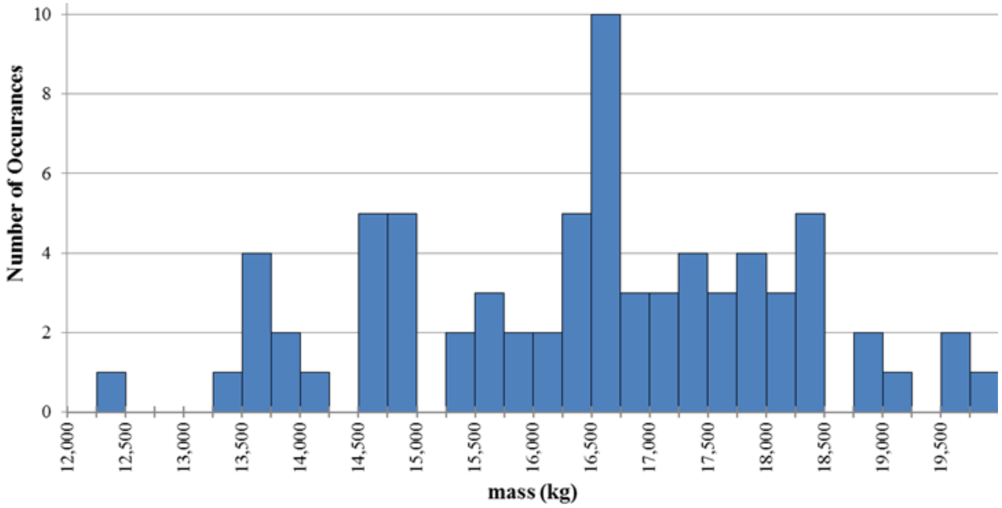


Figure 4.4 – “Weight” of LAV III-ISC’s flown from Afghanistan 2006-2012.

The Canadian Forces Fleet Management System (FMS), queried on 20 Nov 2012, indicated that all the vehicles shown in Figure 4.4 are listed as having a curb “weight” of 13,702 kg and a GVW of 16,958 kg. Due to the configuration of the LAV III, it is unlikely that significant additional payload was added to the vehicle for air transport. Except for the volume of fuel in the vehicle (tank capacity is 200 *l* diesel), the data captured likely reasonably approximate the minimum curb “weights” of these vehicles (since some uparmour might have been removed for transport). Clearly the FMS database was not updated to reflect the new weights after modifications. The “weights” given in Figure 4.4 therefore provide a unique opportunity to investigate the variability of the curb weight for a military vehicle undergoing an upgrade. Given this, three loading cases will be considered:

- Case (1) uparmoured LAV III-ISC prior to the Afghanistan modification program with a deterministic curb “weight” with uparmour of 16,744 kg;
- Case (2) uparmoured LAV III-ISC during LORIT upgrade with a variable curb weight, where pre-upgrade weight is the nominal weight; and,
- Case (3) same Case (2) except that the nominal weight is the post-upgrade weight.

Should a future major deployment of LAV III-ISC vehicles require air movements, it would be valuable to investigate the measured curb weights. If all vehicles have been upgraded to a similar standard, there would likely be a concentration of vehicles around the new curb “weight” of 20,630 kg.

Deficiencies in the FMS database regarding the actual weight of the LAV III-ISC indicates the possibility that these vehicles were operating nearly 3 tonnes heavier than their nominal combat “weight”. If so, this would indicate a lack of control that could undermine the confidence in statistical parameters for vehicle weight based on nominal load data, thus requiring larger load factors for bridge design and evaluation.

The LAV III-ISC was selected, specifically, because of personal awareness of the upgrade program for this vehicle and the indication from informal sources of lack of knowledge in the operational weights. This apparent lack of control on the actual vehicle condition should be considered exceptional.

4.1.2.1 LAV III-ISC Curb Weight

For Case (1), it is assumed that prior to the field modifications in Afghanistan, the curb weight of the LAV III-ISC can be considered deterministic. For Cases (2) and (3), the LAV III-ISC “weights” from the NMDS database are used to define statistical parameters for the curb weight of the LAV III-ISC. Figure 4.5 shows that a Log-Normal distribution accurately represents the curb “weights” of vehicles exceeding 16,000 kg, the fit passes the K-S test at the significance level of 10%.

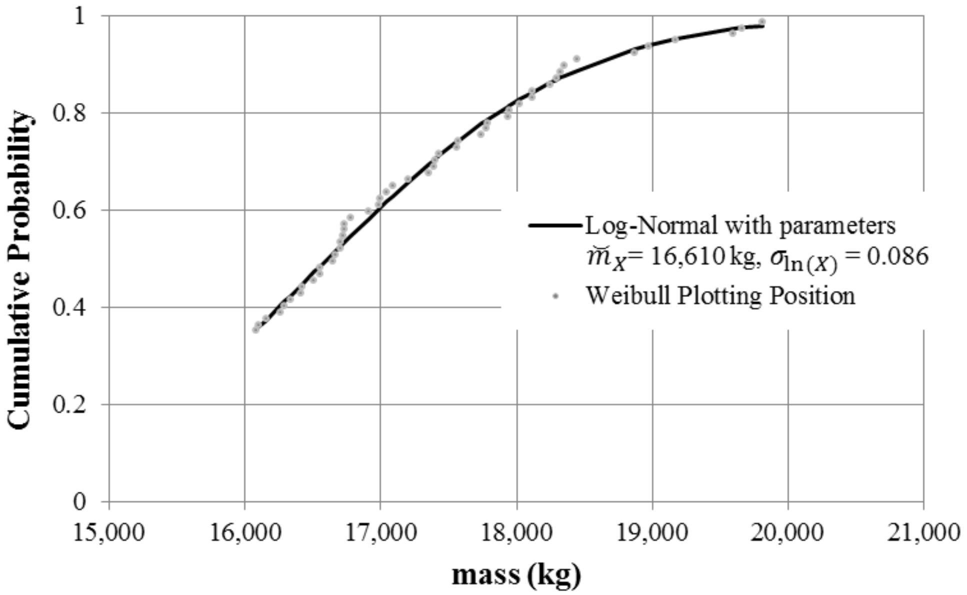


Figure 4.5 – Log-Normal distribution for LAV III-ISC flown "weights"

The fitted Log-Normal Distribution, with parameters of $\breve{m}_X$ of 16,610 kg and $\sigma_{\ln(X)}$ of 0.086, for the curb "weight" of the LAV III-ISC corresponds to a bias coefficient of 0.996 with respect to the nominal curb "weight" of 16,744 kg and CoV of 0.086.

4.1.2.2 LAV III-ISC Gross Vehicle Weight

Table 4.6 presents the assumptions adopted to idealize the various load components of the LAV III-ISC GVW. Where operational payloads are unknown they are assumed to vary uniformly across the range of each parameter shown, which is intended to conservatively envelope (by disallowing the consideration of vehicles lower than the nominal combat weight) the actual parameter range as determined given operational considerations.

Table 4.6 – LAV III – ISC operational loads.

Component of GVW	Nominal Quantity	Mass (kg)	Assumed "Weight" Variability for Idealization	Notes
Curb Weight including Uparmour	-	16,744[a]	Deterministic	Case (1)
		16,744[a]	Log-Normal $\breve{m}_y = 16{,}610$ kg and $\sigma_{\ln(X)} = 0.086$	Case (2)
		20,630[b]		Case (3)
Payload A	-	340[c]	(Total Nominal)*(Uniform Distribution between 1 and 1.5)	Inventoried Items
Payload B	-	1,620	(Total Nominal)*(Uniform Distribution between 1 and 2)	Miscellaneous Equipment / Stowage
Crew and Personnel with Combat Gear	10[a]	1,300	(Nominal Quantity) + (Discrete Uniform Distribution between 0 and 10)	Mass of each soldier 136.5 kg [d]
Total (Combat Weight)		20,000[a]		Cases (1) and (2)
		23,890		Case (3)

Note: Payload is normally distributed with parameters $\mu = 4{,}904$ kg, $\sigma = 643$ kg

[a] Department of National Defence (2011c)

[b] WLAV Chassis Management Team Leader, Department of National Defence (2014)

[c] SNC (n.d.)

[d] Emergency Approach Load (US Army Center for Army Lessons Learned, 2003)

Each component of the GVW was assumed independent. Using the data summarized in Table 4.6, 10,000 vehicle weights were randomly generated for each case, yielding the results shown in Table 4.7. The event distribution, assumed Log-Normal, of the LAV III-ISC weight was used to derive the CDF of the maximum weight over a one-year period using the mapping:

$$F_A(x) = [F_E(x)]^n = \left[\Phi\left(\frac{\ln(x/\breve{m}_X)}{\sigma_{\ln(X)}}\right)\right]^n \tag{4.14}$$

where $F_A(x)$ is the cumulative probability at weight x for the maximum observed value of n observations and $F_E(x)$ is the event cumulative probability at x. Several different annual volumes were considered. Using Equation [4.14] the statistical parameters for each annual traffic volume was calculated as summarized in Table 4.7.

Table 4.7 – GVW of LAV III-ISC with deterministic and variable curb “weight”

LAV-III-ISC (Uparmoured) Nominal “Weights” Curb / Combat [a]	Log-Normal or Gumbel Parameters	Event (Log-Normal)	Maximum Annual (Gumbel)			
			100 veh/yr	1,000 veh/yr	10,000 veh/yr	100,000 veh/yr
Case (1) – Deterministic Curb “Weight” 16,744 kg/20,000 kg	$\breve{m}_y$ or μ (kg)	21,632	23,258	23,820	24,294	24,712
	$\sigma_{\ln(X)}$ or β (kg)	0.031	257	213	187	169
	Bias	1.082	1.170	1.197	1.220	1.240
	CoV	0.030	0.013	0.011	0.010	0.009
Case (2) – Variable Curb “Weight” 16,744 kg/20,000 kg	$\breve{m}_y$ or μ (kg)	21,510	25,513	26,990	28,269	29,428
	$\sigma_{\ln(X)}$ or β (kg)	0.074	670	572	514	475
	Bias	1.077	1.293	1.361	1.428	1.485
	CoV	0.073	0.032	0.026	0.023	0.022
Case (3) – Variable Curb “Weight” 20,630 kg[b]/ 23,890 kg	$\breve{m}_y$ or μ (kg)	21,510	25,513	26,990	28,269	29,428
	$\sigma_{\ln(X)}$ or β (kg)	0.074	670	572	514	475
	Bias	0.903	1.083	1.139	1.195	1.243
	CoV	0.073	0.032	0.026	0.023	0.022

[a] Department of National Defence (2011c)
[b] WLAV Chassis Management Team Leader, Department of National Defence (2014)

When the annual traffic volume equals 100 or more vehicles per year, weight of the maximum annual vehicle is best described by a Gumbel distribution. One might therefore expect that the dispersion factor β would remain constant. The dispersion factors shown in Table 4.7 change slightly for each value of n however, because, the Gumbel fit to the values from a Log-Normal mapped Equation [4.14], is good but not perfect. This was verified by adopting a Gumbel distribution for $F_E(x)$ in Equation [4.14], which yielded a constant dispersion factor β for all values of n.

4.1.3 Leopard 2A4M Tank

The Leopard 2A4M tank is also a fighting vehicle, primarily used to provide direct weapon fire support; with the vehicle designed primarily for the mobility and survivability of the primary weapon system. When compared to the LAV III-ISC, a larger proportion of its GVW is the curb weight; mostly due to requirements for the primary weapon system and armoured protection.

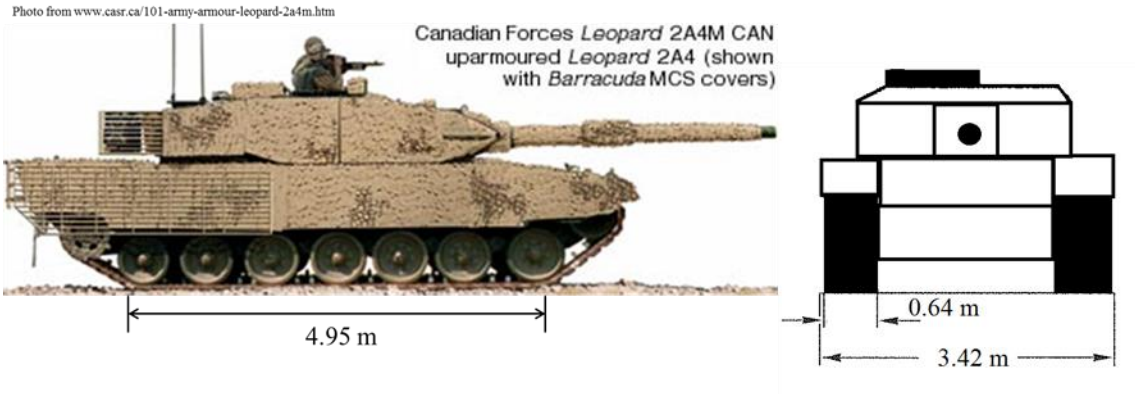


Figure 4.6 – Leopard 2A4M tank

Table 4.8 shows five flown “weights” from the NMDS database for Leopard 2A4M. The curb “weight” has a bias coefficient of 1.005 with respect to the nominal air shipping “weight” of 56,074 kg (Leopard Requirements Officer, Director Land Requirements 3-4-3, Department of National Defence, 2013) with a CoV of 0.016. The NMDS database does not capture the level of fuel in each transported vehicle (1,200 litres when fully fuelled, nominally 300 litres for transport), or if some components normally removed from the vehicle for transport, such as the chassis Add-on-Armour (AoA), were not removed. Some weight differences shown in Table 4.8 may be attributed to differing volumes of fuel within the vehicle and chassis AoA not removed for transport. Of the five Leopard 2A4M tanks shown, one has a notably higher “weight”, 58,163 kg. This closely approximates the “weight” of a Leopard 2A4M with chassis AoA in place, which is 58,424 kg if 300 litres of fuel is included. The bias coefficient and CoV of the remaining four vehicles are 0.997 and 0.004, respectively. Therefore, it is reasonable to assume that the weights of components of the Leopard 2A4M are deterministic, at least when flown.

Table 4.8 – DND NMDS flown vehicle “weights” for Leopard 2A4M tank

Dispatch Date	CFR	Mass (kg)
18/Nov/2011	72308	55,684
29/Nov/2011	72334	55,802
29/Nov/2011	72301	56,001
29/Nov/2011	72321	56,214
29/Nov/2011	72316	58,163

Table 4.9 presents the assumptions adopted to idealize the various load components of the Leopard 2A4M tank GVW. The deterministic curb weight, 59,484 kg, consists of the Leopard 2A4M tank chassis, main gun and turret, AoA, slat armour system, and a full tank of fuel. The crew consisting of four persons at 75 kg each is also assumed deterministic. The nominal masses of the various operational weights are quantified from various DND sources and are sufficient to increase the nominal curb weight to the nominal combat weight. These operational weights are assumed to vary uniformly across the range of each parameter shown, which is intended to conservatively envelope (by disallowing the consideration of vehicles lower than the nominal combat weight) the actual parameter range as determined given the range of possible operational considerations. The potential for an additional operational load of up to ten infantry riding on top of the tank was also considered.

Table 4.9 – Leopard 2A4M tank operational loads

Component of GVW	Nominal Quantity	Combined Nominal Mass (kg)[a]	Assumed "Weight" Variability for Idealization	Notes
Curb "Weight" (fully fueled with AoA and Slat Armour)	-	59,184	Deterministic	
Crew	4	300	Deterministic	75 kg per person
Payload A	-	1,000	(Total Nominal)*(Uniform Distribution between 1 and 1.5)	Inventoried Items
Payload B	-	730	(Total Nominal)*(Uniform Distribution between 1 and 2)	Miscellaneous Equipment / Stowage
Infantry Section Transport	0	0	(Discrete Uniform Distribution between 0 and 10)	Mass of each soldier 136.5 kg [b]
Total "Weight"		61,214		

[a] Leopard Requirements Officer, Director Land Requirements 3-4-3, Department of National Defence, (2013)
[b] Emergency Approach Load (US Army Center for Army Lessons Learned, 2003)

Figure 4.7 shows the cumulative distribution for 10,000 Leopard 2A4M tank weights that were randomly generated assuming the load components shown in Table 4.9 are independent. Above the 35th percentile, Weibull distribution has an excellent fit to the simulated data, (passing the K-S test at a significance level of 10%). The CDF of a Weibull distribution has the form:

$$F(x) = 1 - \exp(-(x/\mu)^k) \tag{4.15}$$

where, μ is the central tendency parameter and k the dispersion parameter.

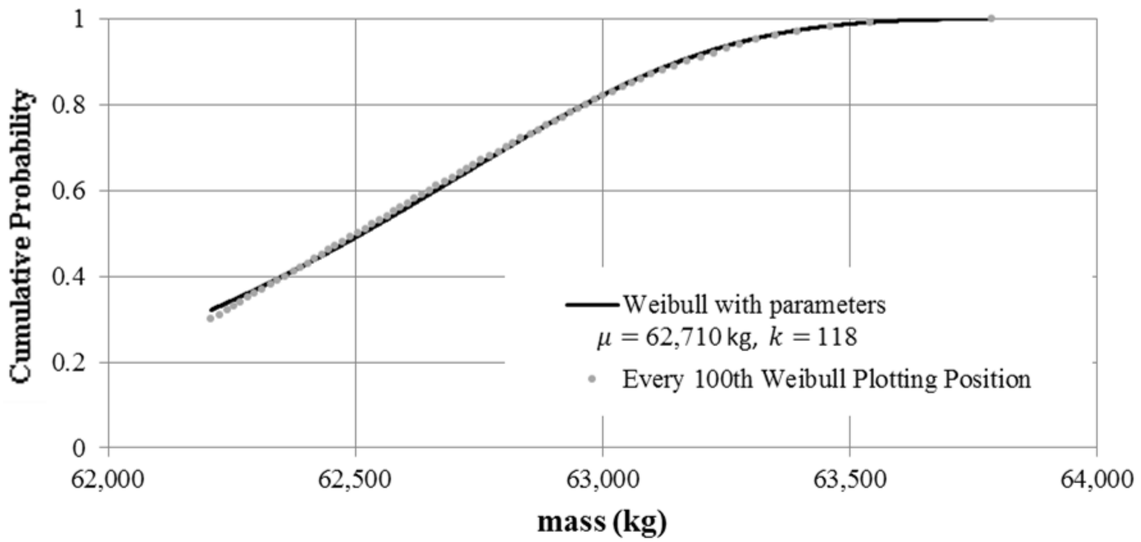


Figure 4.7 – Weibull distribution for simulated Leopard 2A4M tank GVWs

The event and annual maximum statistical parameters for the Leopard 2A4M tank are shown in Table 4.10. The Leopard 2A4M GVW has negligible variability.

Table 4.10 – GVW of Leopard 2A4M tank

Leopard 2A4M Nominal “Weights” Curb / Combat [a]	Weibull or Gumbel Parameters	Event (Weibull)	Maximum Annual (Gumbel)			
			100	1,000	10,000	100,000
59,184 kg / 61,214 kg	μ (kg)	62,710	63,523	63,743	63,900	64,021
	k or β (kg)	118	105	73	56	45
	Bias	1.021	1.039	1.042	1.044	1.046
	CoV	0.008	0.002	0.001	0.001	0.001

[a] Leopard Requirements Officer, Director Land Requirements 3-4-3, Department of National Defence (2013)

Although limited data are available on measured weights of tanks and infantry fighting vehicles (like the LAV III-ISC) at combat weight, Engeler (1994) persents detailed weights of two prototypes of the Austrian Spanish Cooperation Development (ASCOD) armoured fighting vehicle with all crew members and equipment simulated with the use of sand bags. The bias coefficient of the weight of these prototypes are similar to the estimated event bias coefficients calcuated for the both the LAV III-ISC and Leopard 2A4M tanks. The six-roadwheeled (the roadwheel is the wheel that holds the track in place and transfers loads from the vehicle to the track, but does not contribute to driving power) prototype PT2 has a bias coefficient of 0.993 with respect to the nominal combat “weight” of 27,340 kg, and the 7-roadwheeled prototype PT3 has a bias coefficient of 1.012 with respect to the nominal combat “weight” of 27,969 kg (Engeler, 1994). Although more information would be required to assess the accuracy of the statistical parameters for weight presented in this thesis, the independent corraboration of bias coefficients for similar vehicles adds some confidence to the approach.

4.2 Relationship between Payload Weight Fraction and Vehicle Weight Variability

The assumption that all variability of the vehicle weight is due to its payload, causes the curb weight to become an important factor influencing the statistical parameters for the overall load. A particular payload may be associated with a vehicle depending upon its function. Light and heavy tanks, for example, both require the same crew complement, similar equipment for operation and maintenance, similar communications equipment, with somewhat varied ammunition types (all considered payload). Where they mostly differ is the amount of armour and size of weaponry, which directly impacts the curb weight of the vehicle but minimally impacts the payload. Thus for similar payloads, the maximum annual light tank (with a lower combat weight due to a lower curb weight) would have a greater bias coefficient and a higher CoV compared to a heavy tank. The statistical parameters for the overall weight will therefore likely be related to the payload weight fraction, γ:

$$\gamma = \frac{W_p}{W_V} \tag{4.16}$$

where W_p is the nominal payload and W_V is the nominal overall vehicle weight. The nominal vehicle weight can be computed from W_c, the curb weight of the vehicle, as:

[4.17] $$W_V = \frac{W_c}{(1-\gamma)}$$

Since the curb weight is assumed deterministic, the mean vehicle weight, $\overline{W_V}$, is given by:

[4.18] $$\overline{W_V} = \delta_p W_p + W_c$$

where δ_p is the bias coefficient of the payload weight. Using Equation [4.16] to eliminate W_p and Equation [4.17] to eliminate W_V, Equation [4.18] can be written as:

[4.19] $$\overline{W_V} = W_c\left(\frac{\gamma\delta_p}{1-\gamma} + 1\right)$$

The bias coefficient of the vehicle weight, δ_v, is simply the ratio of Equation [4.19] to Equation [4.17]:

[4.20] $$\delta_v = \gamma(\delta_p - 1) + 1$$

Since all variability of the vehicle weight is due to the payload, the standard deviation of the vehicle weight, σ_v, equals the standard deviation of the payload weight, σ_p. After some manipulation, the standard deviation of the vehicle weight is:

[4.21] $$\sigma_v = V_p\delta_p W_c \frac{\gamma}{(1-\gamma)}$$

where V_p is the CoV of the payload. By dividing Equation [4.21] by Equation [4.18] the CoV of the vehicle weight, V_v, is:

[4.22] $$V_v = \frac{V_p\delta_p\gamma}{\gamma(\delta_p - 1) + 1}$$

The payload bias coefficient and CoV for the various levels of maximum annual volume of vehicles as calculated from Equation [4.20] and Equation [4.22] respectively is summarized in Table 4.11.

Table 4.11 – Payload bias coefficient and CoV for annual maximum vehicle

Annual Maximum $n =$ # of vehicles	$n = 1$		$n = 100$		$n = 1{,}000$		$n =$ 10,000		$n =$ 100,000	
Vehicle	δ_p	V_p	δ_p	V_p	δ_p	V_p	δ_p	V_p	δ_p	V_p
AHSVS-PLS	0.43	0.42	1.07	0.17	1.39	0.13	1.71	0.10	2.03	0.09
AHSVS-PLS and trailer with correlated containers	0.41	0.43	1.08	0.17	1.40	0.13	1.73	0.10	2.05	0.09
AHSVS-PLS and trailer with uncorrelated containers	0.43	0.30	0.89	0.14	1.12	0.11	1.35	0.09	1.58	0.08
LAV III-ISC Case (1)	1.50	0.13	2.04	0.05	2.21	0.04	2.35	0.03	2.47	0.03
Leopard 2A4M tank	1.63	0.15	2.18	0.03	2.27	0.01	2.33	0.01	2.39	0.01

Figure 4.8 shows the bias coefficient and CoV for the overall vehicle weight for estimated ranges of payload weight fraction calculated using the payload bias coefficient and CoV for annual traffic volumes of 1,000 vehicles a year given Table 4.11 (other traffic volumes are shown in Appendix E). The relationships for the LAV III-ISC and Leopard 2A4M tank are nearly identical.

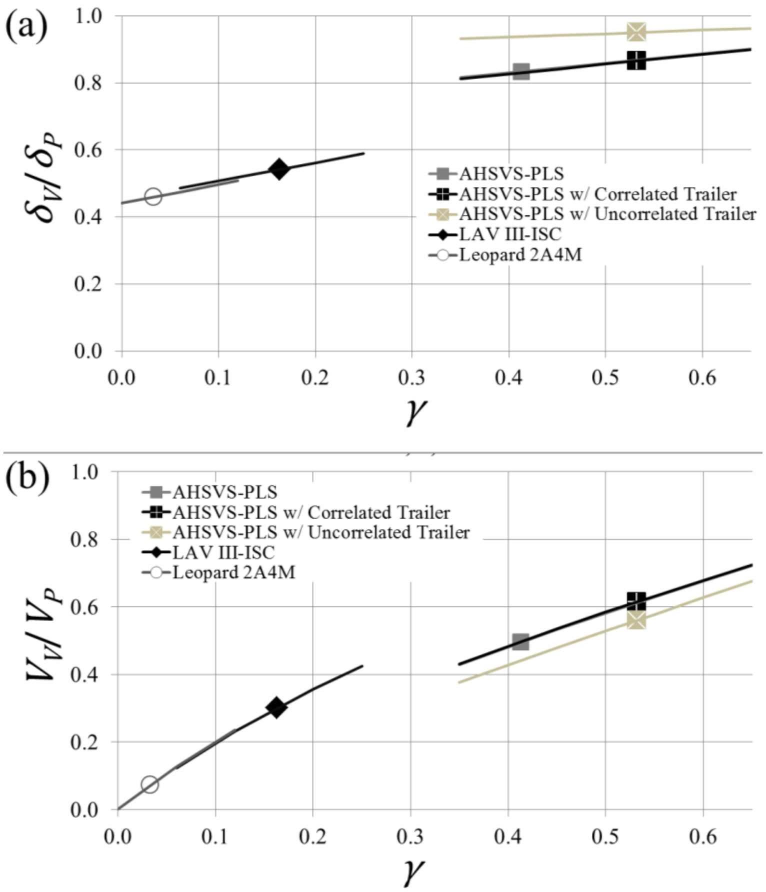


Figure 4.8 – Maximum annual weight statistical parameters ($n = 1{,}000$ veh/yr) versus payload weight fraction: (a) bias coefficient; (b) CoV

4.3 Individual Axle Loads

To assess the reliability of shorter spans, the statistical parameters for axle loads are required. In this section, suitable parameters are derived from the gross vehicle weight parameters.

4.3.1 AHSVS-PLS (Transport) Axle Load

As shown in Figure 4.9, the first four axles of the AHSVS-PLS are in fact two tandem axles. The PLS trailer does not add a fifth wheel load to the rear tandem axle. Thus the axle loads can be estimated from the total load by idealizing the AHSVS-PLS as a simply supported span between the tandem axle centers. When the eccentricity of the payload extends beyond the rear tandem axle, a cantilever is assumed. The PLS trailer axle loads can be computed from the total load by idealizing the trailer as a simply supported span between its axles. Based on the nominal curb "weight" and axle loads given in Table 4.1 for the AHSVS-PLS, the curb weight is represented as a point load (shown as black arrows labeled "C") located 1.52 m from the front support. The curb weight for the PLS trailer would be equivalent to a point load applied at mid-span between the two supports. The nominal maximum payloads are also represented as point loads (shown as white arrows labeled "P"), applied at mid-span on the trailer and at 0.52 m in front of the rear support of the AHSVS-PLS. It is assumed that, if there is no eccentricity of the shipping container centers of gravity, the payload will act at these points for any given weight. Thus simple statics can estimate the loads on the single axle and each axle of the tandem axle, assuming that the tandem axle loads are shared equally.

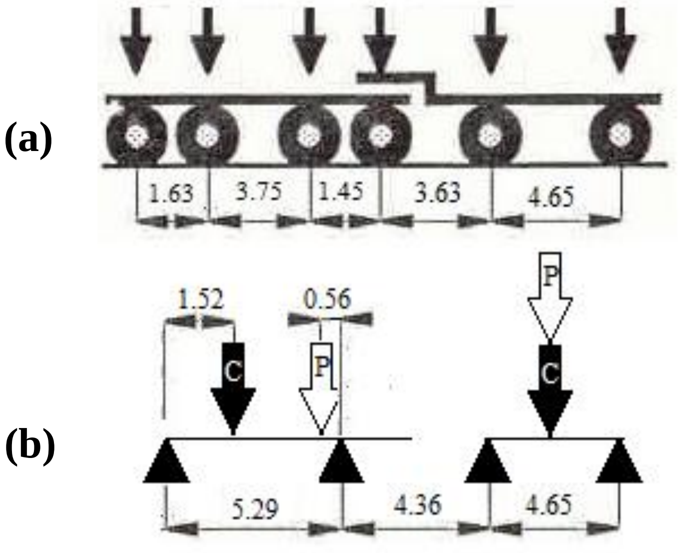


Figure 4.9 – Idealization of AHSVS-PLS with PLS trailer (m):
(a) Vehicle axle spacing; (b) Idealized representation

To generate realistic axle loads, intermodal shipping containers were randomly generated based on the statistical parameters presented in Section 4.1.1.1. For each container, longitudinal eccentricity was randomly generated assuming the statistical parameters presented in Section 4.1.1.1. A total of 10,000 vehicles were generated and analysed to yield the event axle statistics presented in Table 4.12. The front tandem axle of the AHSVS-PLS has a higher bias but lower CoV than the rear tandem axle due to the center of gravity of curb weight. Similarly, the payload of the AHSVS-PLS acts approximately 0.5 m from the rear tandem axle causing the statistical parameters for the weight on these axles to be similar to those of the payload itself. Accounting for payload eccentricity has no impact on the axle load bias coefficients but slightly increases the CoV of the front tandem and two trailer axles.

Table 4.12 – AHSVS-PLS event axle load idealization

Axle	1st and 2nd		3rd and 4th		5th and 6th	
Payload Eccentricity Accounted For?	Yes	No	Yes	No	Yes	No
Mean (kN)	83.5	83.5	62.5	62.5	59.1	59.2
Bias coefficient	0.946	0.946	0.607	0. 607	0.574	0.575
Standard Deviation (kN)	2.1	1.5	12.7	12.7	14.7	14.2
CoV	0.026	0.018	0.203	0.204	0.249	0.240

4.3.2 LAV III-ISC (Armoured Personnel Carrier) Axle Load

For the LAV III-ISC the four axles are assumed to be two tandem axles. As shown in Figure 4.10, the axle loads can be computed from the GVW by idealizing the LAV III-ISC as a simply supported span between the centers of the tandem axles. It was assumed that the center of gravity of the curb weight of the uparmoured LAV III-ISC prior to Afghanistan upgrades is the same as the LAV III-ISC after the LORIT upgrades. The center of gravity for the curb weight of the LAV III-ISC, shown as a black arrow labeled “C”, is assumed to be 3.47 m from the front of the vehicle (WLAV Chassis Management Team Leader, Department of National Defence, 2014), which is 1.89 m behind the front axle or 1.28 m behind the idealized front support. Given the axle ratings of the LAV III-ISC prior to LORIT upgrades, at 4,600 kg for the front axles, and 5,200 kg for the rear axles, the center of gravity for the payload, shown as a white labeled “P”, is applied 4.25 m from the front of the vehicle (which is 2.67 m behind the front axle or 2.05 m behind the idealized front support). The bias coefficient and variability of the payload eccentricity for the LAV III-ISC is not available in the literature, so it was assumed that the center of gravity of the payload is located exactly between the 3rd and 4th axle (4.83 m from the front of the vehicle). This results in changes to the payload only affecting the rear two axles. This is a conservative assumption for short spans, because it results in greater variability for the third and fourth axles than if the payload was shared between the front and rear tandem axles.

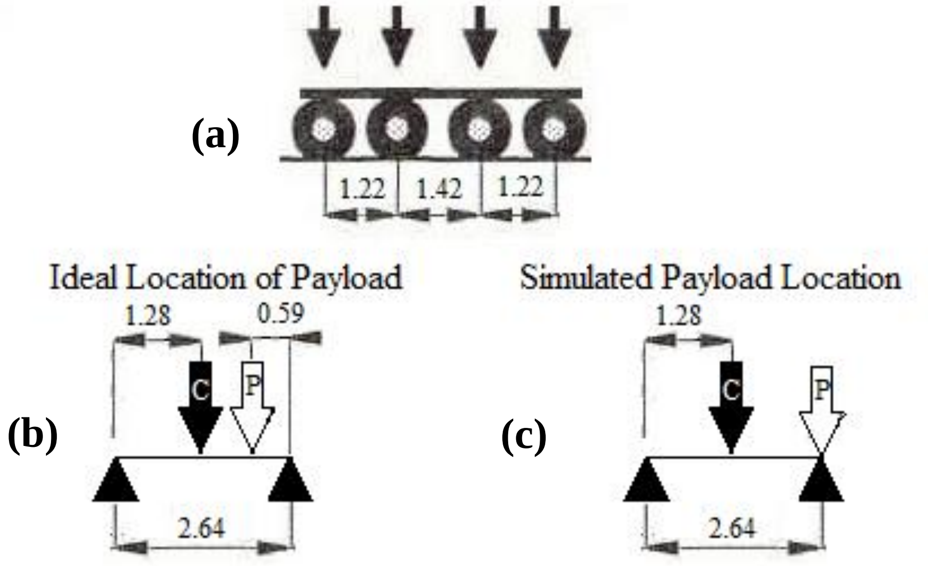


Figure 4.10 – Idealization of LAV III-ISC (m):
(a) Vehicle axle spacing; (b) Idealized representation with nominal location of payload;
(c) Idealized representation with simulated location of payload

Table 4.13 summarizes the axle load bias coefficient and CoV for the three cases investigated. Due to the determinist curb weight for Case (1), the CoV of the rear tandem axle is much smaller than the CoV for Cases (2) and (3). Since they are the same load but have different nominal combat “weights”, the only difference between Case (2) (nominally 20,000 kg) and Case (3) (nominally 23,890 kg), are their bias coefficients.

Table 4.13 – LAV III-ISC event axle load idealization

Case	Axle	Nominal (kN)	Mean (kN)	Bias	Standard Deviation (kN)	CoV
(1)	1st and 2nd	46.0	42.3	0.919	N/A	0
	3rd and 4th	52.1	63.8	1.226	3.2	0.049
(2)	1st and 2nd	46.0	42.1	0.915	3.6	0.085
	3rd and 4th	52.1	63.6	1.222	4.7	0.074
(3)	1st and 2nd	55.8	42.1	0.754	3.6	0.085
	3rd and 4th	61.3	63.6	1.038	4.7	0.073

4.3.3 Leopard 2A4M Tank

For tracked vehicles, the vehicle load is generally assumed to be uniformly distributed over the contact area of the tracks (NATO, 2006). In fact, there are peaks of pressure where roadwheels are located along the track (Wong, 2010). Given this, it is necessary to check the local load applied beneath the tracked vehicle roadwheel (NATO, 2006). Furthermore, the load in each roadwheel may not be equal, depending on how the vehicle is loaded. For longer spans the impact of these slight differences in roadwheel loads is negligible. For shorter spans, particularly those nearing the length of track itself, these differences could have an impact. Case #1 in Figure 4.11 shows the perfect case where loads are distributed equally between roadwheels, thus creating essentially a Uniformly Distributed Load (UDL) along contact surface of the tracks. In practice, some roadwheels may have heavier loads than others. If these heavier loads are near the middle of the vehicle, as represented by Case #2 in Figure 4.11, a greater maximum moment than that caused by a UDL would be produced. They might also be concentrated to one end of the vehicle as shown in Case #3 in Figure 4.11, which would produce a greater maximum shear.

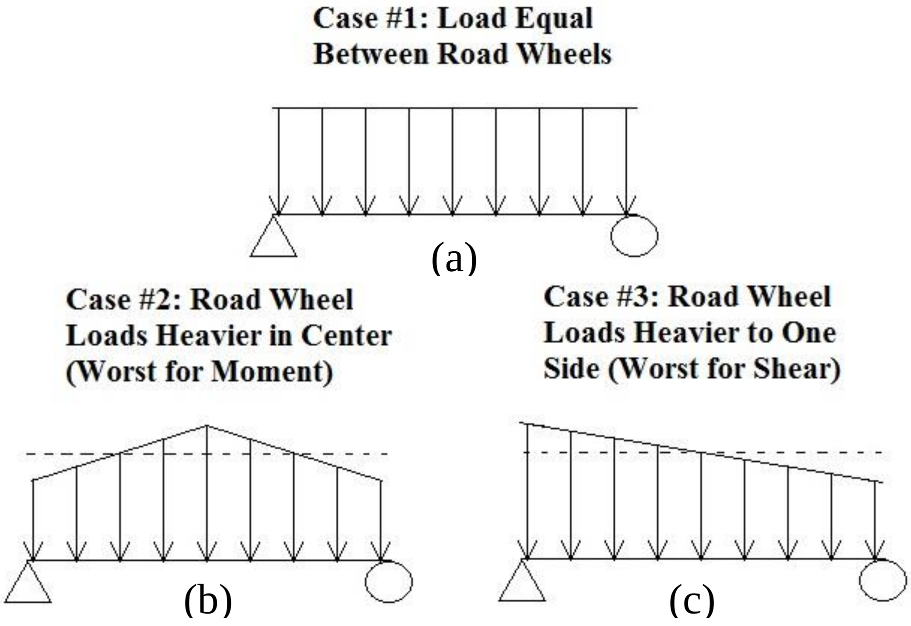


Figure 4.11 – Tracked vehicle load distribution cases:
(a) Idealized load; (b) Worst case for moment; (c) Worst case for shear

In Cases #2 and #3 of Figure 4.11, the load distribution would be caused by differences in the largest roadwheel load and smallest roadwheel load. For Case #2 (for moment) or Case #3 (for shear), if the largest magnitude of the distributed load is 35% larger than the least magnitude, the increase in moment or shear with respect to Case #1 is less than 5%.

For the Leopard 2A4M tank, data could not be obtained for the fully loaded roadwheel loads, although roadwheel loads at curb weight were provided. To estimate the fully loaded nominal road wheel loads for the Leopard 2A4M, the payload and fuel was distributed over the 4 rear roadwheels because a large portion of the fuel and payload is located at the rear of the vehicle. Table 4.14 shows the combined load applied by successive pairs of roadwheels as an absolute load and a percentage of the total vehicle weight. It was assumed that ratio of roadwheel load to total vehicle weight would be maintained for all weights of the Leopard 2A4M tank. This procedure may not yield the actual roadwheel load, but in lieu of better data, may be a reasonable approach.

Table 4.14 – Fully laden Leopard 2A4M road wheel load

Road Wheel Pair	1st	2nd	3rd	4th	5th	6th	7th	SUM
Roadwheel Load (kN)	81.4	88.9	88.0	92.0	91.2	82.9	75.9	600.3
Percent of Total Weight (%)	13.6	14.8	14.7	15.3	15.2	13.8	12.6	100.0

4.4 Discussion

The method used to estimate variability of the AHSVS-PLS combat weight provides a good starting point for investigating other traffic populations. This could indicate if further resources are necessary to gather direct observations of military transport vehicle weights, and so obtain more reliable data to use as a basis for the calibration of Limit States Design based load factors for military transport vehicles.

The methods used to quantify the LAV III-ISC and Leopard 2A4M tank weight variability are based on heuristic assumptions concerning different operational loads that affect the vehicle weight. Given the high level of control, itemized breakdown, and standardization of military fighting vehicle loads, it is possible to make these assumptions with greater confidence than if the payload was uncontrolled. Even though vehicle weight data from the field are required to validate these assumptions, they still yield a useful method of comparing the expected weight variability in different categories of military vehicles.

It is generally assumed that there is higher control in military vehicle loads than civilian vehicle loads (Kim, Tanovic, & Wight, 2010), thus leading to lower weight variability. Based on the observed weights of intermodal containers from Afghanistan and qualitative descriptions of loading practices provided by military personnel while conducting research for this chapter, this assumption may not always be valid, specifically during conflict operations. For example, the AHSVS-PLS, a military transport, had similar statistical parameters for load as Canadian non-permit traffic, indicating no greater load control between the Canadian military and civilian traffic. In using conservative assumptions for the LAV III-ISC and Leopard 2A4M tank loadings, it was illustrated that the weights of these vehicles is less variable because the curb weight, assumed deterministic, is a significant portion of the GVW.

4.5 Chapter Conclusions

Using heuristic assumptions combined with available data, the statistical parameters for the GVW and axle loads for three military vehicles have been quantified. This is a necessary prerequisite to employ Limit State Design (LSD) methods, including the assessment of existing bridges for military vehicles.

This chapter illustrates that many military vehicles have large curb weights and light payloads, and so have weights near to the nominal weight. Reducing the payload weight fraction, i.e., the ratio of the payload to the overall vehicle weight, reduces the overall vehicle weight variability. The following conclusions can be made:

1. The statistical parameters for the GVW of military vehicles differ depending on the general configuration and function of the specific vehicle. Specifically, military fighting vehicles have a lower CoV than military transport vehicles.
2. The lower weight variability of some military vehicles is less due to effective load control but rather is an inevitable outcome of the design and intended functionality of the vehicle itself.
3. Accounting for the eccentricity of the payload has little impact on the axle load bias coefficient, but impacts its CoV.
4. It is possible to estimate the statistical parameters for the GVW of military vehicles using the payload weight fraction.

Chapter 5

5 Probabilistic Quantification of Military Vehicle Load Effects

5.1 Static Load on Simple Spans

5.1.1 AHSVS-PLS (Transport)

Figure 5.1 shows Gumbel distributions fitted to the axle loads determined in Chapter 4 for the AHSVS-PLS. Generally the fit of the distribution to the data is excellent. Figure 5.1 (d) shows the event distribution for shear on a 1 m span caused by the AHSVS-PLS and trailer with uncorrelated container loads. The shear data implies the need for two distinct Gumbel distributions: for cumulative probabilities less than 0.90 it is governed by Axles 1 and 2 and for greater cumulative probabilities, it is governed by Axles 3, 4, 5 and 6. This is corroborated by Figure 5.2, which shows the probability density functions for each axle load and for shear on a 1 m span. The probability density functions for each axle load and for shear Axles 1 & 2 are essentially identical for loads/shears less than 89 kN. The probability density functions for shear and for the maximum axle load from axles 3 to 6 are essentially identical for loads/shears greater than 92 kN. This illustrates the transition on short spans, from the front axles governing the load effect (for most cases) to the rear axles governing the load effect (for the extreme load cases).

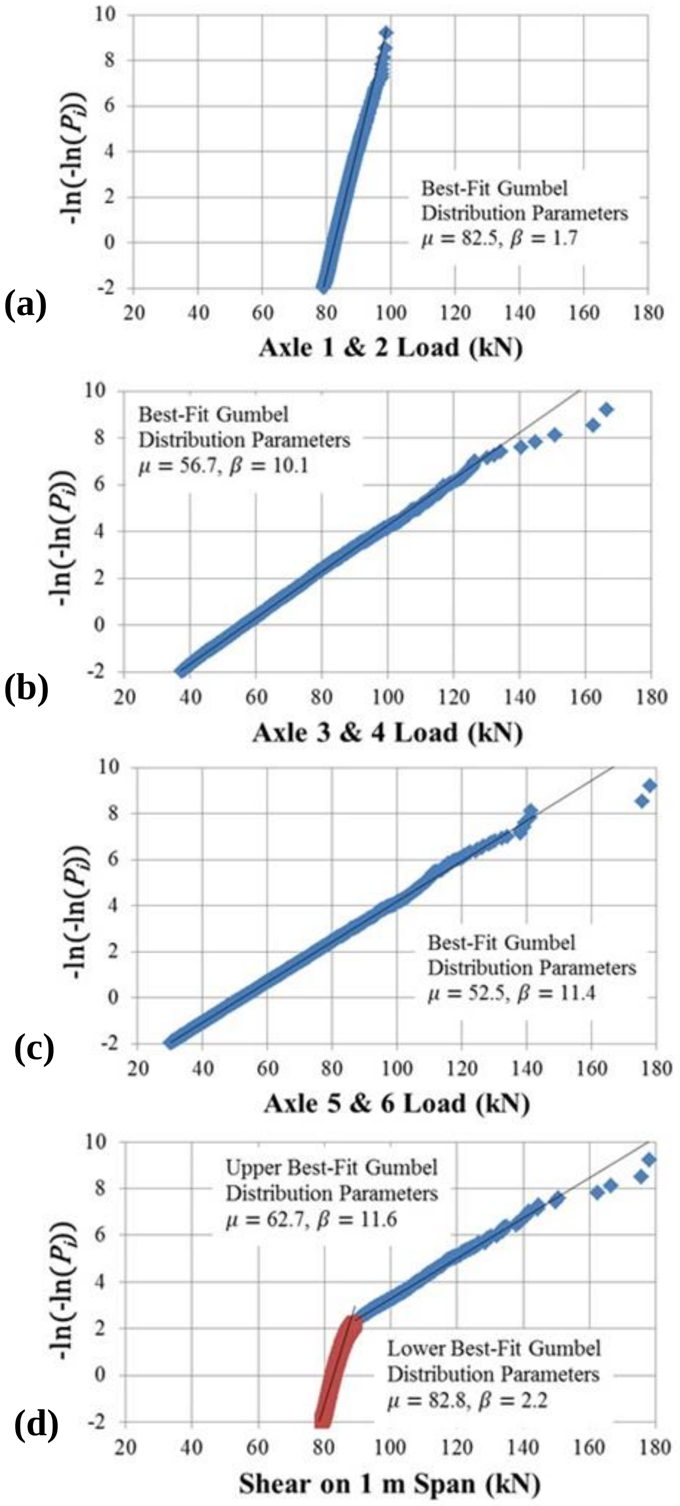


Figure 5.1 – Gumbel distribution for event AHSVS-PLS with trailer axle loads

(a) Axle 1 & 2 loads; (b) Axle 3 & 4 load;

(c) Axle 5 & 6 loads; (d) Shear load effect on 1 m span

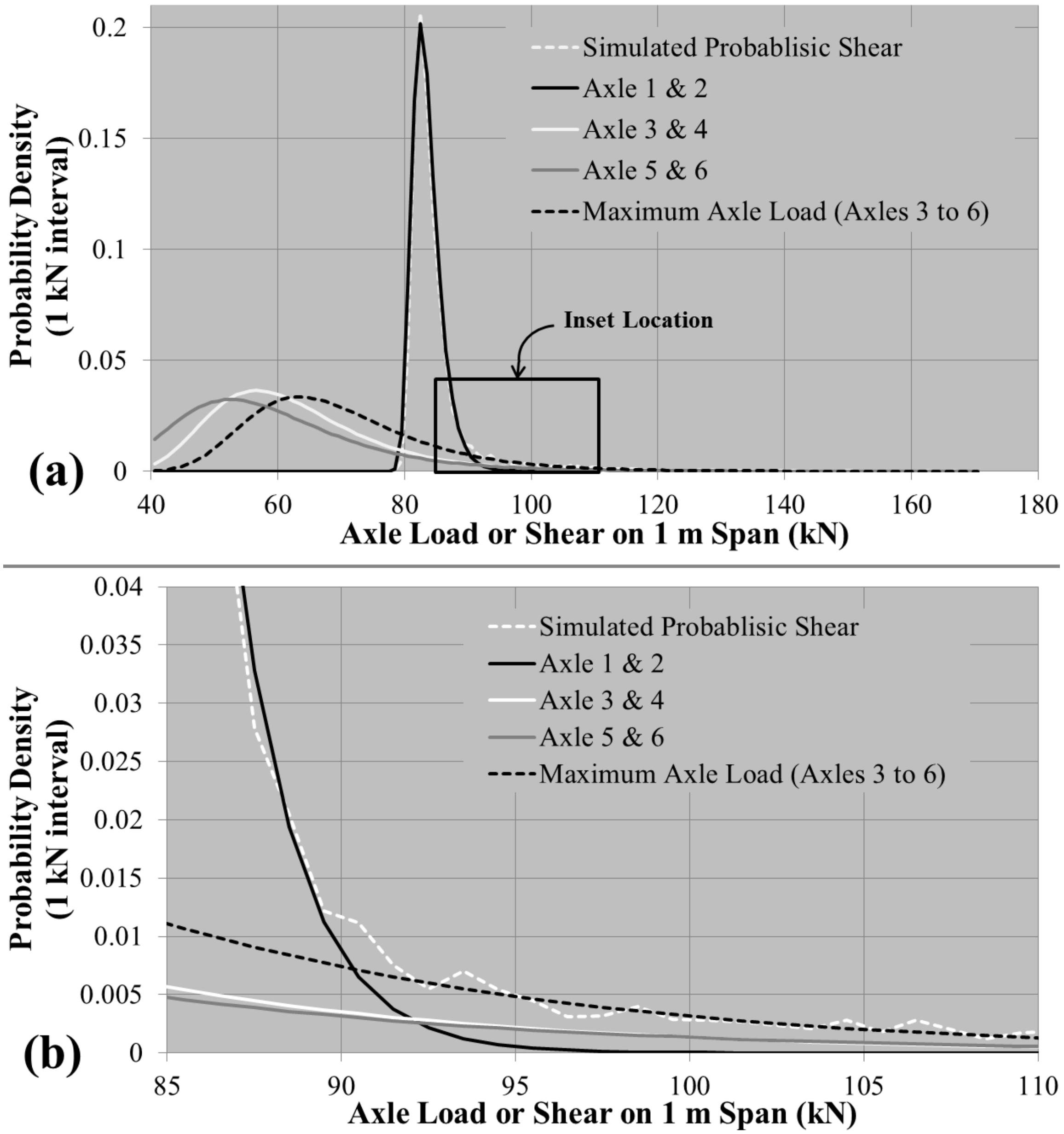


Figure 5.2 – Probability density of AHSVS-PLS with uncorrelated trailer axle loads
(a) Overall; (b) Inset detail

The bilinear cumulative distribution function observed for shear in 1 m spans was also noted for moments. For increasing span lengths, the observed kink at the intersection of the two linear distribution regions decreases. This is due to the load effect of additional axles acting on the span, as well as, the distance between axles being comparatively small to the span length. Eventually, the sample CDFs for shear or moment can be described by a single Gumbel distribution. This occurred between 16 m and 25 m for the different cases investigated.

Figures 5.3 and 5.4 present the bias coefficient and CoV, respectively, for shear and moment for increasing span lengths at different annual traffic volumes (Event, $n = 100$, and $n = 1{,}000$). The nominal shear and moment are as produced by a vehicle of the nominal combat “weight” (AHSVS-PLS at 39,000 kg, AHSVS-PLS and PLS trailer at 60,000 kg). At shorter spans, where different axles can govern the maximum event shear or moment, the extreme value distribution at each traffic volume was defined using the most severe load effect due to the n generated vehicles. One thousand simulated data points were generated to determine the bias coefficient and CoV for the $n = 100$, and $n = 1{,}000$ cases. Since the extreme value distribution for $n = 1{,}000$ can be idealized using a single Gumbel distribution, the distribution parameters for higher annual traffic volumes can be determined using the log-shift principle, e.g., Equations [4.12] and [4.13]. These Gumbel distribution parameters can be converted to the bias coefficient and CoV for shear and moment at short and long spans using Equations [4.10] and [4.7]. Figure 5.3 indicates that for spans of 20 m, the bias coefficient and CoV for shear stabilizes. Likewise, Figure 5.4 indicates that for spans of 25 m the bias coefficient and CoV for moment also stabilizes. The span length is longer for the moment case because the effect of accounting for individual axle loads instead of resultant force is much smaller for shear than for moment.

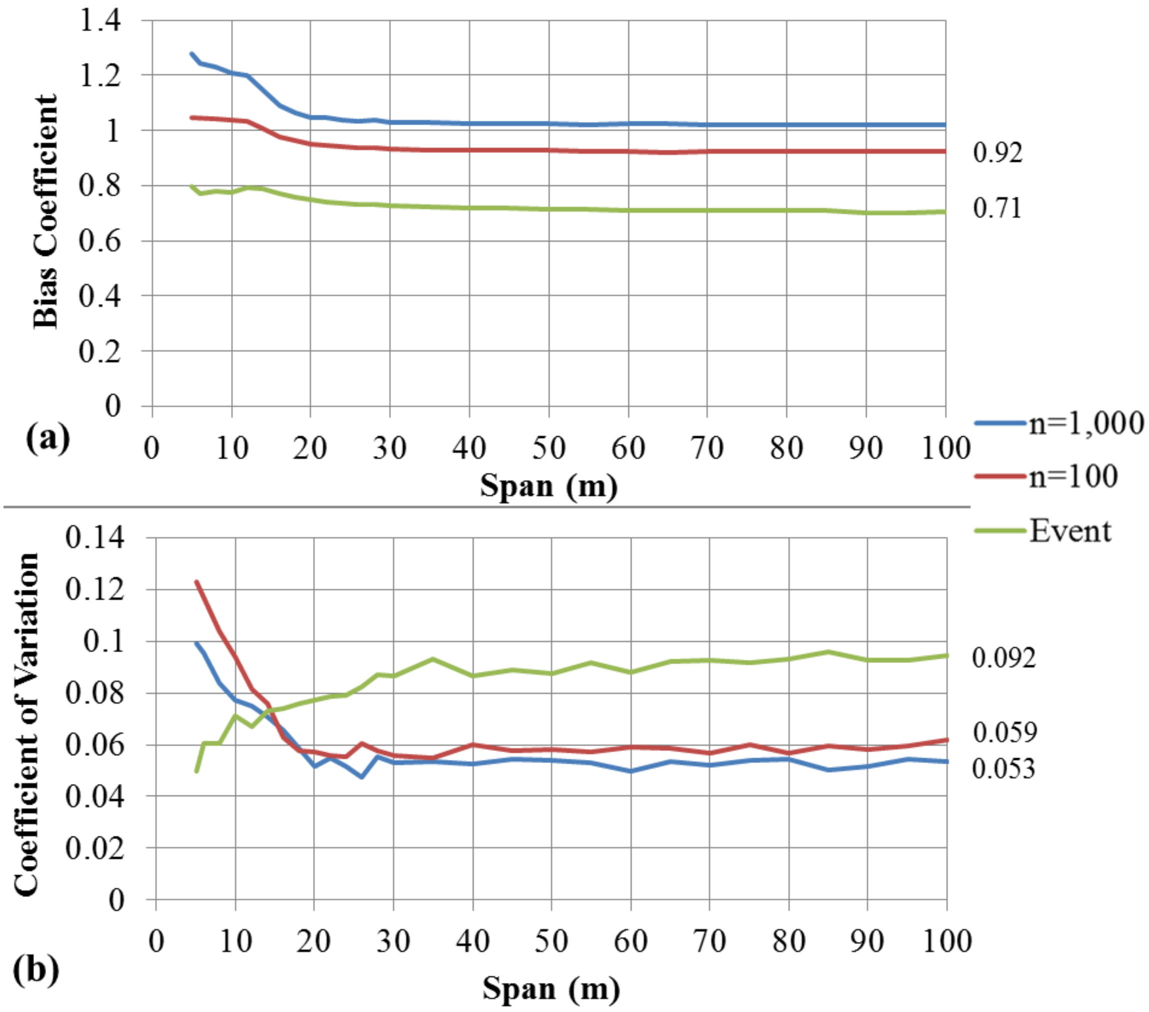


Figure 5.3 – Static shear force demand versus span length: AHSVS-PLS and trailer with uncorrelated container weights:
(a) Bias Coefficient; (b) CoV

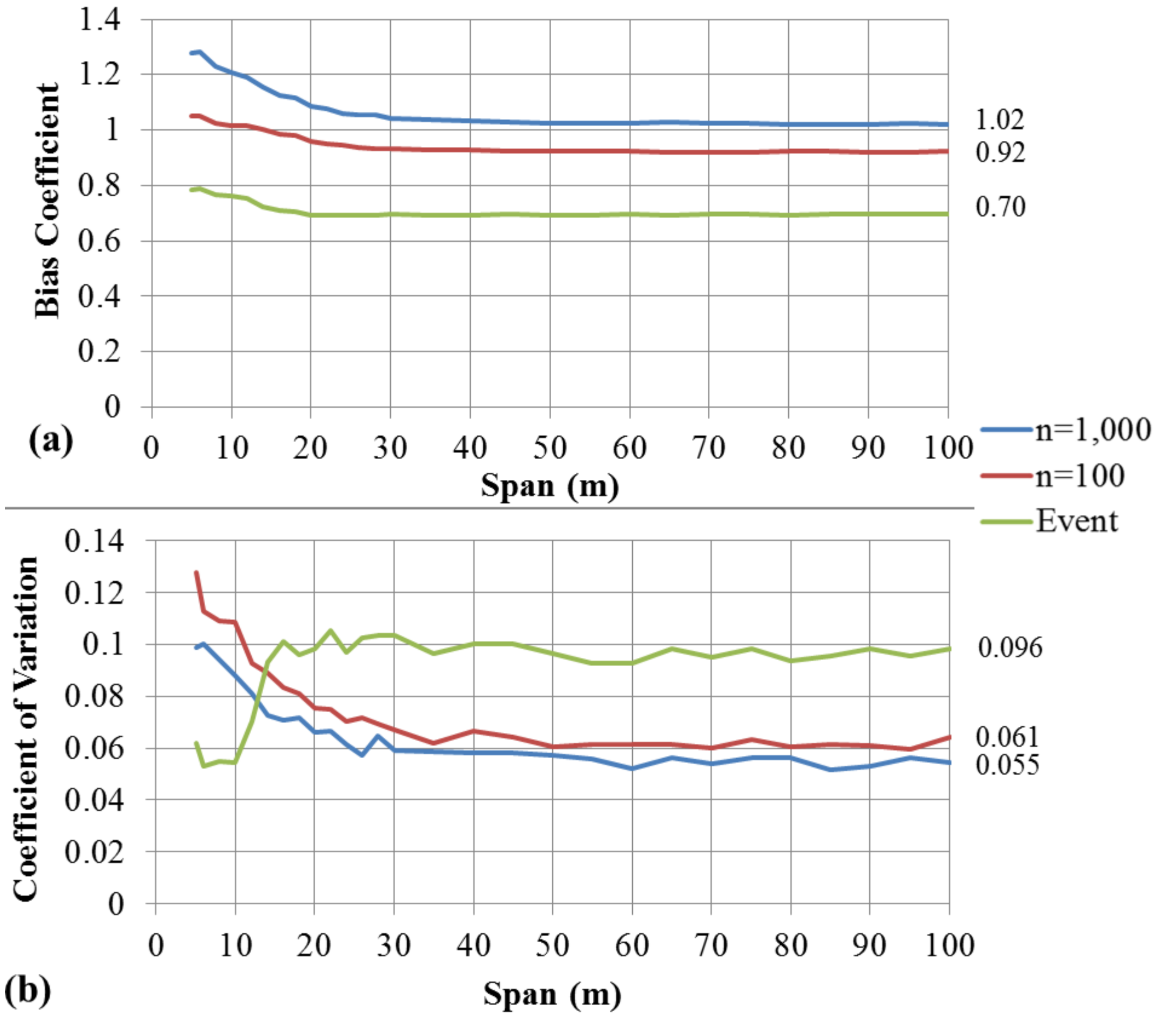


Figure 5.4 – Static bending moment demand versus span length: AHSVS-PLS and trailer with uncorrelated container weights:
(a) Bias Coefficient; (b) CoV

A comparison of Figures 5.3 and 5.4 indicates that the bias coefficient and CoV of the either static load effect depends on the span lengths, and both are greater for shorter span lengths. An exception to this trend is the event CoV, which is reduced for shorter span lengths because the critical force effect is due to a single tandem axle, so the event CoV is closely related to the CoV of that axle, which for most cases would be the front tandem axle with a low CoV. On the other hand, extreme value distributions for traffic volumes of more than 100 vehicles per year are mainly defined by the rarer events where the critical force effect is caused by the rear axles, which have a higher CoV.

Table 5.1 summarizes the static load bias coefficient and CoV for simply supported spans up to 100 m. Given the different bias coefficients and CoVs for short and long spans, unique values of each parameter for short and long spans are necessary. The bias coefficient and CoV for the AHSVS-PLS without a trailer are essentially constant at span lengths greater than 16 m for shear and 20 m for moment. For the AHSVS-PLS and PLS trailer, whether the container weights are uncorrelated or perfectly correlated, the near constant values occur at span lengths of 20 m for shear and 25 m for moment. The bias coefficient is from the nominal shear and moment that would be produced by the vehicle at its combat "weight" (AHSVS-PLS at 39,000 kg, AHSVS-PLS and trailer at 60,000 kg).

Table 5.1 – AHSVS-PLS static load bias coefficient and CoV, for simply supported spans

AHSVS-PLS Configuration	Parameter	Span Range	Event	Maximum Annual (Traffic Volume)			
				(100)	(1,000)	(10,000)	(100,000)
No Trailer (Shear)	Bias	< 16 m	0.816	1.057	1.261	1.502	1.742
	Bias	> 16 m	0.764	1.030	1.164	1.305	1.444
	CoV	< 16 m	0.096	0.116	0.103	0.089	0.077
	CoV	> 16 m	0.096	0.072	0.063	0.059	0.054
No Trailer (Moment)	Bias	< 20 m	0.816	1.057	1.281	1.533	1.788
	Bias	> 20 m	0.765	1.031	1.165	1.308	1.448
	CoV	< 20 m	0.096	0.117	0.103	0.092	0.079
	CoV	> 20 m	0.096	0.072	0.063	0.060	0.054
Trailer with Uncorrelated Container Weights (Shear)	Bias	< 20 m	0.799	1.046	1.277	1.465	1.684
	Bias	> 20 m	0.709	0.924	1.022	1.121	1.220
	CoV	< 20 m	0.092	0.123	0.099	0.084	0.073
	CoV	> 20 m	0.092	0.059	0.053	0.049	0.045
Trailer with Uncorrelated Containers (Moment)	Bias	< 25 m	0.790	1.052	1.283	1.523	1.759
	Bias	> 25 m	0.695	0.922	1.024	1.124	1.225
	CoV	< 25 m	0.096	0.128	0.100	0.086	0.075
	CoV	> 25 m	0.096	0.061	0.055	0.050	0.046
Trailer with Fully Correlated Container Weights (Shear)	Bias	< 20 m	0.799	1.053	1.283	1.522	1.754
	Bias	> 20 m	0.705	1.043	1.204	1.390	1.567
	CoV	< 20 m	0.129	0.117	0.103	0.085	0.074
	CoV	> 20 m	0.129	0.091	0.075	0.071	0.063
Trailer with Fully Correlated Containers (Moment)	Bias	< 25 m	0.783	1.053	1.283	1.523	1.755
	Bias	> 25 m	0.696	1.045	1.211	1.404	1.587
	CoV	< 25 m	0.134	0.117	0.103	0.085	0.074
	CoV	> 25 m	0.134	0.094	0.077	0.073	0.064

Referring to Table 5.1, in considering the three configurations for the AHSVS-PLS (which is more evident at higher traffic volumes), the two cases for AHSVS-PLS and trailer bound the severity of static loads. When the shipping container weights are uncorrelated, the resulting statistical parameters are the least severe, and when the shipping containers are correlated, the parameters are the most severe. The bias coefficient and CoV for the AHSVS-PLS falls between these two cases. The AHSVS-PLS and trailer with uncorrelated shipping container weights has a lower CoV because it is unlikely that an extremely heavy shipping container will occur simultaneously on the truck and the trailer. For shorter spans, the differences between the three configurations are much less, because, primarily axles 3 and 4 have a significant impact on the governing case of moment or shear.

5.1.2 LAV III-ISC (Armoured Personnel Carrier)

Following similar procedures, the bias coefficient and CoV for shear and moment due to the LAV III-ISC for various simply supported span lengths was determined. The nominal shear and moment are as produced by the LAV III-ISC at its nominal combat “weight” (Cases (1) and (2): 20,000 kg; and Case (3): 23,890 kg). Figures 5.5 and 5.6 show the variation of these parameters for shear and moments, respectively, for Case (1) of the LAV III-ISC. For span lengths greater than 15 m for shear and 15 m for moments, the parameters are constant. The shortest span investigated, 2 m, was chosen because the LAV III-ISC would likely self-bridge any lesser span (DND, 2011c).

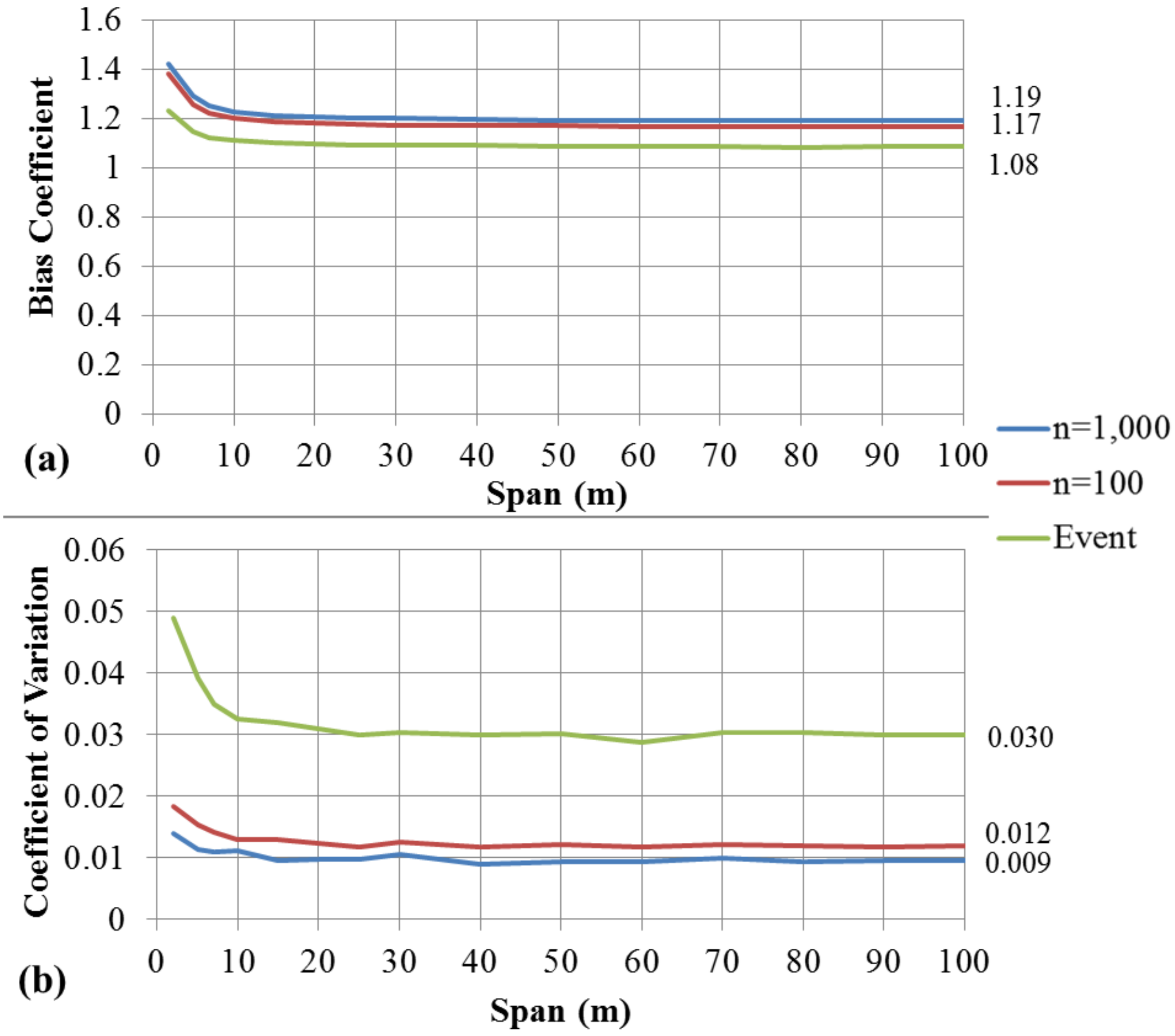


Figure 5.5 - Static force demand shear versus span length: LAV III-ISC – Case (1): (a) Bias Coefficient; (b) CoV

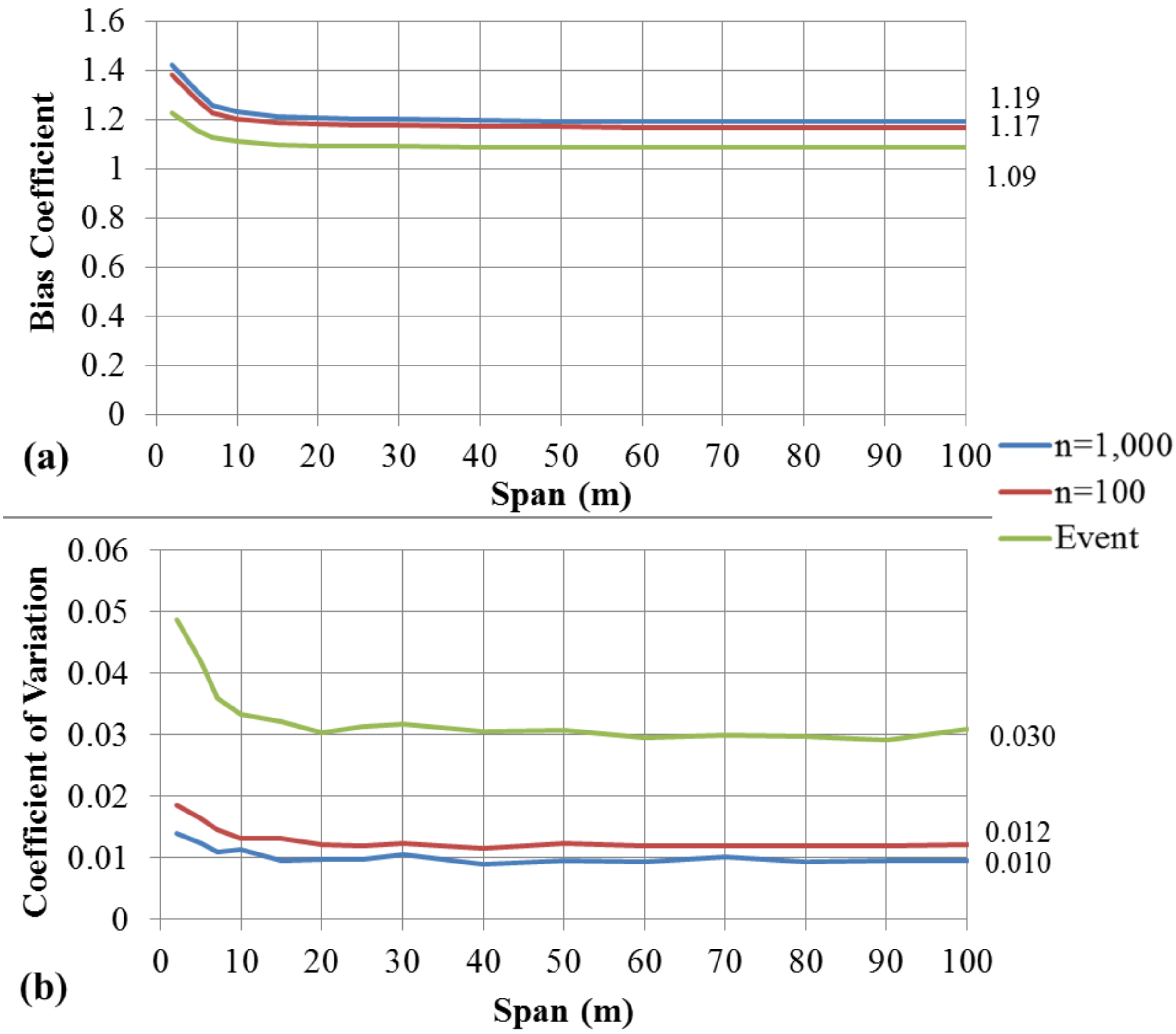


Figure 5.6 - Static force demand moment versus span length: LAV III-ISC – Case (1): (a) Bias Coefficient; (b) CoV

Table 5.2 provides bias coefficient and CoV values caused by the three Cases of the LAV III-ISC for moment and shear on simply supported spans. Two sets of parameters are provided: one set for short spans, less than 15 m; and the other set for longer spans. The span length defining the boundary between short and long spans is shorter than that for the AHSVS-PLS, because the distance between the front and rear axles of the LAV III-ISC is 3.86 m, compared to 6.83m for AHSVS-PLS or 15.11 if a PLS trailer is present. Unlike Case (1), for Cases (2) and (3) only the bias coefficient varies with span length while the CoV remains relatively constant. This occurs because for Cases (2) and (3) there is an assumed variability in the curb weight that causes the CoVs for all axles of the vehicle to be similar.

Table 5.2 – LAV III-ISC static load effect bias coefficient and CoV, for simply supported spans

LAV III-ISC Configuration	Parameter	Span Range	Event	Maximum Annual			
				100	1,000	10,000	100,000
Case (1) (Shear)	Bias	< 15 m	1.232	1.380	1.423	1.459	1.494
	Bias	> 15 m	1.085	1.167	1.191	1.210	1.231
	CoV	< 15 m	0.049	0.018	0.014	0.014	0.013
	CoV	> 15 m	0.030	0.012	0.010	0.010	0.009
Case (1) (Moment)	Bias	< 15 m	1.228	1.380	1.423	1.458	1.493
	Bias	> 15 m	1.085	1.168	1.191	1.211	1.231
	CoV	< 15 m	0.049	0.019	0.014	0.013	0.013
	CoV	> 15 m	0.030	0.012	0.010	0.010	0.009
Case (2) (Shear)	Bias	< 15 m	1.223	1.455	1.531	1.607	1.684
	CoV	> 15 m	1.080	1.294	1.362	1.426	1.489
	CoV	0–100 m	0.074	0.032	0.026	0.026	0.025
Case (2) (Moment)	Bias	< 15 m	1.223	1.455	1.531	1.608	1.684
	CoV	> 15 m	1.080	1.294	1.363	1.426	1.490
	CoV	0–100 m	0.073	0.032	0.028	0.027	0.025
Case (3) (Shear)	Bias	< 15 m	1.039	1.236	1.301	1.358	1.414
	CoV	> 15 m	0.905	1.084	1.141	1.192	1.243
	CoV	0–100 m	0.074	0.032	0.026	0.023	0.022
Case (3) (Moment)	Bias	< 15 m	1.039	1.236	1.301	1.358	1.414
	CoV	> 15 m	0.905	1.084	1.141	1.193	1.245
	CoV	0–100 m	0.073	0.032	0.026	0.024	0.023

Table 5.2 shows that Case (1), with its deterministic curb weight, has the lowest event CoV which, when compared to other cases at greater traffic volumes, results in a lower bias coefficient and CoV. Cases (2) and (3) differ only in bias coefficient due to the different nominal combat “weights” (Case (2): 20,000 kg; and Case (3): 23,890 kg).

5.1.3 Leopard 2A4M Tank

Following the same procedures, the bias coefficients and CoV values for shear and moment on simply supported spans was quantified for the Leopard 2A4M tank. The shortest span investigated is 3 m, which corresponds to the maximum trench width the

Leopard 2A4M tank can cross (Leopard Requirements Officer, Director Land Requirements 3-4-3, Department of National Defence, 2013). Figure 5.7 shows the bias coefficient for shear is greater for spans shorter than 10 m, due to the difference between the nominal UDL and the simulated roadwheel loads described in Section 4.3.3 . If only a simulated UDL was considered, the bias coefficient for shear would be constant for all spans. For the Leopard 2A4M, only the bias coefficient for shear was shown in Figure 5.7 because it is the only statistical parameter that changes with span length.

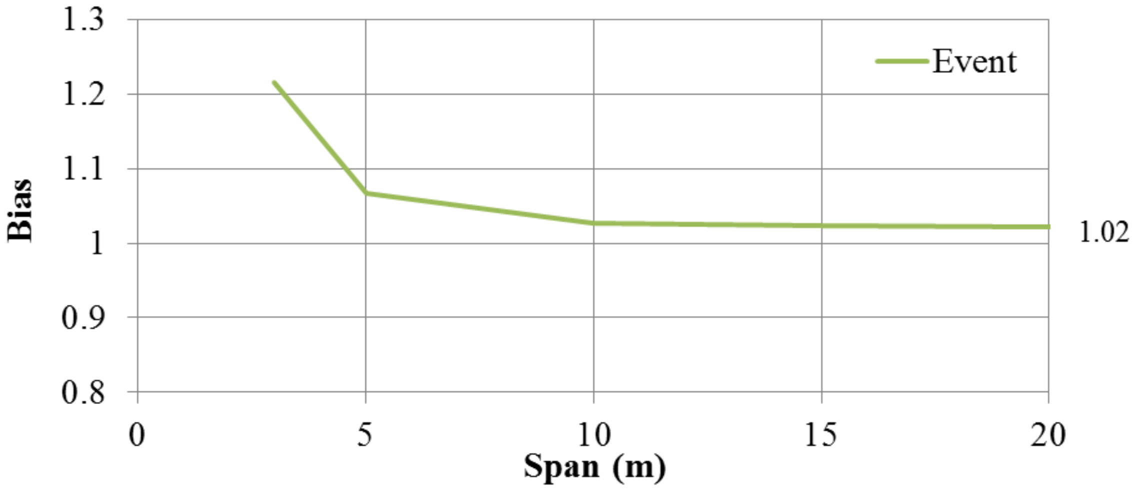


Figure 5.7 – Static force shear demand versus span length: Leopard 2A4M tank

Table 5.3 presents the bias coefficients and CoV values for the Leopard 2A4M tank, where the simulated shear and moment is the worst case between roadwheel loads or idealized as a UDL. The nominal shear and moment are as produced by the Leopard 2A4M at its nominal combat “weight” (61,214 kg) if idealized as a UDL. Due to the different bias coefficient for shear at spans less than 10 m, two categories of span are considered for shear in Table 5.3. The coefficients of variation for the event and the extreme annual distributions are very small.

Table 5.3 – Leopard 2A4M static load effect bias coefficient and CoV, for simply supported spans

Leopard 2A4M	Parameter	Span Range	Event	Maximum Annual			
				100	1,000	10,000	100,000
Shear	Bias	< 10 m	1.215	1.237	1.241	1.245	1.248
	Bias	> 10 m	1.020	1.039	1.042	1.045	1.047
	CoV	0-100 m	0.011	0.002	0.001	0.001	0.001
Moment	Bias	0-100 m	1.020	1.039	1.042	1.045	1.047
	CoV	0-100 m	0.011	0.002	0.001	0.001	0.001

5.2 Dynamic Load Effects

The Dynamic Load Allowance is “an equivalent static load that is expressed as a fraction of the traffic load and is considered to be equivalent to the dynamic and vibratory effects of the interaction of the moving vehicle and the bridge, including the vehicle response to irregularity in the riding surface” (CSA, 2006a).

Lenner (2014) recently noted that a “…review of literature does not provide a single value for [Dynamic Load Allowance] that can be used for military vehicles in general terms”, but rather “varies from country to country or even agency to agency due to different assumptions and test outcomes”. References recommending Dynamic Load Allowance (DLA) or similar factors are “mainly concerned with [the] deterministic value of the [DLA] and no regard is given to the stochastic properties” (Lenner, 2014). For military vehicles speeds less than 25km/hr, a DLA of 0.15 is recommended, with 0.20 for ramps (Hornbeck, Kluck, & Connor, 2005). Lenner (2014) cites Homberg (1970), who proposes DLA at spans less than 18 m of 0.25 for wheeled vehicles and 0.10 for tracked vehicles that in both cases reduce to DLA of zero for spans of 50 m or greater. DND (2007a) recommends a DLA of 0.15 for all bridge types and span lengths, except for timber stringer bridges where DLA is taken as zero. DND (2007a) however, makes an exception for extremely unfavorable pavement conditions, where the DLA is increased to 0.30, and “for extremely short elements of deck (one axle on the span)…a DLA of [0.40] may apply”. Lenner (2014) recommends the CoV for Dynamic Amplification Factor

(DAF) between 0.05 to 0.15 but “proposed to assess the dynamic amplification on a case-specific basis”. The low CoV for dynamic amplification apply to “bridges with an exceptionally smooth profile or for all bridges with span lengths over 15 m” (Lenner, 2014). The CoV for DLA can be determined from CoV for DAF from:

[5.1]
$$\mathrm{V_{DLA}} = \frac{\mathrm{V_{DAF}} \cdot (\overline{\mathrm{DLA}} + 1)}{\overline{\mathrm{DLA}}}$$

where, $\overline{\mathrm{DLA}}$ is the mean DLA, $\mathrm{V_{DLA}}$ is the CoV for the DLA and $\mathrm{V_{DAF}}$ is the CoV for the DAF.

Given the lack of consensus concerning the dynamic effects of military vehicles, it is useful to review existing experimental research of the dynamic loads for several military vehicles, shown in Table 5.4. The results of these investigations can be compared to the statistical parameters for dynamic loads caused by civilian traffic. Some of these vehicles are similar to vehicles investigated in this thesis: the M1-A1 Abrams tank is comparable in size, weight, and function to the Leopard 2A4M tank; the M1075 PLS is similarly comparable to the AHSVS-PLS; and the Bison is comparable to the LAV III-ISC.

Table 5.4 – Description of military vehicles from experimental research of the dynamic loads

Name	Description	Military Vehicle Category	Weight (kN)	Number of Axles (Roadwheels)	Front to Rear Axle (m)	Axle Group Spacing (m)		
M1-A1	Tank	Tracked-Fighting (T-F)	614	(7)	4.57	0.73		
HET	Tank Transporter	Wheeled-Transport (W-T)	1,044	9	13.65	1.10	1.30	
M113	Armoured Personnel Carrier	Tracked-Fighting (T-F)	121	(5)	2.68	0.67		
M1075 PLS(1)	PLS Truck	Wheeled-Transport (W-T)	383	5	7.97	1.52		
M1075 PLS(2)	PLS Truck (lighter load)	Wheeled-Transport (W-T)	210	“	“	“		
Bison	Armoured Personnel Carrier	Wheeled-Fighting (W-F)	126	4	3.47	1.10	1.34	1.04
HLVW	Transport Truck	Wheeled-Transport (W-T)	147	3	5.40	1.4		

Table 5.5 shows the dynamic effects of military vehicles observed in these studies. The observed dynamic load effects from the studies are compared to the statistical parameters for DLA in CSA (2006b), shown in Table 5.6. Statistical parameters for “Short spans” are for spans up to 10 m, for all other conditions “Other span” - 1 lane loaded are used (CSA, 2006a). The DLA was designated based on the axles acting on each span from CL-W Truck which produced the greatest moment for the span length. The DLA shall be: “[a] 0.40 where only one axle of the CL-W Truck is used…; [b] 0.30 where any two axles of the CL-W Truck, or axles nos. 1 to 3, are used; or [c] where three axles of the CL-W Truck, except for axles nos. 1 to 3, or more than

three axles, are used". Following this, the 15.6 m span (Concrete T-Beam, Patrick) has a DLA of 0.25, while all other bridges have a DLA of 0.30.

Table 5.5 – Dynamic effects for military vehicles on various bridge types

Study	Type	Span (m)	Vehicle	Number of Trials	Observed Dynamic Effects			DLA CSA (2006b)	
					Max	Mean	CoV	Mean	CoV
Fixed Non-Standard									
Trimble, Cousins and Seda-Sanabria (2003)	Concrete T-Beam (Franklin)	12	M1075 PLS (2)	4	0.15	0.10	0.30	0.18	0.80
	Concrete T-Beam (Patrick)	15.6	M1075 PLS(2)	4	0.46	0.39	0.15	0.15	0.80
Deployable / Mobile Bridging									
Kosmatka (2011)	Carbon / Epoxy	11.9	M1-A1	15	0.26	0.23	0.13	0.18	0.80
			HET	15	0.69	0.62	0.15	0.18	0.80
Robinson and Kosmatka (2011)	Low Profile FRP Composite	4.7	M113	11	0.12	0.02	3.00	0.20	0.60
			M1075 PLS(1)	9	0.71	0.49	0.39	0.20	0.60
Landherr (2008)	FRP Box Beam	10	Bison	6	0.28	0.13	0.54	0.20	0.60
			HLVW	1	0.27	0.27	N/A	0.20	0.60

Table 5.6 – Statistical parameters for dynamic load allowance (CSA, 2006b)

Span		δ_{DLA}	V_{DLA}
Short		0.67	0.60
Other	- 1 lane loaded	0.60	0.80

In the literature reviewed, only Trimble, Cousins and Seda-Sanabria (2003) report experimental dynamic effects of fixed bridges, specifically two concrete T-beam bridges: Franklin County, and Patrick County (these bridges will be referred to herein as "Franklin Bridge" and "Patrick Bridge" respectively). Referring to Table 5.5, for the Franklin Bridge, the DLA specified in CSA (2006a, 2006b) is conservative compared to the observed DLA. Conversely, for the Patrick Bridge, the DLA specified in CSA (2006a, 2006b) is unconservative. For each bridge the maximum dynamic increment observed during four crossings of a M1075 PLS truck was reported. Table 5.7 presents the mean dynamic load allowance and its standard deviation for the combined data statistics for both bridges. The overall mean DLA, considering all runs on both bridges, yields a bias coefficient between 1.33 and 1.60 with respect to the mean DLA given in CSA(2006b) with a lower CoV, 0.63 versus 0.80 (CSA, 2006b).

Table 5.7 – Trimble, et al. (2003) dynamic load increment for M1075 PLS(1)

	Franklin Bridge	Patrick Bridge	Both Bridges
Mean	0.10	0.39	0.24
Standard Deviation	0.03	0.06	0.15
CoV	0.30	0.15	0.63

In considering all the bridges listed in Table 5.5, observed statistical parameters concerning the DLA show some general trends. Clearly the mean dynamic increments for wheeled vehicles are consistently greater than CSA (2006b) in all cases except for the Bison investigated by Landherr (2008). Tracked vehicles and/or fighting vehicles have consistently lower DLAs compared to wheeled-transport vehicles crossing the same bridge. Also, deployable bridges require greater DLAs than fixed bridges.

It is evident that it is not appropriate to designate a single DLA for all possible combinations of military vehicles and bridge types. Only tracked and fighting vehicles have statistical parameters for DLA that are enveloped by the values recommended in CSA (2006a, 2006b). Given the general trend that deployable bridges require a greater DLA than fixed bridges, then it would be conservative to apply the statistical parameters for DLA given in CSA (2006a, 2006b) to military tracked vehicles or wheeled-fighting vehicles.

Figure 5.8 compares observed mean DLA and corresponding CoV from Table 5.5 to the DLA and $\mathrm{CoV_{DLA}}$ proposed by Lenner (2014). Vehicles are described by their configuration and function as Wheeled-Transport (W-T), Wheeled-Fighting (W-F), or Tracked-Fighting (T-F). Not shown in Figure 5.8 is the Tracked-Fighting vehicle M113 (on deployable 4.8 m span) with a mean DLA of 0.02 and CoV of 3.00. The lower dashed line corresponds to $\mathrm{CoV_{DAF}} = 0.05$, and the upper dashed line corresponds to

$\mathrm{CoV}_{\mathrm{DAF}} = 0.15$. If situation-specific DLAs can be calculated accurately for military vehicles, the approach to probabilistically quantify the CoV of dynamic load effects proposed by Lenner (2014) might be applicable. A major shortfall in the approach proposed by Lenner (2014) is the requirement to calculate a situation-specific DLA, which based on limited experimental data, is difficult to quantify accurately. For all studies reviewed, the combined statistical parameters for tracked vehicles show a lower mean DLA with a higher CoV than for wheeled vehicles.

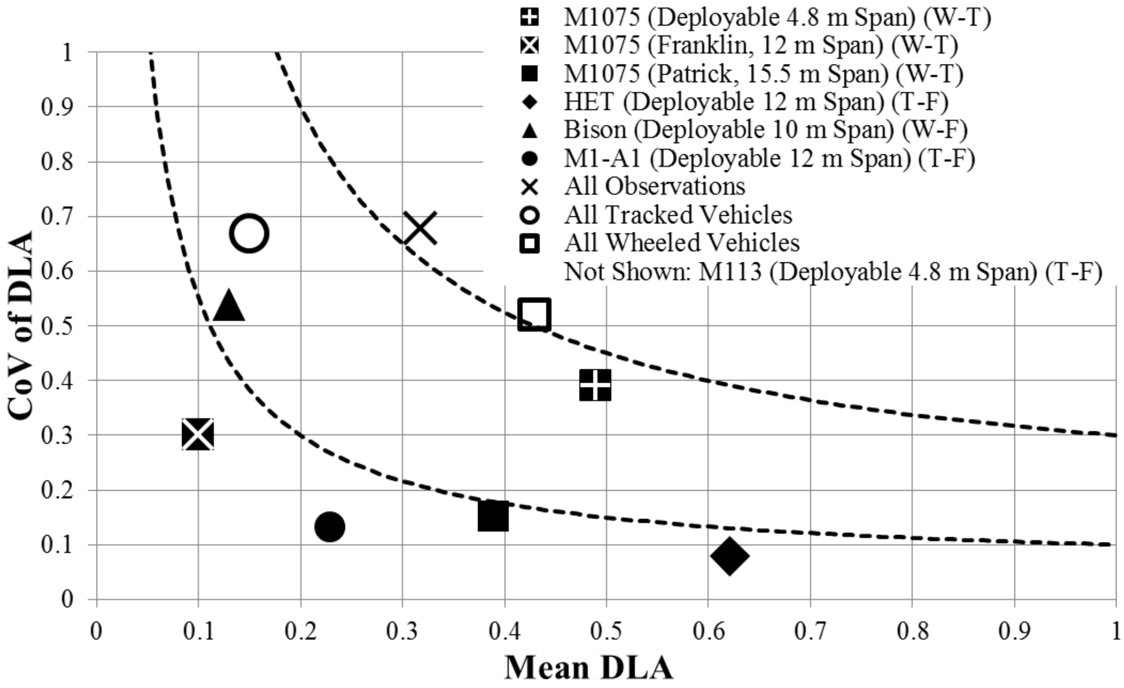


Figure 5.8 – Mean DLA and CoV from Table 5.5 and CoV range for DLA as proposed by Lenner (2014)

Further research into the dynamic amplification caused by military vehicles is required. In lieu of better information, the mean dynamic load and CoV of the three cases given in Table 5.7 and CSA (2006a, 2006b) will be used in the current study.

5.3 Lateral Load Distribution

Lateral load distribution is the assignment of live load demands per lane to demands per girder (or other longitudinal load-resisting element). Much like dynamic load effects, there is limited available literature on the lateral live load distribution for military vehicles on bridges. Based on the available literature, a brief investigation for lateral distribution of a single lane of military vehicle moment to an interior girder of slab-on-girder bridges (e.g., steel girder, pre-stressed concrete, and concrete T-beam) will be presented. This has potential merit because, beam type bridges are very common (Dunker & Rabbat, 1990) and can support single lane military traffic, which is a rating used in the NATO Military Load Classification System.

Kim, Tanovic and Wight (2010) examined the lateral load distribution of NATO Military Load Classification (MLC) wheeled design trucks on a 36 m, simple-span, steel I-girder bridge. Using a calibrated three-dimensional Finite-Element Analysis (FEA), the lateral load distributions of these trucks were examined and compared to AASHTO (2007) Load Distribution Factors (LDF). The LDF for moment is defined as follows (Kim, Tanovic, & Wight, 2010):

[5.2] $$\mathrm{LDF} = \frac{M_{ref}}{M_{l_0}}$$

where, M_{ref} is the moment per girder and M_{l_0} is the moment per design lane.

Pinero (2001) derived formulas similar to those specified in AASHTO (1996, 2007, 2012) that are specific to different types of wheeled and tracked military vehicles used by the US military. Harmonic decomposition was used to find the maximum live load effects on a simply supported multi-girder slab-on-girder system. Three bridge types were investigated: steel girder, pre-stressed concrete, and concrete T-beam. Using the LDF determined for specific vehicle and bridge combinations, nonlinear regression analysis was applied to develop proposed load distribution formulas.

CSA (2006a) approaches lateral load distribution differently than AASHTO (2012), so the LDF’s reported by others were converted to amplification factors that are consistent with the CSA proceedures. For AASHTO (2012) the LDF is multiplied by single lane traffic load to find the moment for each girder. CSA (2006a) defines the girder moment as the product of an amplification factor, F_m, and the average load girder force effect. The design moment per girder, M_g, is therefore (CSA, 2006a):

[5.3] $$M_g = F_m M_{g,avg}$$

where $M_{g,avg}$, the average moment per girder calculated by (CSA, 2006a):

[5.4] $$M_{g,avg} = \frac{nM_T R_L}{N}$$

where, n is the number of design lanes, M_T is the maximum moment per design lane, R_L is a modification factor for multi-lane loading, and N is the number of girders. Since only single lane traffic is being considered, n and R_L both equal 1.0. Thus, M_{l_0} and M_{ref} from AASHTO (2012) are equivalent to M_T and M_g from CSA (2006a) respectively. As such, the CSA (2006a) amplification factor, F_m, can be derived for a given LDF using:

[5.5] $$F_m = \frac{LDF \cdot M_T}{M_{g,avg}}$$

For single lane traffic, $M_{g,avg} = M_T/N$, so Equation [5.5] becomes:

[5.6] $$F_m = LDF \cdot N$$

Conveniently, as shown by Equation [5.6], the bias coefficients and CoVs of the LDF and the F_m are identical.

Appendix F compares graphically the load distribution formulas from Pinero (2001), AASHTO (2012), and CSA (2006a), for Class A & B Highways, by converting the LDF to an equivalent F_m. Pinero (2001) proposes “52 new formulas for different types of [US military] vehicles, different types of [girder] bridges, bending moment and shear force values, interior and exterior girders, and for single and multiple lane loading cases”. In AASHTO (2012), the distribution of live load moment to interior girders, for one design lane loaded on a slab-on-girder bridge is given by:

[5.7] $$LDF = 0.06 + \left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12Lt_s{}^3}\right)^{0.1}$$

where, S is the girder spacing (ft), L is the span (ft), t_s is the depth of concrete slab (inches), and K_g is the longitudinal stiffness parameters (in^4). Parameter K_g is computed as:

[5.8] $$K_g = \frac{E_B}{E_D}\left(I + Ae_g{}^2\right)$$

where, E_B is the modulus of elasticity of the girder, E_D is the modulus of elasticity of the deck, I is the moment of inertia of the girder, A is the area of the girder, and e_g is the distance between the centers of gravity of the girder and deck. Simplified values of $\left(\frac{K_g}{12Lt_s{}^3}\right)^{0.1}$ are also given for certain types of bridges specified in AASHTO (2012). For the cases under investigation, the derivation of LDFs in AASHTO (2012) has remained unchanged to AASHTO (1996)

The various amplification factors proposed by Pinero (2001) do not differ greatly from each other and are generally bounded by CSA (2006a), as a conservative upper bound, and AASHTO (2012), as a slightly unconservative lower bound.

Figure 5.9 shows the variation of amplification factor with span. The equations from Pinero (2001) are for *All Beam Bridges*, the bridge used to vary the span is a 36 m steel girder bridge from Kim, Tanovic, & Wight, (2010).

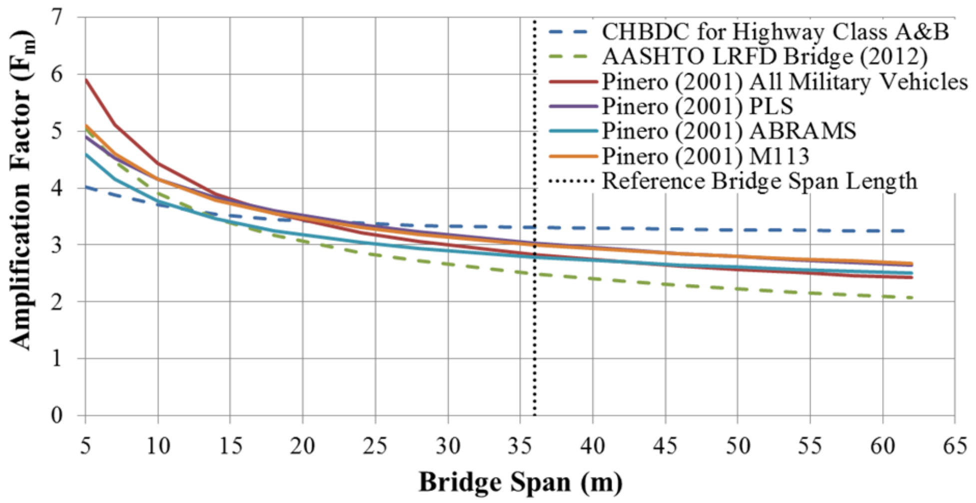


Figure 5.9 – Amplification factor versus span length: *All Beam Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

Figure 5.10 shows the variation in of amplification factor with girder spacing. The equations from Pinero (2001) are for *Pre-Stressed Concrete Bridges*, the bridge used to vary the girder spacing is a 37 m CPCI girder concrete bridge (Morrison Hershfield Ltd., 2012).

Figure 5.10 – Amplification factor versus girder spacing: *Pre-Stressed Concrete Bridge* (Pinero, 2001), 37 m CPCI girder bridge (Morrison Hershfield Ltd., 2012)

Figure 5.11 shows the variation of amplification factor with girder spacing. The equations from Pinero (2001) are for *Steel Girder Bridges*, the bridge used to vary the span is a 36 m steel girder bridge described by Kim, Tanovic, & Wight, (2010). One formula given in Pinero (2001), *Bending Moment for Interior Girders, PLS and HEMMT Vehicles, Steel Girder*, is shown circled because it produced abnormally large values.

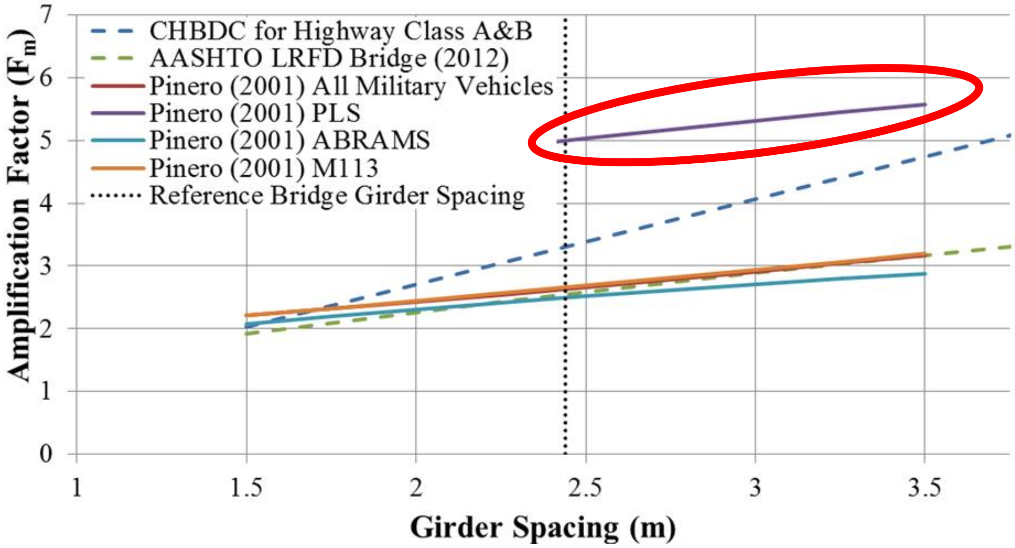


Figure 5.11 – Amplification factor versus span length: *Steel Girder Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

Table 5.8 presents a comparison between the lateral load distribution amplification factors from CSA (2006a), AASHTO (2012) and Pinero (2001) for several bridges. The formula by Pinero (2001) that was previously identified as possibly incorrect, for PLS on a steel girder bridge, is highlighted in grey. With the exception of this entry and, to a much lesser extent, both concrete T-beam bridges, CSA (2006a) is conservative when compared to Pinero (2001). Thus, military vehicles are likely in most cases less severe than civilian vehicles in terms of lateral load distribution. Given this, it is assumed that CSA (2006a) can be conservatively applied when evaluating for military vehicle loads.

Table 5.8 – Lateral load distribution factors

Bridge Classification from Pinero (2001)			All Beam Bridges (Steel Girder)	All Beam Bridges (Pre-Stressed)	Steel Girder	Concrete T-Beam (Franklin)	Concrete T-Beam (Patrick)	Pre-Stressed Concrete
Span Length (m)			36	37	36	12	15.6	37
Number of Girders			6	5	6	4	4	5
Bridge Specifications Sources			Kim, Tanovic and Wight (2010)	Morrison Hershfield Ltd. (2012)	Kim, Tanovic and Wight (2010)	Trimble, Cousins and Seda-Sanabria (2003)		Morrison Hershfield Ltd. (2012)
CSA (2006a) Highway Class A&B, (F_m)			3.30	2.71	3.30	2.10	2.34	2.71
AASHTO LRFD Bridge (2012), ($F_m = LDF \cdot N$)			2.49	2.00	2.54	2.14	2.17	2.21
Experimental Results			Avg – 1.59 Max – 1.72 (FEA)	-	Avg – 1.59 Max – 1.72 (FEA)	1.48 (measured on site)	2.52 (measured on site)	-
Pinero (2001)	All Military Vehicles	Amplification Factor	2.83	2.04	2.63	1.69	1.89	2.27
		Fraction of CSA (2006a)	0.86	0.76	0.79	0.80	0.81	0.84
		Fraction of AASHTO	1.14	1.02	1.03	0.79	0.87	1.03
	M1075 PLS	Amplification Factor	3.03	2.26	**5.00**	2.22	2.45	2.34
		Fraction of CSA (2006a)	0.92	0.84	**1.51**	1.06	1.05	0.86
		Fraction of AASHTO	1.22	1.13	**1.97**	1.04	1.13	1.06
	M113	Amplification Factor	3.00	2.24	2.66	1.78	2.12	2.35
		Fraction of CSA (2006a)	0.91	0.83	0.80	0.85	0.91	0.87
		Fraction of AASHTO	1.21	1.12	1.04	0.83	0.98	1.07
	ABRAMS M1-A1	Amplification Factor	2.78	2.08	2.49	1.63	1.81	2.30
		Fraction of CSA (2006a)	0.84	0.77	0.75	0.78	0.77	0.85
		Fraction of AASHTO	1.12	1.04	0.98	0.76	0.84	1.04

Pinero (2001) conducted harmonic analysis to determine the governing LDF on 137 beam bridges. Table 5.9 summarizes the mean LDF and corresponding CoV from his analyses for different vehicles. The track dimension is the vehicle width between center lines of wheels (or tracks). The M1075-PLS is similar to the Canadian AHSVS-PLS; and the ABRAMS M1-A1 is similar to the Canadian Leopard 2A4M tank. Consistently, the ABRAMS M1-A1 has a lower average LDF than the M1075-PLS or M113, probably because it has a markedly greater track dimension. This suggests that tanks could be considered differently from other vehicle types for live load lateral load distribution.

Table 5.9 – Statistical parameters for load distribution factors, interior girder bending (Pinero, 2001)

Bridge Type	Coefficient	Vehicle Type (Track dimension)		
		M1075-PLS (2.0 m)	M113 (2.2 m)	ABRAMS M1-A1 (2.8 m)
All Beam (137 Bridges)	Mean	0.47	0.43	0.40
	CoV	0.24	0.24	0.22
Steel Girder (66 Bridges)	Mean	0.40	0.39	0.37
	CoV	0.14	0.14	0.12
Pre-Stressed Concrete (38 Bridges)	Mean	0.50	0.47	0.43
	CoV	0.22	0.24	0.23
Concrete T-Beam (33 Bridges)	Mean	0.56	0.48	0.44
	CoV	0.26	0.18	0.16

Table 5.10 summarizes Pinero’s (2001) assessment of the accuracy of his proposed formulas in the context of his harmonic results. The bias coefficients and CoVs shown are based on the ratio of harmonic analysis result to the result obtained from his proposed formula.

Table 5.10 – Accuracy of proposed load distribution factors for interior girder bending moments (Pinero, 2001)

Bridge Type	Coefficient	Vehicle Type			
		M1075-PLS	M113	ABRAMS M1-A1	All Vehicles
All Beam	Mean	1.05	1.007	1.01	1.015
	CoV	0.159	0.069	0.098	0.119
Steel Girder	Mean	0.999	1.003	1.001	1.018
	CoV	0.078	0.042	0.059	0.066
Pre-Stressed Concrete	Mean	1.023	1.019	1.008	1.006
	CoV	0.115	0.091	0.102	0.12
Concrete T-Beam	Mean	1.021	1.015	1.073	0.997
	CoV	0.170	0.074	0.119	0.111

With the assumption of Log-Normal distribution for the ratios in Table 5.10, using the given mean and CoV, 10,000 data points were randomly generated using MS Excel. Table 5.11 shows statistical parameters computed from the reciprocals of these generated data points that are applicable to the present study.

Table 5.11 – Bias coefficient and CoV of load distribution factors from Pinero (2001)

Bridge Type	Coefficient	Vehicle Type			
		M1075-PLS	M113	ABRAMS M1-A1	All Vehicles
All Beam	Bias	0.98	1.00	1.00	1.00
	CoV	0.16	0.10	0.07	0.12
Steel Girder	Bias	1.01	1.00	1.00	0.99
	CoV	0.08	0.06	0.04	0.07
Pre-Stressed Concrete	Bias	0.99	1.00	1.00	1.01
	CoV	0.12	0.10	0.10	0.12
Concrete T-Beam	Bias	1.01	0.95	0.99	1.02
	CoV	0.17	0.12	0.07	0.11

The statistical parameters in CSA (2006b) for the "Simplified" lateral load distribution category are a bias coefficient of 0.93 and CoV of 0.12. Compared to the bias coefficient and CoV for the equations proposed by Pinero (2001), some important observations can be made. With the exception of two cases for the M1075-PLS, Pinero's CoV values in Table 5.11 do not exceed 0.12. For all but these two cases presented in

Table 5.8, Pinero's bias coefficients are never greaer than 93% of the CSA (2006a) value. Given that Pinero's harmonic analysis shows his proposed equations have a bias coefficient close to 1.00, it can be inferred that the bias coefficient for lateral load distribution for military vehicles as computed using the "Simplified Method" in CSA (2006a) will be less than 0.93, which conveniently, is the bias coefficient reported in CSA (2006b) for this lateral distribution category. Furthermore, the lateral load distribution factors derived from CSA (2006a) can be applied conservatively for military vehicular loads for the circumstances investigated.

Thus, the statistical parameters for the "Simplified Method" of lateral live load distribution from CSA (2006b) can be used conservatively for bridge evaluation involving military vehicle loads. Equations given in Pinero (2001), can also be used with less conservatism. Given the similarities in mass and track dimension of the ABRAMS M1-A1 tank (mass of 63,600 kg, track width of 0.64 m, track length of 4.58 m, center-to-center spacing of tracks of 2.85 m, (Pinero, 2001)) and Leopard 2A4M tank (mass of 61,214kg, track width of 0.64 m, track length of 4.95 m, center-to-center spacing of tracks of 2.78 m), equations proposed for the ABRAMS by Pinero (2001) are likely also appropriate for the Leopard 2A4M tank. Table 5.12 presents two empirical equations by Pinero (2001) with associated statistical parameters that are assumed for the present study to be applicable to Canadian military vehicles. The symbols for parameters and corresponding units are as defined for Equations [5.7] and [5.8].

Table 5.12 –Load distribution factor formulas for interior girder bending moments for single lane traffic on slab-on-girder bridges (Pinero, 2001)

Vehicle Type	Load Distribution Factor (Pinero, 2001)	Bias	CoV
All Military Vehicles (Wheeled or Tracked)	$0.21+\left(\frac{S}{12.24}\right)^{0.73}\left(\frac{S}{L}\right)^{0.37}\left(\frac{\frac{E_B}{E_D}I}{12Lt_s{}^3}\right)^{0.18}$	1.00	0.12
ABRAMS M1-A1 (or Leopard 2A4M)	$0.24+\left(\frac{S}{12.56}\right)^{1.58}\left(\frac{S}{L}\right)^{0.28}\left(\frac{\frac{E_B}{E_D}I}{12Lt_s{}^3}\right)^{0.15}$	1.00	0.07

5.4 Overall Live Load Effects

The nominal live load effect, L_1, is (CSA, 2006a):

[5.9] $$L_1 = A\,L(1 + \mathrm{DLA})$$

where A is the analysis coefficient (based on the lateral live load distribution), L is the nominal live load, and DLA is the dynamic load allowance factor. The mean live load effect, $\overline{L_1}$ is simply Equation [5.9] evaluated at the mean values of A, L, and DLA:

[5.10] $$\overline{L_1} = \bar{A}\,\bar{L}(1 + \overline{\mathrm{DLA}}) = \delta_L L \delta_A A(1 + \delta_{\mathrm{DLA}}\mathrm{DLA})$$

where the mean values $\bar{A}$, $\bar{L}$, and $\overline{\mathrm{DLA}}$ can be defined as the respective bias coefficients (δ_L, δ_A, and δ_{DLA}) multiplied by their respective nominal values. Dividing Equation [5.10] by Equation [5.9], the bias coefficient of the live load effect, δ_{L_1}, is:

[5.11] $$\delta_{L_1} = \delta_L \delta_A \left(\frac{1 + \delta_{\mathrm{DLA}}\mathrm{DLA}}{1 + \mathrm{DLA}}\right)$$

The CoV for the live load effect, V_{L_1}, is (Kennedy, Gagnon, & Allen, 1992):

[5.12] $$V_{L_1} = \sqrt{{V_A}^2 + {V_L}^2 + \left(\frac{\delta_{\mathrm{DLA}}\mathrm{DLA}}{1 + \mathrm{DLA}}\right)^2 {V_{\mathrm{DLA}}}^2}$$

where V_A, V_L, and V_{DLA} are the CoV for A, L, and DLA respectively.

Accounting for the dynamic load allowance and tranverse live load analysis, a sampling of the annual maximum load effects bias coefficients and CoVs for several military vehicles investigated are shown in Table 5.13 through Table 5.17, bias coefficients and CoV values for all vehicles are given in Appendix G. These statistical parameters apply to single lane traffic moment on interior girders of slab-on-girder type bridges. The statistical parameters for the static live load of military vehicles are taken from Section 5.1. Four sets of statistical parameters are considered for Dynamic Load Allowance, taken as DLA = 0.25 for all cases, with statistical parameters corresponding to the three cases in Table 5.7 (“Franklin Bridge”: δ_{DLA}= 0.40 and V_{DLA}= 0.30, “Patrick Bridge”: δ_{DLA}= 1.56 and V_{DLA}= 0.15, “Both Bridges”: δ_{DLA}= 0.96 and V_{DLA}= 0.63) and those given in CSA (2006b), δ_{DLA}= 0.60 and V_{DLA}= 0.80. Two methods to derive lateral load distribution amplification factors are considered: CSA (2006a), and Pinero (2001) for all types of slab-on-girder bridges. The statistical parameters for CSA (2006a) are for the “Simplified” lateral distribution category with, δ_A= 0.93 and V_A= 0.12 (CSA 2006b). Two equations given by Pinero (2001), given in Table 5.12 are also considered, specifically the, “All Military Vehicles” statistical parameters (δ_A= 1.00 and V_A=0.12) for the AHSVS-PLS and LAV III-ISC and the “ABRAMS M1-A1” statistical parameters (δ_A= 1.00 and V_A=0.07) for the Leopard 2A4M tank.

Table 5.13 – Load effects for AHSVS-PLS, short spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.698	0.187	0.668	0.160	0.844	0.195	0.753	0.216
	Pinero (2001)	0.751	0.187	0.718	0.160	0.907	0.195	0.809	0.216
100	CSA (2006a)	0.904	0.199	0.865	0.173	1.093	0.207	0.975	0.227
	Pinero (2001)	0.972	0.199	0.930	0.173	1.175	0.207	1.049	0.227
1,000	CSA (2006a)	1.096	0.191	1.048	0.164	1.325	0.199	1.182	0.220
	Pinero (2001)	1.179	0.191	1.127	0.164	1.424	0.199	1.271	0.220
10,000	CSA (2006a)	1.312	0.185	1.255	0.157	1.585	0.194	1.414	0.215
	Pinero (2001)	1.410	0.185	1.349	0.157	1.705	0.194	1.521	0.215
100,000	CSA (2006a)	1.530	0.179	1.463	0.150	1.849	0.188	1.650	0.209
	Pinero (2001)	1.645	0.179	1.573	0.150	1.988	0.188	1.774	0.209

Table 5.14 – Load effects for AHSVS-PLS, other spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.655	0.187	0.626	0.160	0.791	0.195	0.706	0.216
	Pinero (2001)	0.704	0.187	0.673	0.160	0.851	0.195	0.759	0.216
100	CSA (2006a)	0.882	0.176	0.844	0.147	1.066	0.185	0.951	0.207
	Pinero (2001)	0.949	0.176	0.907	0.147	1.146	0.185	1.023	0.207
1,000	CSA (2006a)	0.997	0.173	0.953	0.142	1.205	0.182	1.075	0.204
	Pinero (2001)	1.072	0.173	1.025	0.142	1.295	0.182	1.156	0.204
10,000	CSA (2006a)	1.119	0.172	1.070	0.141	1.353	0.181	1.207	0.203
	Pinero (2001)	1.203	0.172	1.151	0.141	1.454	0.181	1.298	0.203
100,000	CSA (2006a)	1.239	0.170	1.185	0.139	1.497	0.179	1.336	0.201
	Pinero (2001)	1.332	0.170	1.274	0.139	1.610	0.179	1.436	0.201

Table 5.15 – Load effects for LAV III-ISC Case (1), short spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	1.051	0.168	1.005	0.137	1.270	0.177	1.133	0.200
	Pinero (2001)	1.130	0.168	1.081	0.137	1.366	0.177	1.218	0.200
100	CSA (2006a)	1.181	0.162	1.129	0.129	1.427	0.171	1.273	0.195
	Pinero (2001)	1.270	0.162	1.214	0.129	1.535	0.171	1.369	0.195
1,000	CSA (2006a)	1.218	0.162	1.165	0.129	1.472	0.171	1.313	0.194
	Pinero (2001)	1.309	0.162	1.252	0.129	1.582	0.171	1.412	0.194
10,000	CSA (2006a)	1.247	0.162	1.193	0.128	1.508	0.171	1.345	0.194
	Pinero (2001)	1.341	0.162	1.283	0.128	1.621	0.171	1.446	0.194
100,000	CSA (2006a)	1.277	0.162	1.222	0.128	1.544	0.171	1.377	0.194
	Pinero (2001)	1.374	0.162	1.314	0.128	1.660	0.171	1.481	0.194

Table 5.16 – Load effects for LAV III-ISC Case (1), other spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.928	0.164	0.888	0.131	1.122	0.173	1.001	0.196
	Pinero (2001)	0.998	0.164	0.955	0.131	1.207	0.173	1.076	0.196
100	CSA (2006a)	0.999	0.161	0.956	0.128	1.208	0.171	1.078	0.194
	Pinero (2001)	1.075	0.161	1.028	0.128	1.299	0.171	1.159	0.194
1,000	CSA (2006a)	1.019	0.161	0.975	0.128	1.232	0.171	1.099	0.194
	Pinero (2001)	1.096	0.161	1.048	0.128	1.324	0.171	1.181	0.194
10,000	CSA (2006a)	1.036	0.161	0.991	0.128	1.252	0.171	1.117	0.194
	Pinero (2001)	1.114	0.161	1.066	0.128	1.347	0.171	1.201	0.194
100,000	CSA (2006a)	1.053	0.161	1.007	0.128	1.273	0.171	1.136	0.194
	Pinero (2001)	1.133	0.161	1.083	0.128	1.369	0.171	1.221	0.194

Table 5.17 – Load effects for Leopard 2A4M tank, short and other Spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.873	0.161	0.835	0.128	1.055	0.171	0.941	0.194
	Pinero (2001)	0.938	0.129	0.898	0.083	1.134	0.140	1.012	0.168
100	CSA (2006a)	0.889	0.161	0.850	0.128	1.074	0.170	0.959	0.194
	Pinero (2001)	0.956	0.128	0.914	0.083	1.155	0.140	1.031	0.168
1,000	CSA (2006a)	0.892	0.161	0.853	0.128	1.078	0.170	0.961	0.194
	Pinero (2001)	0.959	0.128	0.917	0.083	1.159	0.140	1.034	0.168
10,000	CSA (2006a)	0.894	0.161	0.855	0.128	1.081	0.170	0.964	0.194
	Pinero (2001)	0.961	0.128	0.920	0.083	1.162	0.140	1.037	0.168
100,000	CSA (2006a)	0.896	0.161	0.857	0.128	1.083	0.170	0.966	0.194
	Pinero (2001)	0.963	0.128	0.921	0.083	1.164	0.140	1.039	0.168

Table 5.18 compares the load effect bias coefficients derived by using different combinations of statistical parameters for lateral load distribution and DLA. The bias coefficients of different combinations is divided by the bias coefficient if statistical parameters from CSA (2006b) are used for both lateral load distribution and DLA.

Statical parameters for Patrick Bridge presents the greatest increase in live load effects bias coefficient (21% to 30% increase).

Table 5.18 – Bias coefficient of load effect using different statistical parameters as a fraction of using statistical parameters in CSA (2006b)

Lateral Load Distribution Parameteres	Dynamic Load Allowance Parameters			
	CSA (2006b)	Trimble, Cousins and Seda-Sanabria (2003)		
		Franklin Bridge	Patrick Bridge	Both Bridges
CSA (2006b)	1.00	0.96	1.21	1.08
Pinero (2001) – "All Military Vehicles"	1.08	1.03	1.30	1.16
Pinero (2001) – "ABRAMS M1-A1"	1.07	1.03	1.30	1.16

Table 5.19 compares the load effects CoV values derived by using different combinations of statistical parameters for lateral load distribution and DLA. The CoV values of different combinations is divided by the CoV values if statistical parameters from CSA (2006b) are used for both lateral load distribution and DLA. Parameters for both "Both Bridges" presents the greatest increase in CoV values (4% to 17% increase).

Table 5.19 – CoV of load effect using different statistical parameters as a fraction of using statistical parameters in CSA (2006b)

Lateral Load Distribution Parameteres	Dynamic Load Allowance Parameters			
	CSA (2006b)	Trimble, Cousins and Seda-Sanabria (2003)		
		Franklin Bridge	Patrick Bridge	Both Bridges
CSA (2006b)	1.00	0.83	1.05	1.17
Pinero (2001) – "All Military Vehicles"	1.00	0.83	1.05	1.17
Pinero (2001) – "ABRAMS M1-A1"	0.80	0.52	0.87	1.04

5.5 Chapter Conclusions

This chapter has presented statistical parameters for the load effects of military vehicles by quantifying probabilistically the static load, the static load effect, the lateral load distribution and the dynamic effects of military vehicles. It has been demonstrated that the CSA (2006a, 2006b) "Simplified Method" can be conservatively applied to determine the military vehicle lateral load distribution for slab-on-girder bridges. Pinero's approach for lateral load distribution of military vehicles may be particularly applicable for large tracked vehicles (e.g., the Leopard A4M tank) which would be conservatively analyzed using the CSA "Simplified Method".

A major gap in knowledge is the dynamic load effects caused by military vehicles. Based on the few available observations, applying CSA (2006a, 2006b) procedures to quantify the dynamic load effects of military vehicles seems unconservative for Wheeled-Transport military vehicles, but, applicable for Tracked or Fighting military vehicles.

Using the static loads presented in Section 5.1, the following criteria are suggested for the design and evaluation of bridges for each military vehicle investigated:

1. Leopard 2A4M tank (Tracked-Fighting): DLA from CSA (2006a, 2006b), lateral load distribution from Pinero (2001) *ABRAMS M1-A1*;
2. AHSVS-PLS (Wheeled-Transport): DLA from the combined statistics for both bridges investigated in Trimble, Cousins and Seda-Sanabria (2003), lateral load distribution from CSA (2006a, 2006b); and
3. LAV III-ISC (Wheeled-Fighting): DLA and lateral load distribution from CSA (2006a, 2006b).

Table 5.20 summarizes these criteria in the context of general military vehicle categories. An exception is recommend for Leopard 2A tank (Tracked-Fighting), where lateral load distribution should be calculated following Pinero (2001) equations for *M1-A1 ABRAMS*, where the bias is taken as 1.00 with a CoV of 0.07.

Table 5.20 – Summary of dynamic effects and lateral load distributions

Military Vehicle Category	Dynamic Effects (for DLA=0.25), other spans		Lateral Load Distribution CSA (2006a and 2006b)	
	Bias	CoV	Bias	CoV
Tracked -Fighting (T-F)	0.60	0.80	0.93	0.12
Tracked – Transport (T-T)	0.60	0.80	0.93	0.12
Wheeled – Fighting (W-F)	0.60	0.80	0.93	0.12
Wheeled – Transport (W-T)	0.96	0.63	0.93	0.12

Chapter 6

6 Load Factors for Military Loading

6.1 Load Factor Derivation

The application of load and resistance factors the bridge design and evaluation is expedient and desirable. In this chapter, load factors for military vehicle loads will be calibrated using resistance factors, dead loads and dead load factors, and material properties specified in CSA (2006a, 2006b). Tables 6.1 and 6.2 show dead load factors and statistical parameters for dead loads from CSA (2006a, 2006b). The statistical parameters for the live load effects due to a single lane loaded with a military vehicle are as reported in Chapter 5.

Table 6.1 – Dead load factors, α_D (CSA, 2006a)

	Target Reliability Index, β								
Dead load category	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
D_1	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11
D_2	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22
D_3	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55

Table 6.2 – Statistical parameters for dead load effects (CSA, 2006b)

Dead load type	δ_D	V_D
D_1	1.03	0.08
D_2	1.05	0.10
D_3	1.03	0.30

Live load factors were calibrated for ten different bridges including four CPCI girder bridges, two concrete T-beam bridges, two composite steel girder bridges, one steel stringer girder bridge and one pre-stressed precast box girder bridge. All bridges were designed by others to resist modern civilian traffic loadings. Details of the bridges are presented in Appendix H. Table 6.3 summarizes nominal dead load moments per girder for each bridge and resistance parameters. The resistance factors shown are computed by determining the factored resistance using the material resistance factors specified in CSA (2006a) for structural steel, reinforcing steel, pre-stressing steel and concrete. The nominal live loads per girder are shown in Table 6.4.

Table 6.3 – Dead load moment per girder and resistance parameters

No	Source	Type (# Girders)	Span (m)	D_1 (kNm)	D_2 (kNm)	D_3 (kNm)	ϕ	CSA (2006b)	
								δ_R	V_R
1	(Morrison Hershfield Ltd., 2012)	CPCI Girder (5)	37	2,362	3,015	796	0.935	1.06	0.05
2	(Trimblel, Cousins, & Seda-Sanabria, 2003) - Franklin	Concrete T-Beam (4)	12	151	187	-	0.924	1.04	0.08
3	(DND 2007a) – Section F.2.2	Steel-Stringer (5)	22	581	576	-	0.950	1.13	0.10
4	(DND 2007a) – Section F.2.3	Composite Steel Girder (4)	24.4	364	846	-	0.934	1.10	0.10
5	(DND 2007a) – Section F.2.7	Concrete T-Beam (4)	15.3	280	357	-	0.894	1.04	0.08
6	(DND 2007a) – Section F.2.9	CPCI Girder (5)	22.9	911	754	-	0.886	1.06	0.05
7	(Bartlett, 1980)	CPCI Girder (6)	20	592	983	-	0.940	1.06	0.05
8	(Bartlett, 1980)	CPCI Girder (5)	25	1,002	1,200	-	0.938	1.06	0.05
9	(Bartlett, 1980)	Composite Steel Girder (4)	35	1,150	3,098	-	0.924	1.10	0.10
10	(Genivar, 2012)	Pre-stressed Box Girder (8)	30.8	2,363	313	-	0.932	1.06	0.05

Table 6.4 – Live load moments per girder

No	Reference Bridge Source	L_1 (kNm)					
		AHSVS-PLS		LAV III-ISC		Leopard 2A4M	
		No Trailer	Trailer	Case (1) / (2)	Case (3)	Lateral Load Dist.	
			Uncorrelated / Correlated			Pinero (2001)	CSA (2006a)
1	(Morrison Hershfield Ltd., 2012)	1,663	2,566	916	1,093	2,156	2,809
2	(Trimblel, Cousins, & Seda-Sanabria, 2003) - Franklin	364	377	244	291	583	751
3	(DND 2007) – F.2.2	909	1,118	529	632	1,386	1,625
4	(DND 2007) – F.2.3	1,097	1,393	630	752	1,596	1,933
5	(DND 2007) – F.2.7	537	598	335	400	1,093	1,030
6	(DND 2007) – F.2.9	1,166	1,529	659	787	1,817	2,023
7	(Bartlett, 1980)	930	1,106	550	656	1,486	1,688
8	(Bartlett, 1980)	1,104	1,411	632	755	1,623	1,941
9	(Bartlett, 1980)	2,151	2,948	1,190	1,420	3,661	3,649
10	(Genivar, 2012)	353	472	198	236	-	606

Assuming the load effects and resistance are log-normally distributed with small coefficients of variation, load factors were calculated using the log-normal approximation for the reliability index, β, given in CSA (2011):

[6.1]

$$\beta = \frac{\ln(\bar{R}/\bar{S})}{\sqrt{{V_R}^2 + {V_S}^2}}$$

where, $\bar{R}$ and $\bar{S}$ are the mean resistance and mean load effect, respectively, and V_R and V_S are the CoVs of the resistance and load effect, respectively.

The variable $\bar{R}$ can be computed using:

[6.1a] $$\bar{R} = \bar{S} \cdot \exp\left(\beta\sqrt{{V_R}^2 + {V_S}^2}\right)$$

For calibration, it is assumed that the factored resistance exactly equals the summation of the factored load effects:

[6.2] $$\phi R = \sum \alpha_i S_i$$

where R is the nominal resistance, ϕ is the structural action resistance factor (calculated as the factored resistance divided by the specified resistance), S_i are the effects due to specified load type, and α_i are the associated load factors. The nominal resistance can be isolated as:

[6.2a] $$R = \frac{\sum \alpha_i S_i}{\phi}$$

The mean resistance, $\bar{R}$, is the product of the nominal resistance, R, and the bias coefficient, δ_R. Using Equation [6.2a] to eliminate R from Equation [6.1a]:

[6.3] $$\frac{\delta_R \sum \alpha_i S_i}{\phi} = \bar{S} \exp\left(\beta\sqrt{{V_R}^2 + {V_S}^2}\right)$$

For bridges:

[6.4] $$\sum \alpha_i S_i = \alpha_{D_1} D_1 + \alpha_{D_2} D_2 + \alpha_{D_3} D_3 + \alpha_{L_1} L_1$$

where, D_1 is the nominal dead load effect for “factory-produced components and cast-in-place concrete excluding decks” CSA (2006a), D_2 is the nominal dead load effect for “cast-in-place concrete decks, wood, field-measured bituminous surfacing, and non-structural components” CSA (2006a), and D_3 is the nominal dead load effect for “bituminous surfacing where the nominal thickness is assumed to be 90 mm for evaluation” CSA (2006a) . The nominal live load effect, L_1, is computed using Equation [5.9].

Substituting Equation [6.4] into Equation [6.3] and rearranging to isolate α_{L_1}:

[6.5]
$$\alpha_{L_1} = \frac{\frac{\phi\bar{S}}{\delta_R}\exp\left(\beta\sqrt{{V_R}^2 + {V_S}^2}\right) - (\alpha_{D_1}D_1 + \alpha_{D_2}D_2 + \alpha_{D_3}D_3)}{L_1}$$

The mean load effect, $\bar{S}$, is the summation of the nominal load effects multiplied by their respective bias coefficients:

[6.6]
$$\bar{S} = \delta_{D_1}D_1 + \delta_{D_2}D_2 + \delta_{D_3}D_3 + \delta_{L_1}L_1$$

The CoV of the load effect, V_S, is calculated by:

[6.7]
$$V_s = \frac{\sqrt{\left(V_{D_1}\delta_{D_1}D_1\right)^2 + \left(V_{D_2}\delta_{D_2}D_2\right)^2 + \left(V_{D_3}\delta_{D_3}D_3\right)^2 + \left(V_{L_1}\delta_{L_1}L_1\right)^2}}{\bar{S}}$$

where, V_{L_1}, V_{D_1}, V_{D_2}, and V_{D_3} are the coefficients of variation for load effect types L_1, D_1, D_2, and D_3 respectively.

6.2 Specific Load Factors for Canadian Military Vehicles

Live load factors are calculated for the AHSVS-PLS, LAV III-ISC and Leopard 2A4M tank. Table 6.5 presents the average load factors computed for $\beta = 3.75$, the value conventionally assumed for civilian bridge design (CSA 2006b) – all values computed for all cases are summarized in Appendix I. Although investigation of a larger bridge inventory would be desirable, live load factors computed for the bridges shown in Table 6.3 are likely indicative. The reliability index obtained when average live load factors are used may be higher or lower than the target value. Table 6.5 therefore also shows the reliability index ranges obtained using Equations [6.1] and [6.2] when the average live load factors are assumed. The ranges are typically between 3.15 and 4.65, which correspond to annual probability of failure of 8.2 x10^{-4} and 1.7 x10^{-6}, respectively. The target reliability index, 3.75, corresponds to an annual probability of failure of 8.8 x10^{-5}.

Table 6.5 – Achieved reliability indices using average load factors derived from a target index 3.75, 1,000 vehicles per year

Vehicle	Avg. Factor	Lowest Reliability		Highest Reliability	
		Bridge	β	Bridge	β
AHSVS-PLS	1.79	(DND 2007) – F.2.3	3.20	(Morrison Hershfield Ltd., 2012)	4.06
AHSVS-PLS with Uncorrelated Trailer	1.57		3.21		4.06
AHSVS-PLS with Correlated Trailer	1.89		3.21		4.02
LAV III-ISC (Case 1)	1.65	(Genivar, 2012)	3.15	(DND 2007) – F.2.9	4.75
LAV III-ISC (Case 2)	1.85	(Bartlett, 1980) - # 9	3.12		4.65
LAV III-ISC (Case 3)	1.55		3.13		4.65
Leopard 2A4M	1.36		3.21		4.46

6.2.1 AHSVS-PLS (Transport)

Tables 6.6, 6.7, and 6.8 present the average live load factors for the ten bridges, AHSVS-PLS with no trailer, with a trailer with uncorrelated container weights, and with a trailer with fully correlated container weights, respectively. Live load factors are more severe for short spans due to the greater variability in static load, they are similar between all three configurations since the load action from the second tandem axle governs the majority of extreme load cases on short spans. For other spans at traffic volumes equal to or greater than 1,000 vehicles per year, the AHSVS-PLS and trailer with fully correlated container weights has the greatest live load factor, while a trailer with uncorrelated container weights as the least. This reflects the higher CoV in static load effects for the AHSVS-PLS and trailer with fully correlated container weights. At lower traffic volumes, the AHSVS-PLS with no trailer has the greatest live load factor because of the greater bias coefficient for the event vehicle for this configuration, with a smaller payload weight fraction compared to the configuration. At traffic volumes between 1,000 and 10,000 vehicles per year, the AHSVS-PLS has live load factors similar to that in CSA (2006a) for non-permit traffic, which for $\beta = 3.75$, the live load factors are 2.30 for short spans and 1.70 for other spans.

Table 6.6 – Avg. load factors for bending moments, AHSVS-PLS

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.94	0.99	1.04	1.10	1.15	1.21	1.27	1.33	1.39
100	1.25	1.32	1.39	1.46	1.54	1.62	1.70	1.79	1.88
1000	1.51	1.59	1.68	1.76	1.85	1.95	2.05	2.15	2.26
10000	1.81	1.90	2.00	2.11	2.21	2.33	2.45	2.57	2.70
100000	2.11	2.21	2.33	2.45	2.57	2.70	2.84	2.98	3.13
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.86	0.91	0.95	1.00	1.05	1.10	1.16	1.21	1.27
100	1.15	1.21	1.26	1.33	1.39	1.45	1.52	1.59	1.67
1000	1.30	1.36	1.43	1.49	1.56	1.63	1.71	1.79	1.87
10000	1.46	1.53	1.60	1.68	1.75	1.84	1.92	2.01	2.10
100000	1.62	1.69	1.77	1.86	1.94	2.03	2.12	2.22	2.32

Table 6.7 – Avg. load factors for bending moment, AHSVS-PLS and trailer, uncorrelated container weight

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.96	1.01	1.06	1.12	1.17	1.23	1.29	1.35
100	1.26	1.33	1.40	1.48	1.55	1.64	1.72	1.81	1.90
1000	1.52	1.60	1.68	1.77	1.86	1.95	2.05	2.16	2.26
10000	1.80	1.89	1.99	2.09	2.19	2.31	2.42	2.54	2.67
100000	2.07	2.18	2.29	2.41	2.53	2.66	2.79	2.93	3.07
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.78	0.82	0.86	0.91	0.95	1.00	1.04	1.09	1.15
100	1.03	1.08	1.13	1.18	1.23	1.29	1.35	1.41	1.48
1000	1.14	1.20	1.25	1.31	1.37	1.43	1.50	1.57	1.64
10000	1.26	1.31	1.37	1.44	1.50	1.57	1.64	1.72	1.80
100000	1.37	1.43	1.50	1.57	1.64	1.72	1.79	1.88	1.96

Table 6.8 – Avg. load factors for bending moment, AHSVS-PLS and trailer, fully correlated container weight

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.93	0.98	1.03	1.09	1.15	1.21	1.27	1.34	1.40
100	1.25	1.32	1.39	1.46	1.54	1.62	1.70	1.79	1.88
1000	1.52	1.60	1.68	1.77	1.86	1.96	2.06	2.16	2.27
10000	1.79	1.89	1.98	2.09	2.19	2.30	2.42	2.54	2.67
100000	2.06	2.17	2.28	2.40	2.52	2.65	2.78	2.92	3.06
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.80	0.84	0.89	0.93	0.98	1.03	1.08	1.14	1.19
100	1.19	1.25	1.31	1.37	1.44	1.51	1.58	1.65	1.73
1000	1.37	1.44	1.51	1.58	1.65	1.73	1.81	1.89	1.98
10000	1.60	1.67	1.75	1.84	1.92	2.01	2.11	2.20	2.31
100000	1.81	1.89	1.98	2.07	2.17	2.27	2.38	2.49	2.60

6.2.2 LAV III-ISC (Armoured Personnel Carrier)

Tables 6.9, 6.10, and 6.11 present the average live load factors for the ten bridges for the LAV III- ISC, Cases (1), (2), and (3), respectively. The LAV III-ISC live load factors are less sensitive to traffic volumes for other spans, due to the relatively low CoV in static load effect for this vehicle. Case (2) has the greatest live load factors due to the higher bias coefficient (because the nominal vehicle weight does not account for the larger weight of the vehicle after the upgrade program). Coincidently, Cases (1) and (3) have very similar live load factors, where Case (1) has a larger bias coefficient (which contributes to a larger live load factor) and lower CoV (which contributes to a lower live load factor) than Case (3). Conveniently, this implies that load factors might not need to change if a vehicle fleet is undergoing a major upgrade that changes its GVW; as long as these end changes in GVW are reflected in data for the vehicle (or in an updated Military Load Classification). At a traffic volume of 1,000 vehicles per year, Cases (1) and (3) of the LAV III-ISC have live load factors similar to that given in CSA (2006a) for Permit – Annual (PA) traffic "Simplified", which for $\beta = 3.75$, the live load factors are 1.87 for short spans and 1.60 for other spans).

Table 6.9 – Avg. load factors for bending moment, LAV III-ISC (Case 1)

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.23	1.29	1.35	1.40	1.47	1.53	1.60	1.66	1.74
100	1.38	1.44	1.50	1.56	1.63	1.70	1.77	1.85	1.92
1000	1.42	1.48	1.55	1.61	1.68	1.75	1.83	1.90	1.98
10000	1.46	1.52	1.58	1.65	1.72	1.79	1.87	1.95	2.03
100000	1.49	1.56	1.62	1.69	1.76	1.84	1.92	2.00	2.08
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.09	1.15	1.20	1.26	1.32	1.39	1.46	1.53	1.60
100	1.17	1.23	1.28	1.35	1.41	1.48	1.55	1.62	1.69
1000	1.19	1.25	1.31	1.37	1.43	1.50	1.57	1.65	1.72
10000	1.21	1.27	1.33	1.39	1.46	1.52	1.59	1.67	1.75
100000	1.23	1.29	1.35	1.41	1.48	1.55	1.62	1.69	1.77

Table 6.10 – Avg. load factors for bending moment, LAV III-ISC (Case 2)

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.24	1.30	1.36	1.42	1.48	1.55	1.62	1.69	1.76
100	1.46	1.52	1.59	1.66	1.73	1.80	1.88	1.96	2.04
1000	1.53	1.60	1.67	1.74	1.82	1.89	1.97	2.06	2.14
10000	1.61	1.68	1.75	1.83	1.91	1.99	2.07	2.16	2.25
100000	1.69	1.76	1.84	1.92	2.00	2.08	2.17	2.26	2.36
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.10	1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.62
100	1.29	1.35	1.42	1.48	1.55	1.62	1.70	1.77	1.86
1000	1.36	1.42	1.48	1.55	1.62	1.70	1.77	1.85	1.94
10000	1.42	1.48	1.55	1.62	1.69	1.77	1.85	1.93	2.02
100000	1.48	1.54	1.61	1.69	1.76	1.84	1.92	2.01	2.10

Table 6.11 – Avg. load factors for bending moment, LAV III-ISC (Case 3)

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.10	1.15	1.21	1.26	1.32	1.37	1.43	1.50
100	1.24	1.29	1.35	1.41	1.47	1.53	1.59	1.66	1.73
1000	1.30	1.36	1.42	1.48	1.54	1.61	1.68	1.75	1.82
10000	1.36	1.42	1.48	1.54	1.61	1.68	1.75	1.82	1.90
100000	1.42	1.48	1.54	1.61	1.68	1.75	1.82	1.90	1.98
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.92	0.97	1.02	1.07	1.12	1.18	1.24	1.30	1.36
100	1.08	1.13	1.19	1.24	1.30	1.36	1.42	1.49	1.55
1000	1.14	1.19	1.24	1.30	1.36	1.42	1.49	1.55	1.62
10000	1.18	1.24	1.30	1.35	1.42	1.48	1.55	1.61	1.69
100000	1.23	1.29	1.35	1.41	1.47	1.54	1.61	1.68	1.75

6.2.3 Leopard 2A4M Tank

Conveniently, load factors for the Leopard 2A4M are essentially independent of annual traffic volume because the coefficient of variation of the event vehicle load effects is so small. Furthermore, the lateral load distribution and associated statistical parameters presented by Pinero (2001) and CSA (2006a, 2006b) yield a negligible difference between the calculated live load factors. As such, for each target reliability, β, there is a single a corresponding live load factor for the Leopard 2A4M tank for both approaches regarding lateral load, as shown in Table 6.12. The Leopard 2A4M has live load factors similar to that given in CSA (2006a) for Permit – Bulk Haul (PB) traffic "Simplified", which for $\beta = 3.75$, the live load factor is 1.36 for other spans.

Table 6.12 – Avg. load factors for bending moment, Leopard 2A4M tank

All Spans									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
All Traffic Volumes	1.08	1.12	1.16	1.20	1.24	1.29	1.34	1.38	1.44

6.3 Partial Load Factors

Given the need under NATO (2006) for the Military Load Classification System to be interoperable between member nations, the calibration of live load factors for military traffic is complicated because the resistances may be computed differently. It may be necessary to derive partial load factors for military bridge evaluation and design using:

$$\alpha_{L_1} = \delta_{L_1} e^{(\beta \alpha^* \mathrm{V}_{L_1})} \tag{6.8}$$

where α_{L_1} is the partial live load factor, α^* is a separation factor is 0.70 (European Committee for Standardization, 2010), β is the annual target reliability index and δ_{L_1} and V_{L_1} are the same as defined in Section 5.4. Although this equation is at best an approximate method to compute load factors (Bartlett, 2008), it has been historically been widely used for live load factor calculation.

Table 6.13 shows the partial load factors for the annual maximum load effects bias coefficient and CoV for a traffic volument of 1,000 vehicles per year, by accounting for the dynamic load allowance and tranverse live load analysis. These partial load factors are compared to the average load factors given in Section 6.2. The partial load factors for all cases of the AHSVS-PLS, LAV III-ISC, and Leopard 2A4M tank are given in Appendix J. There is close agreement between the average live load factors and partial load factors, being slightly conservative compared to the average live load factors for the AHSVS-PLS configurations, with higher CoV, and slightly unconservative for the other vehicles, with a lower CoV. Table 6.14 shows, given a target reliability $\beta = 3.75$, the achieved reliabilities of the partial load factors, for the ten bridges given in Table 6.3. Overall, the range of reliability using partial load factors appears to be adequate for use in lieu of better information or if expediency is required.

Table 6.13 – Average load factors compared to partial load factors for a traffic volume 1,000 vehicles per year

Vehicle			*β* =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
AHSVS-PLS	No Trailer		Avg. Eq [6.5]	1.30	1.36	1.43	1.49	1.56	1.63	1.71	1.79	1.87
			Eq [6.8]	1.43	1.48	1.54	1.59	1.65	1.71	1.77	1.84	1.90
	Trailer	No Correlation	Avg. Eq [6.5]	1.14	1.20	1.25	1.31	1.37	1.43	1.50	1.57	1.64
			Eq. [6.8]	1.25	1.30	1.34	1.39	1.44	1.49	1.55	1.60	1.66
		Fully Correlated	Avg. Eq [6.5]	1.37	1.44	1.51	1.58	1.65	1.73	1.81	1.89	1.98
			Eq [6.8]	1.50	1.55	1.61	1.67	1.73	1.80	1.86	1.93	2.00
LAV III-ISC	Case (1)		Avg. Eq [6.5]	1.19	1.25	1.31	1.37	1.43	1.50	1.57	1.65	1.72
			Eq [6.8]	1.28	1.31	1.35	1.39	1.43	1.47	1.51	1.56	1.60
	Case (2)		Avg. Eq [6.5]	1.36	1.42	1.48	1.55	1.62	1.70	1.77	1.85	1.94
			Eq [6.8]	1.47	1.51	1.55	1.60	1.64	1.69	1.74	1.79	1.84
	Case (3)		Avg. Eq [6.5]	1.14	1.19	1.24	1.30	1.36	1.42	1.49	1.55	1.62
			Eq [6.8]	1.23	1.26	1.30	1.34	1.37	1.41	1.46	1.50	1.54
Leopard 2A4M tank			Avg. Eq [6.5]	1.08	1.12	1.16	1.20	1.24	1.29	1.34	1.38	1.44
			Eq [6.8]	1.15	1.17	1.20	1.23	1.25	1.28	1.31	1.34	1.37

Table 6.14 – Reliability achieved using partial load factors

No	Bridge	Traffic Rate of 1,000 Vehicles/year, Target $\beta = 3.75$, $\alpha^* = 0.70$						
		AHSVS-PLS	AHSVS-PLS and Trailer		LAV III-ISC			Leopard 2A4M
			Uncorrelated	Correlated	(1)	(2)	(3)	
1	(Morrison Hershfield Ltd., 2012)	4.15	4.13	4.10	3.82	3.88	3.88	4.02
2	(Trimblel, Cousins, & Seda-Sanabria, 2003) - Franklin	3.46	3.46	3.47	3.49	3.49	3.50	3.42
3	(DND 2007) – F.2.2	3.36	3.34	3.35	3.15	3.19	3.19	3.17
4	(DND 2007) – F.2.3	3.31	3.28	3.29	3.12	3.15	3.15	3.12
5	(DND 2007) – F.2.7	3.49	3.48	3.48	3.44	3.46	3.46	3.39
6	(DND 2007) – F.2.9	4.26	4.18	4.08	4.52	4.50	4.51	4.36
7	(Bartlett, 1980)	3.80	3.77	3.72	3.78	3.79	3.80	3.79
8	(Bartlett, 1980)	3.86	3.82	3.77	3.76	3.80	3.80	3.84
9	(Bartlett, 1980)	3.34	3.34	3.38	2.99	3.04	3.05	3.15
10	(Genivar, 2012)	3.55	3.59	3.67	3.04	3.12	3.12	3.50

6.4 Generalized Load Factors for Military Vehicles

6.4.1 Proposed Military Load Classification System Vehicle Categories

As shown in Chapters 4 and 5, military transport vehicles cause inherently different load effects than fighting vehicles. As such, it is reasonable to derive different load factors for bridge design and evaluation for these two vehicle categories. At present, NATO (2006) specifies two vehicle types: Wheeled (W); and Tracked (T). It is recommended, so that fighting vehicles are not overly penalized in bridge evaluation, to differentiate in future editions of NATO (2006) four vehicle load types: Wheeled-Transport (W-T), Wheeled-Fighting (W-F), Tracked-Transport (T-T), and Tracked-Fighting (T-F). This allows the further benefit of adjusting the target reliability index (or risk) for a particular vehicle category.

The classification of a vehicle as fighting and transport would requires further investigation, including review of NATO's full military vehicle inventory. However, Table 6.15 categorizes vehicles used by the Canadian Forces based on their intended function, as: Transport (Tpt.), Armoured Personnel Carrier (APC) or Tank. These three functions also correspond to the three vehicles investigated in Chapters 4 and 5; AHSVS-PLS (Transport), LAV III-ISC (APC), and Leopard 2A4M (Tank). The ranges of payload weight fractions, for these vehicles are 2-13% for tanks, 7-21% for APCs and 38-60% for transport vehicles. The payload weight fractions for transport vehicles are clearly distinct from those for the other two categories. It might therefore be appropriate to define Fighting vehicles (such as Tanks or APCs) as those with payload weight fractions less than 25% and Transport vehicles as those with payload weight fractions greater than 35%. Vehicles with payload weight fractions between 25% and 35%, such as an APC with a trailer attached, require additional investigation to be classified as Transport or Fighting.

Table 6.15 – Payload “weight” fraction for Canadian Forces vehicles

Vehicle Name (source)	Type	Mass (kg)			Payload Weight Fraction
		Payload	Curb	Total	
Leopard 1 ARV – Uparmoured (DND, 2006a)	Tank	760	44,286	45,046	0.02
Leopard 1ARV (DND, 2006a)	Tank	780	39,800	40,580	0.02
Badger AEV (Leo C2 Variant) – Uparmoured (DND, 2006b)	Tank	1,244	46,222	47,466	0.03
Badger AEV (Leo C2 Variant) (DND, 2006b)	Tank	1,244	41,756	43,000	0.03
Leopard 2A4M – Uparmoured (Leopard Requirements Officer, 2013)	Tank	2,030	59,184	61,214	0.03
Leopard 2A6M (Leopard Requirements Officer, 2013)	Tank	1,728	58,673	62,342	0.03
Leopard 2A6M – Uparmoured (Leopard Requirements Officer, 2013)	Tank	1,728	61,500	63,228	0.03
Leopard C2 MBT –uparmoured (DND, 2006c)	Tank	2,600	48,013	50,613	0.05
Leopard C2 MBT (DND, 2006c)	Tank	2,600	40,400	43,000	0.06
Leopard 2 ARV (Leopard Requirements Officer, 2013)	Tank	7,900	57,000	64,900	0.12
Coyote (DND, 2010a)	APC	811	12,569	13,380	0.06
Bison (Ambulance) – Uparmoured (DND, 2010b)	APC	950	12,948	13,989	0.07
M113-A3 (TLAV) – Uparmoured (DND, 2011b)	APC	1,299	15,463	16,762	0.08
Bison (Ambulance) (DND, 2010b)	APC	950	11,500	12,450	0.08
Bison (EW) (DND, 1997)	APC	1,859	11,050	12,909	0.14
LAV LORIT (WLAV Chassis Management Team Leader, 2014)	APC	3,260	20,630	23,890	0.14
LAV III-ISC – Uparmoured	APC	3,260	16,740	20,000	0.16
LAV III-ISC (DND, 2011c)	APC	3,260	13,702	16,958	0.19
LAV III-Engr w Blade (DND, 2011c)	APC	4,105	15,351	19,456	0.21
Heavy Logistics Vehicle Wheeled – Uparmoured (DND, 2006d)	Tpt.	9,000	14,648	23,648	0.38
Heavy Logistics Vehicle Wheeled (DND, 2006d)	Tpt.	9,600	13,076	22,676	0.41
AHSVS-PLS (DND, 2011d)	Tpt.	16,100	22,900	39,000	0.41
Heavy Equipment Support Vehicle (Military Today, n.d.)	Tpt.	15,000	15,360	30,360	0.49
AHSVS-PLS with Trailer (DND, 1999 and 2011d)	Tpt.	31,920	28,080	60,000	0.53
AHSVS-24t Tractor with 72 Tonne Trailer (DND, 2011e)	Tpt.	76,300	50,700	127,000	0.60

6.4.2 Statistical Load Parameters for Other Unsurveyed Vehicle Populations

Statistical loads parameters have been derived for three specific vehicles in use by the Canadian Forces. These load parameters, or their associated load factors, may be applicable to similar military vehicles of interest. However, in lieu of better information, vehicle specific statistical load parameters might be estimated using the payload weight fraction relationship presented in Section 4.2. Following the methodology presented in Chapters 4, 5 and 6, vehicle load effects and associated load factors can be derived. For longer spans, the statistical parameters for the vehicle load are approximately the same as those for the vehicle weight (Kennedy, Gagnon, & Allen, 1992). For preliminary evaluation, partial load factors, as described in Section 6.3 could be derived. Table 6.16 presents typical statistical load parameter functions for transport, armoured personnel carrier and tanks. Partial load factors for those vehicles can be computed using the method illustrated by the example in Appendix K.

Table 6.16 – Military vehicle payload bias coefficient and CoV

Annual Maximum $n =$ # of vehicles	$n = 1$		$n = 100$		$n = 1{,}000$		$n = 10{,}000$		$n = 100{,}000$	
Vehicle Description	δ_p	V_p	δ_p	V_p	δ_p	V_p	δ_p	V_p	δ_p	V_p
Military Transport	0.428	0.415	1.070	0.168	1.392	0.129	1.712	0.104	2.034	0.087
Armoured Personnel Carrier (APC)	1.503	0.132	2.043	0.046	2.209	0.037	2.350	0.032	2.472	0.028
Tank	1.633	0.151	2.176	0.029	2.266	0.014	2.327	0.014	2.387	0.013

6.4.3 Load Factors by Military Vehicle Category

For evaluation, unless traffic volumes can be anticipated, 1,000 to 10,000 vehicles per year are suggested for bridges on a Main Supply Route (MSR) and 100 and 1,000 vehicles per year for all other bridges. For design, a traffic volume of 1,000 vehicles per year is a suggested minimum, even if lower traffic volumes are anticipated.

Figure 6.1 shows the partial load factors calculated for each vehicle listed in Table 6.15. Payload weight fractions for each classification were then used to compute vehicle static load bias coefficients and CoVs using Equations [4.20] and [4.22] respectively. Statistical parameters for dynamic load effect and lateral load distribution are determined based on the vehicle category as specified in Table 5.20. The partial load factors shown were calculated using Equation [6.8], for traffic volumes of 1,000 veh/year with a target reliability index of $\beta = 3.75$.

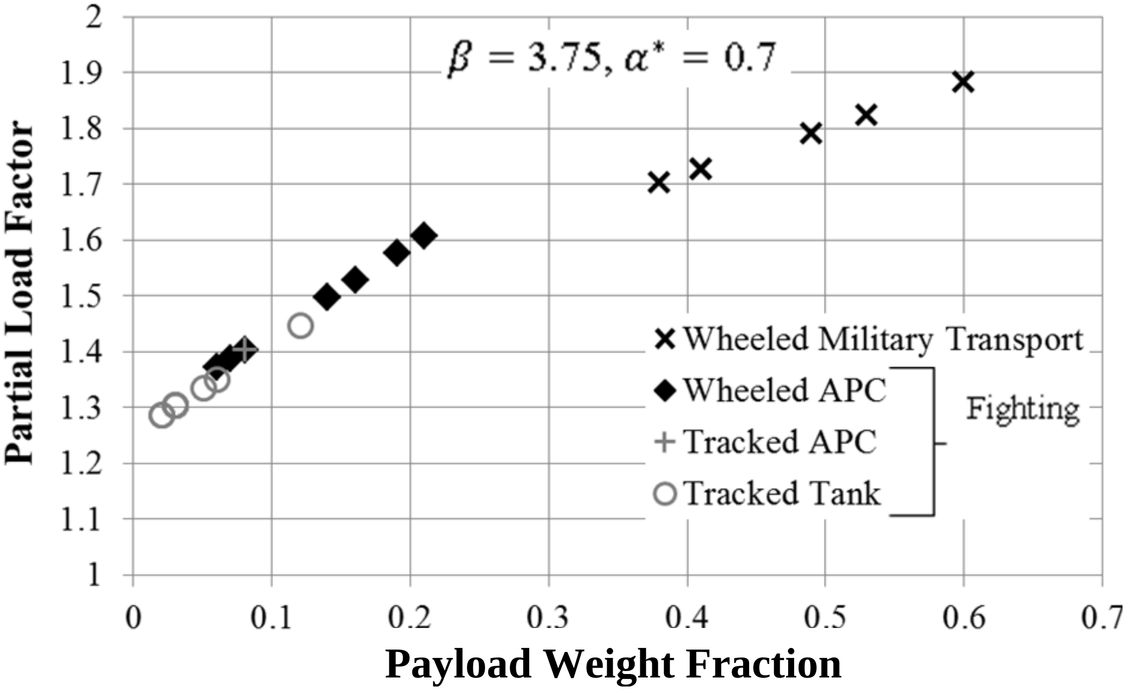


Figure 6.1 – Partial load factors computed using separation factors for vehicles from Table 6.15 ($n = 1{,}000$ Veh/yr)

Figure 6.1 indicates that the partial load factors for Fighting Vehicles (Wheeled APC, Tracked APC and Tanks) closely align. Given this, it is possible to simplify Figure 6.1 by assigning a trendline for all fighting vehicles and a second trendline for all military transport vehicles, as shown in Figure 6.2. This simplified approach could be used to assign partial load factors based on the payload weight fraction, γ. Table 6.17 summarizes the load factors computed for the average values of γ shown in Table 6.15.

These load factors may be applicable each category of military vehicle used by the Canadian Forces. No data are available for military Tracked-Transport Vehicles, so it has been assumed that their statistical load parameters are similar to those for Wheeled-Transport Vehicles.

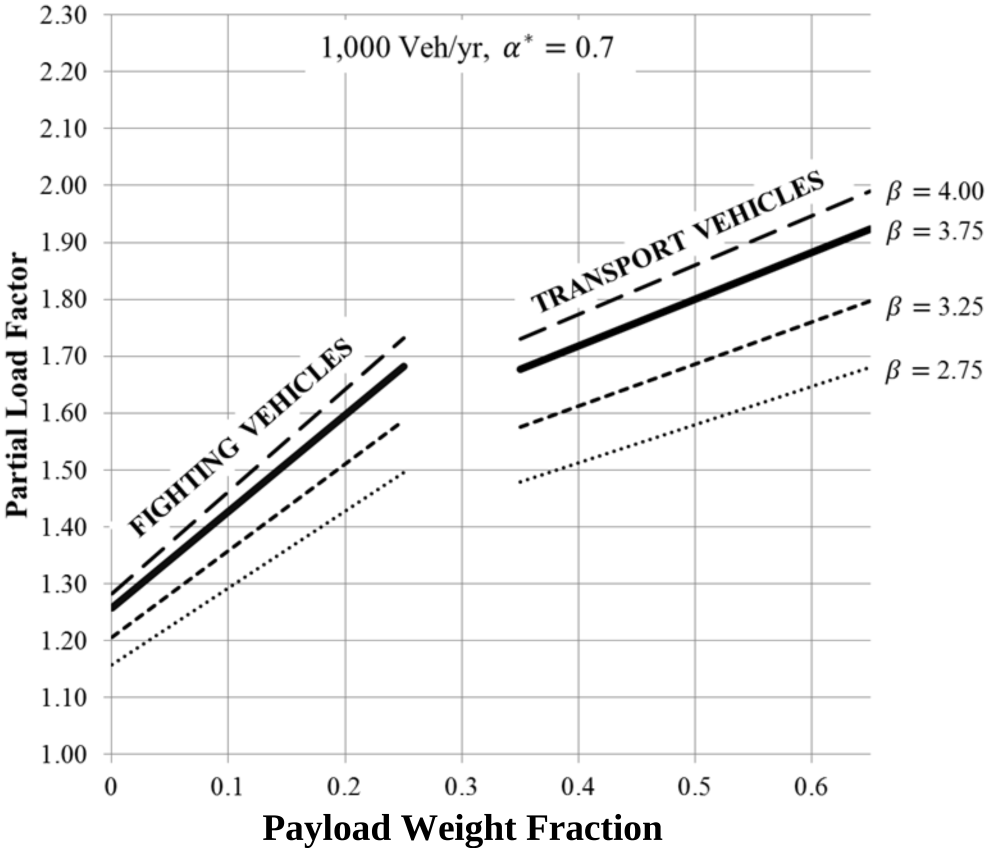


Figure 6.2 – Partial load factor (1,000 Veh/yr), based on payload weight fraction

Table 6.17 – Partial load factors for different military vehicle categories, $\beta = 3.75$

Military Vehicle Category	Avg. γ	Load Factor		Applicable Spans
		100 veh/yr	1,000 veh/yr	
Wheeled – Fighting (W-F)	0.131	1.46	1.48	> 15 m
Tracked -Fighting (T-F)	0.045	1.33	1.33	All Spans
Wheeled – Transport (W-T)	0.470	1.57	1.77	> 20 m
Tracked – Transport (T-T)	No Data: Use W-T load factor	1.57	1.77	All Spans

Figure 6.3 shows partial load factors at different traffic volumes for a given reliability index, $\beta = 3.75$. Load factors for all combinations of traffic volume (Event, 100 veh/yr, 1,000 veh/yr, and 10,000 veh/yr) and reliability indices ($\beta = 2.75$, 3.25, 3.75, and 4.00) are presented in Appendix L.

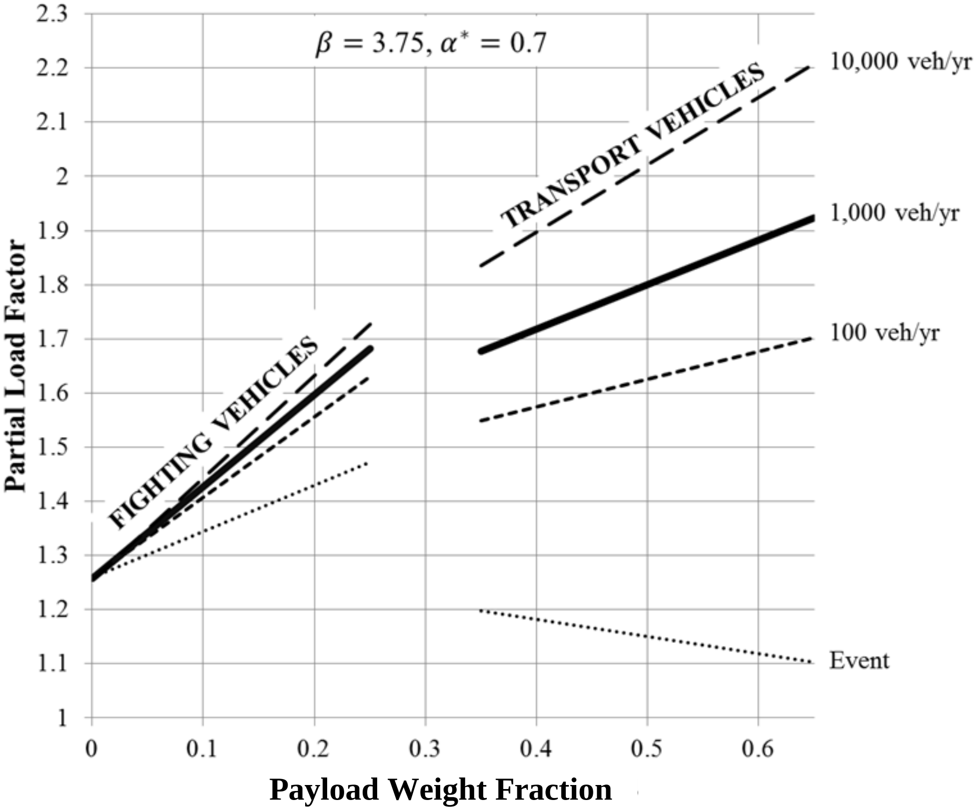


Figure 6.3 – Impact of annual traffic volume on partial load factor

6.5 Discussion

The derivation of general load factors for military vehicles has assumed the curb weight to be deterministic. Specifically for APCs, implies using LAV III-ISC (Case 1) data to define the statistical parameters of the payload. As previously discussed, there is a non-negligible variability in the curb weight of the LAV III-ISC that can be attributed to a vehicle upgrade program. The specified weights in the Canadian Forces Fleet Management System (FMS), accessed 20 Nov 2012, for the LAV III-ISC are those prior to upgrade. The upgrade increases both the greater curb weight and total vehicle weight, so the application of load factors to these nominal weights for the vehicles that have subsequently been upgraded would be unconservative. Based on the flown vehicle weight data from Afghanistan, this inaccurate specification of the actual vehicle condition seems to be the exception, not the rule. Should inaccuracies like those found for the LAV III-ISC be more common, it is more appropriate to use load factors derived for LAV III-ISC (Case 2) with the erroneous weights in the FMS database that do not reflect the effects of the vehicle upgrades.

Based on available information regarding military vehicles in use by the Canadian Forces, the following partial load factors for interior girders in bending are suggested for each Military Vehicle Category as described in Section 6.4.1. Tables 6.18, 6.19, 6.20 and 6.21 show recommended partial load factors for Wheeled-Transport, Wheeled-Fighting, Tracked-Transport, and Tracked-Fighting vehicles, respectively, in use by the Canadian Forces. These factors are specifically derived for interior girders subjected to bending and may be more broadly applicable. Thus, Wheeled-Transport and Tracked-Transport vehicles have relatively high load factors when compared to Wheeled-Fighting and Tracked-Fighting vehicles. For short spans, pending further investigation, it is suggested specific load factors for the three vehicles investigated in detail (AHSVS-PLS, LAV III-ISC, and Leopard 2A4M) are used.

Table 6.18 – Load factors for military Wheeled-Transport (W-T) vehicles

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.94	0.99	1.04	1.10	1.15	1.21	1.27	1.33	1.39
100	1.25	1.32	1.39	1.46	1.54	1.62	1.70	1.79	1.88
1000	1.51	1.59	1.68	1.76	1.85	1.95	2.05	2.15	2.26
10000	1.81	1.90	2.00	2.11	2.21	2.33	2.45	2.57	2.70
100000	2.11	2.21	2.33	2.45	2.57	2.70	2.84	2.98	3.13
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.90	0.94	0.97	1.01	1.04	1.08	1.12	1.16	1.20
100	1.24	1.29	1.33	1.38	1.42	1.47	1.52	1.57	1.62
1000	1.42	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.83
10000	1.59	1.64	1.69	1.75	1.81	1.86	1.92	1.99	2.05
100000	1.76	1.82	1.88	1.94	2.00	2.06	2.13	2.20	2.27

Table 6.19 – Load factors for military Wheeled-Fighting (W-F) vehicles

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.23	1.29	1.35	1.40	1.47	1.53	1.60	1.66	1.74
100	1.38	1.44	1.50	1.56	1.63	1.70	1.77	1.85	1.92
1000	1.42	1.48	1.55	1.61	1.68	1.75	1.83	1.90	1.98
10000	1.46	1.52	1.58	1.65	1.72	1.79	1.87	1.95	2.03
100000	1.49	1.56	1.62	1.69	1.76	1.84	1.92	2.00	2.08
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.14	1.17	1.20	1.23	1.26	1.30	1.33	1.37	1.42
100	1.21	1.24	1.28	1.31	1.34	1.38	1.42	1.46	1.50
1000	1.23	1.27	1.30	1.33	1.37	1.41	1.44	1.48	1.53
10000	1.25	1.29	1.32	1.35	1.39	1.43	1.47	1.51	1.55
100000	1.27	1.30	1.34	1.37	1.41	1.45	1.49	1.53	1.57

Table 6.20 – Load factors for military Tracked-Transport (T-T) vehicles

All Spans									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.90	0.94	0.97	1.01	1.04	1.08	1.12	1.16	1.20
100	1.24	1.29	1.33	1.38	1.42	1.47	1.52	1.57	1.62
1000	1.42	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.83
10000	1.59	1.64	1.69	1.75	1.81	1.86	1.92	1.99	2.05
100000	1.76	1.82	1.88	1.94	2.00	2.06	2.13	2.20	2.27

Table 6.21 – Load factors for military Tracked-Fighting (T-F) vehicles

All Spans									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
All Traffic Volumes	1.15	1.17	1.20	1.22	1.25	1.24	1.30	1.33	1.36

6.6 Chapter Conclusions

Live load factors computed for the AHSVS-PLS, LAV III-ISC, and Leopard 2A4M tank were derived using the statistical parameters for dead load and resistance given in CSA (2006a, 2006b) for ten representative bridges. The computed load factors are for interior girders resisting bending in simply supported, slab-on-girder type bridges. Using the average load factor to evaluate for a reliability index of 3.75, the ten representative bridges resulted in reliability indices between 3.12 and 4.71.

Partial load factors were presented for general use. Using partial load factors derived on the basis of payload weight fraction, it was possible to quantify partial load factors for other military vehicles. Using these values, Military Fighting Vehicles and Military Transport Vehicles were found to represent different loading categories. Given this, four vehicle categories, rather than two, should be considered under STANAG 2021, (NATO, 2006): Wheeled-Fighting (W-F); Wheeled-Transport (W-T); Tracked-Fighting (T-F); and Tracked-Transport (T-T). This would reflect the difference in the payload weight fraction for Fighting vehicles (0.02 – 0.25) and Transport vehicles (0.35-0.60), and the consequential difference in partial live load factors for bridge evaluation.

Chapter 7

7 Bridge Evaluation and Design Using Military Load Classification System

7.1 Military Load Classification using Load and Resistance Factor Design

Combining CSA (2006a) and NATO (2006), a Military Load Classification (MLC) can be developed based on Limit States Design. Using results from previous chapters, it is possible to designate a moment classification in terms of an MLC for single lane traffic on simply supported slab-on-girder bridges (e.g., “Type C” bridges (CSA, 2006a)).

First, the factored live load capacity per girder must be determined. This is simply the difference between the factored resistance and the factored dead load moments divided by the live load factors:

[7.1] $$M_g = \frac{M_r - M_{D_f}}{\alpha_{L_1}(1 + \text{DLA})}$$

where M_g is the factored live load capacity per girder, M_r is the factored moment resistance, M_{D_f} is the factored dead load moment, α_{L_1} is the live load factor for the Military Vehicle Category of interest, and DLA is the dynamic load allowance (taken as 0.25 for the load factors presented in this document).

The factored live load capacity per girder must next be converted to a lane load capacity as follows:

[7.2] $$M_T = M_g \frac{N}{F_m \cdot n \cdot R_L}$$

where M_T is the maximum moment per design lane, N is the number of girders, F_m is the lateral load distribution amplification factor (CSA, 2006a), n is the number of design lanes, and R_L is the modification factor for multi-lane loading (CSA, 2006a). Since single lane traffic is being investigated, n and R_L are both equal to 1. Tables given in NATO (2006) are used to designate the MLC of a bridge. Unit bending moments are used, i.e., M_T is divided by the length of the bridge. An example of unit bending moment tables for wheeled vehicles is shown in Figure 1.3. The bridge MLC corresponds to where the unit bending moment of M_T falls with respect to the predefined MLC lines.

Table 7.1 shows the MLC designations, based on bending moments, computed using Limit States Design (LSD) and Allowable Stress Design (ASD) for three bridges from DND (2007a). The MLC bridge designations for Transport vehicles computed using LSD based methods are markedly smaller than those for Fighting vehicles computed using LSD. There is no such distinction in ASD-Based methods. This clearly articulates the benefit in differentiating between Fighting and Transport vehicles for bridge evaluation.

Table 7.1 – MLC designation for moment classification comparison ASD and LSD

Type	Span (m)	ASD - DND (2007a)		LSD - following Section 7.1			
				Tracked		Wheeled	
		Tracked	Wheeled	Fighting	Transport	Fighting	Transport
Steel-Stringer (5)	22	60	63	71	52	67	55
Composite Steel Girder (4)	24.4	82	87	117	86	114	92
CPCI Girder (5)	22.9	150	150	150	124	150	145

7.2 Case-Specific Evaluation

In certain circumstances it may be required to evaluate the capacity of a bridge for a particular vehicle rather than to designate an MLC. This would most likely occur when the bridge MLC is too low for a particular mission-essential vehicle and a less generic evaluation might reach a more favourable conclusion.

7.2.1 Vehicle-Specific Live Load Factors

The procedure given in Section 7.1 can be used to compute vehicle-specific live load factors. Vehicle-specific live load factors were previously presented in Section 6.2.1 for the AHSVS-PLS, Section 6.2.2 for the LAV III-ISC and Section 6.2.3 for the Leopard 2A4M tank. Otherwise, vehicle specific load factors can be computed from the payload weight fraction using Figures 6.2 and 6.3, or following the procedure outlined in Appendix K.

7.2.2 Mean Load Method

The Mean Load Method calculates the approximate reliability index, β, using Equation [6.1]. Should this value be satisfactory, the vehicle would be permitted to use the bridge. The method requires calculation of the mean load and resistance ($\bar{R}$ and $\bar{S}$, respectively) and their associated CoVs (V_R and V_S, respectively). The mean resistance, $\bar{R}$, is the product of the unfactored (or nominal) resistance, R, and bias coefficient, δ_R:

[7.3] $$\bar{R} = \delta_R R$$

Resistance statistical parameters, δ_R, and V_R, are specified in Table C14.6 of CSA (2006b). The mean load, $\bar{S}$, and associated CoV, V_S, are calculated by Equations [6.6] and [6.7], respectively. The load effects, L_1, δ_{L_1}, and V_{L_1}, are calculated using Equations [5.9], [5.11] and [5.12], respectively. For these equations, the nominal static load effect, L, for the specific vehicle must be calculated. If detailed analysis of the vehicle static load has not been conducted, the bias coefficient and CoV of the static load effect, respectively δ_L and V_L, can be estimated with Equations [4.20] and [4.22], respectively. In this case δ_v and V_v are approximately equal to δ_L and V_L, respectively, when individual axle load variability does not govern (which is only applicable for wheeled vehicles).

7.2.3 Inherent Conservatism in Military Load Classification System

The Military Load Classification System determines the MLC of a vehicle by comparing its shear and moment demand to those of design vehicles. The MLC of a vehicle is defined by the span that produces the highest comparable design vehicle MLC, due to static shear or moment. This results in a critical span length that governs the classification, while all other span lengths have varying degrees of conservatism for that MLC classification. Figure 7.1 shows that some vehicles, such as the TLAV-M113A3-RWS (MLC 19 (T)), (DND, 2011b), have static loads that closely mirror the static load of the design vehicle at all spans. However, the configurations of some vehicle types are sufficiently different from the design vehicle that this is not the case. For example, Figure 7.2 shows the MLC for the AHSVS Tractor with 72t trailer (classified as a MLC 113 (W)): it is governed by moment on a 70m span and shear on a 45m span. Specifically, the AHSVS Tractor with 72t trailer at spans lengths less than 5 m has an equivalent classification no greater than MLC 56 (W). This is because the most severe axle load of this vehicle is 12.5 tonnes (DND, 2011e), where the most severe axle load of the design vehicle for MLC 50 (W) is 18.14 tonnes (NATO, 2006). An engineer could therefore determine if a specific vehicle could exceed the rated MLC of a simply supported span, by referring to either a diagram such as Figure 7.2 or a simplified table such as Table 7.2. It could quickly be judged whether any additional risk occurs when the vehicle crossing exceeds the posted MLC of the bridge. Appendix M summarizes comparative MLCs for different span lengths for vehicles in use by the Canadian Forces.

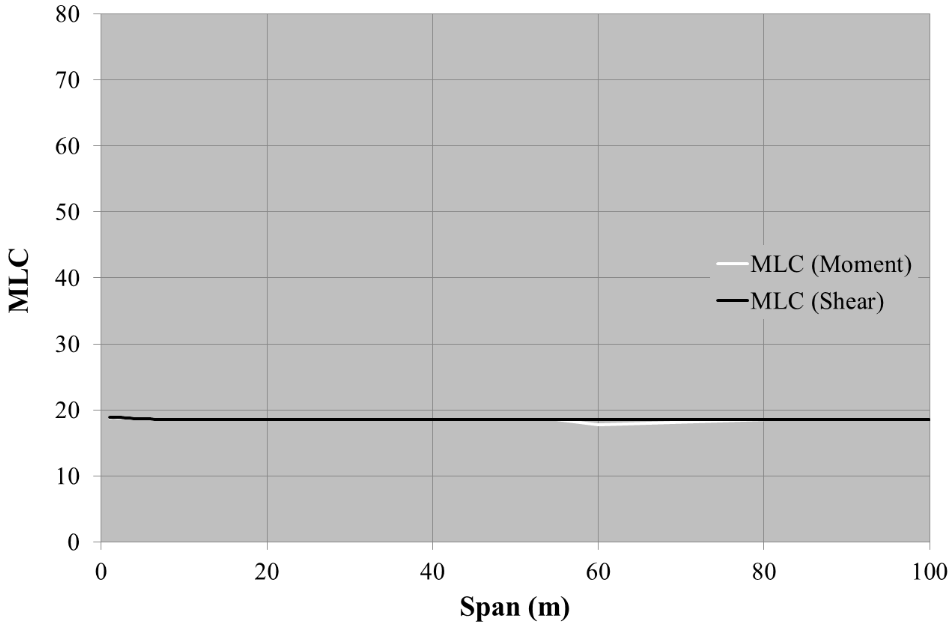


Figure 7.1 – TLAV-M113A3-RWS (MLC 19 - Tracked), MLC versus span length

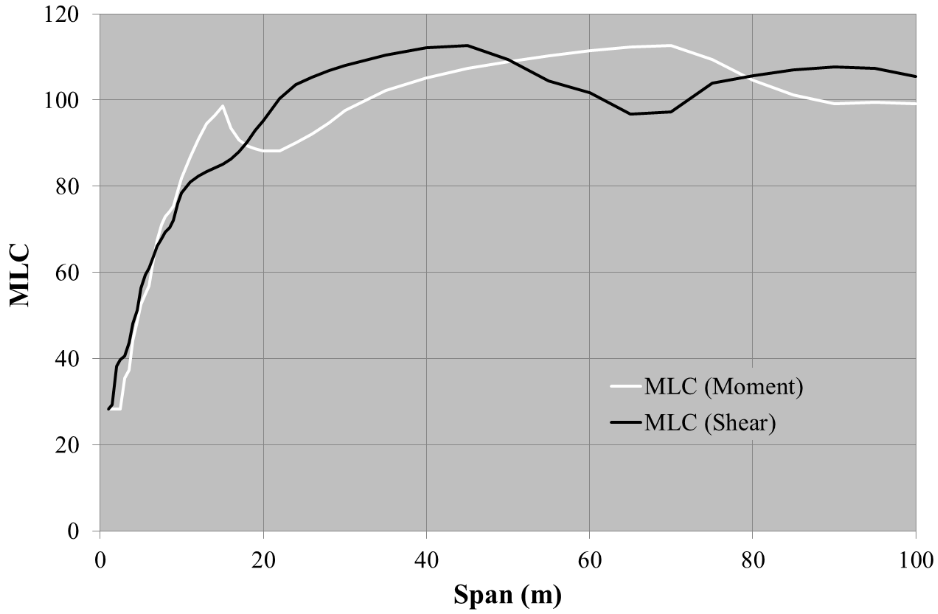


Figure 7.2 – AHSVS Tractor with 72t trailer (MLC 113 - Wheeled), MLC versus span length

Table 7.2 – MLC versus span length, AHSVS Tractor with 72t Trailer

Span Range (m)	0 – 5	5 – 10	10 – 20	20 – 60	60 - 100
Span Specific MLC	56	82	99	113	113

7.3 Bridge Evaluation for Different Acceptable Risk Levels

As outlined in Chapters 2 and 3, it may be desirable for the military to evaluate bridges using different reliability levels. A bridge assigned a certain MLC at NEGLIGIBLE risk, would be assigned a higher MLC, if evaluated at LOW, MODERATE, HIGH, or EXTREME Acceptable Risk Levels (ARLs).

CSA (2006a) specifies different target reliability indices for component evaluation based on: System behavior; Element behavior; and, Inspection level. At NEGLIGIBLE acceptable risk, the target reliability indices are satisfactory for bridge evaluation for military loads. Ideally, a general relationship between bridge reliability and component reliability could be established. This would allow target reliabilities based on component: system behavior; element behavior; and inspection level at NEGLIGIBLE risk to be adjusted for other ARLs. This would allow for less stringent load factors to be applied for ARLs of LOW, MODERATE, HIGH and EXTREME.

7.4 Chapter Conclusions

This chapter has presented several methods available to reconcile LSD with the Military Load Classification System. Load and resistance factors used in conjunction with design tables from NATO (2006) are shown to be compatible to assign an MLC to a bridge. When comparing LSD, as proposed in this chapter, to ASD (which does not differentiate between Fighting and Transport vehicles) higher MLCs are achieved for Wheeled-Fighting and Tracked-Fighting vehicles, whereas similar or lower MLCs are achieved for Wheeled-Transport and Tracked-Transport vehicles. Case-specific evaluation is also presented using vehicle-specific load factors, mean load method, and exploiting inherent conservatism in the Military Load Classification System.

Chapter 8

8 Summary, Conclusions, and Recommendations for Future Work

8.1 Summary

8.1.1 Acceptable Risk of Bridge Collapse in the Context of Military Operations

Chapter 2 showed that in military operations, varying levels of risk can be appropriate to achieve mission success. In conducting a mission risk assessment, a military commander might benefit from allowing personnel to assume greater risk during bridge crossings. Thus, a continuum of acceptable risk exists for bridges used by the military which depends on the operational context. Acceptable Risk Levels presented by Wight (1997), are an effective mechanism to relate military operations risk to bridge risk. Chapter 3 indicated that acceptable risk is not the only factor needed to be considered when determining target risk for bridge design and evaluation. General considerations for economic and life-safety risk optimization of military bridges are presented but are not quantified.

8.1.2 Statistical Parameters for Weight of Military Transport and Fighting Vehicles

Chapter 4 quantified the probabilistic weight of a military transport vehicle, the AHSVS-PLS, by assuming its curb weight is deterministic and so all weight variability is due to the vehicle payload, typical 6.1 m intermodal shipping containers. The statistical parameters for the container weights are quantified based on the weights of containers flown from Afghanistan to Canada between 2006 and 2012. Based on these assumptions, the statistical parameters for the weight of the AHSVS-PLS were determined.

Chapter 4 also quantified the statistical parameters for the weights of two military fighting vehicles, the LAV III-ISC and Leopard 2A4M tank. Without field data for the weights of these vehicles, the operational weights were quantified using heuristic assumptions. Both of these military fighting vehicles have smaller payload weight fractions, i.e., the weight of the payload to the total weight, than transport vehicles.

8.1.3 Live Load Effects Caused by Military Vehicles

Chapter 5 summarized and critically reviews prior research regarding dynamic loading and lateral load distribution of military vehicles to derive statistical parameters for live load effects. The lack of experimental data makes it difficult to quantify these parameters. Thus, the statistical parameters for the "Simplified Method" of lateral live load distribution from CSA (2006b) were assumed to be conservative for bridge evaluation involving military vehicle loads based on analysis of Pinero (2001). The statistical parameters for dynamic load effects of military vehicles were assumed to be the same as those reported by Trimble, Cousins and Seda-Sanabria (2003) for the M1075 PLS (a Wheeled-Transport) on two concrete T-beam bridges for military Wheeled-Transport vehicles and the same as CSA (2006b) for all other military vehicle categories. These assumed statistical parameters for dynamic loading and lateral load distribution were used in conjunction with those for the vehicle weight of military vehicles from Chapter 4 to quantify the live load effects statistical parameters.

8.1.4 Live Load Factors for Military Vehicles

Load factors were derived in Chapter 6 for the three vehicles investigated, using the statistical parameters for dead load and resistance given in CSA (2006a, 2006b) for ten representative bridges. The computed load factors are for interior girders resisting bending in simply supported, slab-on-girder type bridges. Partial load factors are also presented for general use.

8.1.5 Applying Limit State Design to Military Load Classification System

Chapter 7 provided suggestions on how Limit State Design can be applied to the Military Load Classification System. The Mean Load Method is proposed as an alternative means to evaluate vehicle specific crossings of bridges, and thus circumventing the vehicle and bridge MLC.

8.2 Conclusions

8.2.1 Target Reliability for Military Bridge Design and Evaluation

1. Bridge evaluation for military vehicle loading should not be limited to a single level of acceptable risk for normal use (e.g. crossings not considered as Caution or Risk crossing as defined by NATO (2006)). There should instead be a risk continuum for military bridge evaluation that depends on the military operational context.
2. In the context of combat operations, a major factor that is unique to military bridge risk optimization is the direct consequence or cost of limiting mobility when conducting military operations against an enemy force.
3. The design of new bridges for regular military loading in both combat and domestic situations can be based on a higher reliability than similar civilian bridges.
4. When evaluating existing bridge infrastructure in the context of combat operations, lower target reliabilities seem justifiable, except for Main Supply Routes.

8.2.2 Statistical Parameters of Weight of Military Vehicles

5. The lower weight variability of some military vehicles is less due to effective load control, (as has been previously suggested by, Kim, Y. J., et. al. (2010), DND (2007a)), but instead is an inevitable outcome of the design and intended functionality of the vehicle itself.
6. The payload weight fraction, defined as the ratio of the payload to the total combat weight, impacts the statistical parameters for the vehicle weight. Smaller payload weight fractions are associated with lower overall weight variability. This is important when assessing a bridge crossing by a vehicle with a relatively low

payload and a large self-weight, which would be safer than a crossing by a vehicle with the same weight but a higher payload weight fraction.

7. Military Fighting Vehicles have a lower payload weight fraction, than Military Transport Vehicles, and so have lower weight variability.

8.2.3 Live Load Effects of Military Vehicles

8. Dynamic load effects of wheeled military vehicles, in general, appear to be more severe than those specified in the Canadian Highway Bridge Design Code (CSA, 2006a, 2006b) for civilian truck traffic. Tracked vehicles are consistently less severe than wheeled military vehicles with statistical parameters for DLA that are enveloped by the values recommend in the CHBDC, (CSA, 2006a, 2006b).
9. Based on available literature, the lateral load distribution of load effects caused by military vehicles can be conservatively evaluated using the “Simplified Method” CSA (2006a, 2006b). This is particularly conservative for tanks that are markedly wider than civilian vehicles.

8.2.4 Live Load Factors for Military Vehicles

10. Military Fighting Vehicles and military Transport Vehicles represent different loading categories. Given this, four vehicle categories, rather than two, should be considered under STANAG 2021, (NATO, 2006): Wheeled-Fighting (W-F); Wheeled-Transport (W-T); Tracked-Fighting (T-F); and Tracked-Transport (T-T). This would reflect the difference in the payload weight fraction for Fighting vehicles (0.02 – 0.25) and Transport vehicles (0.35-0.60), and the consequential difference in statistical parameters for live load.
11. Vehicle-specific live load factors (for 1,000 veh/year with a target reliability of $\beta = 3.75$, other spans) are:

    - AHSVS-PLS, 1.79;
    - AHSVS-PLS and trailer, correlated container, 1.57;
    - AHSVS-PLS and Trailer, uncorrelated container, 1.89;
    - Uparmoured LAV III-ISC, 1.65; and

- Leopard 2A4M tank, 1.38.

Higher values apply to short spans for all vehicles except the Leopard 2A4M tank.

12. Live load factors for different military vehicle categories (1,000 veh/year with a target reliability of $\beta = 3.75$, other spans) are:

- Wheeled-Transport (W-T), 1.77;
- Wheeled-Fighting (W-F), 1.48;
- Tracked-Transport (T-T), 1.77; and
- Tracked-Fighting (T-F), 1.33.

Higher values apply to short spans for both Wheeled vehicle categories, but do not apply to the Tracked vehicle categories.

8.3 Recommendations for Future Research

Several areas of research that would further the calibration of load factors for military bridge design and assessment has been identified. They are briefly described in this section.

8.3.1 Dynamic Load Effect Caused by Military Vehicles

The dynamic load effect caused by military vehicles on bridges is not well quantified. As shown in Section 5.2, the limited experimental data suggest a wide range of dynamic responses. Military wheeled vehicles cause distinctly different dynamic responses than civilian traffic. Furthermore, tracked military vehicles cause distinctly different dynamic behaviour than wheeled military vehicles. From available experimental data, the provisions of CSA (2006a, 2006b) are unconservative to account for the dynamic loads of wheeled military vehicles. To quantify probabilistically the dynamic load effect of military vehicles, it is recommended that new experimental studies be undertaken for both tracked and wheeled vehicles, especially for spans greater than 15 m. Should the actual behaviour significantly differ from the assumptions made in Chapter 5, load factors provided in Chapter 6 will need to be revised.

8.3.2 Lateral Load Distribution of Military Vehicles

Pinero (2001) derived Load Distribution Factors (LDFs) for several vehicles used by the US Military. This research was limited to single lane traffic. New research should aim to develop an approach that yields more accurate results based on the current CSA (2006a) provision for an amplification factor, F_m. Furthermore, the lateral load distribution of the load effects caused by two lanes of military vehicles still needs to be quantified.

Review of Pinero (2001) also indicated that, as the ground contact width of the vehicle increased, the load effect per girder decreased (or in other words, the amplification factor, F_m, reduced). This is especially important given that the ground contact width of military vehicles can range from 1.8 m to 4.67 m (NATO, 2006), with the heaviest vehicles generally having a greater ground contact width. Although NATO (2006), DND (2007a), and US Department of the Army (2002), already account for this with corrections to the MLC designation of a vehicle based on the ground contact width: with higher MLCs for vehicles that are not as wide as the design vehicles; and only specified by US Department of the Army (2002) with lower MLCs for vehicles wider than the design vehicles. This correction should be verified to determine their impact on the bias coefficient and CoV of lateral load distribution provision. This would be benificial in eliminating excess conservatism for the assessment of the heaviest military vehicles.

8.3.3 Review of Bridge Inventory to Calibrate of Load Factors

Only ten bridges were investigated for the load factor calibration. A more comprehensive investigation should be undertaken for a wider range of bridges that represent the Canadian inventory.

8.3.4 Review of Other Military Vehicles in use by NATO and Canadian Forces

The statistical parameters for the weights of three vehicles in use by the Canadian Forces were used as the basis for the derivation of general load factors for different Military Vehicle Categories. To better quantify these statistical parameters, other military vehicles in use by the Canadian Forces or NATO should be investigated. This will help to quantify target reliabilities that are better suited for the overall vehicle population of each Military Vehicle Category.

In this research, no Tracked-Transport vehicles were investigated. If specifications for a Tracked-Transport vehicle were available, it would be a worthwhile exercise to follow the methods presented in Chapters 4 through 6 to derive vehicle-specific load factors.

8.3.5 Collection of Field Data for Military Vehicles

8.3.5.1 Traffic Composition and Volume

It has been difficult quantify the expected traffic volumes of military vehicles. Given that load factors are dependent on annual traffic volumes, it would be important to verify, based on pervious operations, what traffic volumes can be expected.

Also, military traffic composition should be verified to improve the average load factors for each Military Vehicle Category presented in Section 6.4.3.

8.3.5.2 Operational Weights of Military Vehicles

A major shortfall in this research is the absence of field data for the weights of military vehicles while on operations. To quantify statistical parameters for static loads of military vehicles, it was assumed that the curb weight of the vehicle was deterministic and the variability of the total weight of the vehicle was due entirely to its payload. Based on this assumption, the payload of the AHSVS-PLS was inferred based on shipping container weights flown by the Canadian Forces during the Afghanistan conflict. Conservative, heuristic assumptions were made to simulate the payload weights of the LAV III-ISC and Leopard 2A4M tank. To validate these assumptions, field data of the operational weights of military vehicles should be collected through either Weigh in Motion (WiM) or with scales.

The inferred payload behaviour of the AHSVS-PLS using shipping container flown by the Canadian Force is, at the very least, indicative that the military does not have greater control on excessively loaded vehicles during combat operations. Given the greater payload weight fraction for military transport vehicles when compared to military fighting vehicles, it would be important to investigate other types of payloads (other than shipping containers) carried by military transport vehicles.

8.3.6 Risk Optimization of Bridge Evaluation in the Context of Military Operations

Although only briefly investigated in Chapter 3, the optimal risk for military bridge evaluation in the context of military operations should be investigated thoroughly. Given the importance of mobility in a battlespace, optimizing the risk associated with bridge usage is a worthwhile exercise.

8.3.7 Target Reliability for Acceptable Risk Levels other than NEGLIGIBLE

As explained in Chapter 2, under various circumstances it may be acceptable to permit a greater overall risk for all vehicles in crossing bridges. Whereas early in a combat operation, greater mobility requirements to counter enemy actions would warrant bridges rated for a MODERATE risk level. As the military operation continues and the situation stabilizes, bridges might be re-rated to a NEGLIGIBLE or LOW risk level. The basis of these levels of risk is the probability of death in using the structure for its intended purpose. This is best quantified as the probability of system failure. Reliability levels used for engineering design and evaluation have been calibrated for the annual probability of failure for the individual components of a structure. To adequately relate the lower allowable system reliability to the component reliability in a simplified, general sense is essential to create a framework for engineers to rate bridges at different risk levels.

8.3.8 Load Factor Calibration for Shear and Other Types of Spans

Live load factors were derived for the evaluation of flexural loads on interior girders of simply supported slab-on-girder bridges for single lane traffic. Further research is required to calibrate factors related to flexural loads of exterior girders, shear, and other types of bridges.

8.3.9 Multiple Vehicle Loading and Traffic Combinations

The presence of multiple military vehicles or military vehicles mixed with other traffic, including multi-lane traffic has not been considered. Although it is assumed by NATO (2006) that the nearest ground contact points of successive military vehicles are 30.5 m apart, there is no indication that this is actually practiced in the field. No data concerning to the actual vehicle spacing or convoy combinations were found. To accurately quantify the load effects of the presence of multiple military vehicles on bridges requires more information. It is therefore warranted to collect field data relating vehicle spacing and traffic composition of military vehicles under different circumstances, including: on military installations; on bridges owned by civilian authorities near military installations; and during military deployments (domestic and foreign). Video surveillance has probably captured this information on and off military installations, but may be difficult to access.

8.3.10 Calibration for Evaluation of Bridges in Other Nations

Given the need for the Canadian Forces to operate in other nations, it would be beneficial to conduct a thorough investigation of material properties and bridge forms and geometries in other nations. Load factors calibrated for Canadian bridges could be tested for applicability to evaluate bridges in regions or specific nations.

References

AASHTO. (1996). Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials, 16^{th} Edition. Washington, D.C.

AASHTO. (2007). AASHTO LRFD Bridge Design Specifications, 4th Edition. Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO. (2012). AASHTO LRFD Bridge Design Specifications, 6th Edition. Washington, DC: American Association of State Highway and Transportation Officials.

Allen, D. E. (1992). Canadian highway bridge evaluation: reliability index. Canadian Journal of Civil Engineering, 987-991.

Allen, T. M., Nowak, A. S., & Bathurst, R. J. (2005). Calibration to Determine Load and Resistance Factors for Geotechnical and Structural Design, E-C079. Washington, D.C.: Transportation Research Board.

Ang, A. & Tang, W. (1984). Probability concepts in engineering planning and design volume 1 basic principles. New York, NY: John Wiley & Sons, Inc.

Armed Forces Epidemiological Board. (1996). Injuries in the Military - A Hidden Epidemic. Washington, D.C.: Armed Forces Epidemiological Board.

Army Guide. (n.d.). Army Guide. Retrieved March 27, 2014, from http://www.army-guide.com/eng/product1645.html

Army Trucks Inc. (2014, November 24). *Cargo*. Retrieved from Army Trucks Inc.: http://armytrucksinc.homestead.com/cargo.html

Bartlett, F.M. (1980). Class Notes, CE 600 Bridge Design, Waterloo, ON

Bartlett, F. M. (2008). Separation Factors for Load or Resistance Factor Computation: A Sacred Cow to be Put Out to Pasture. Annual Conference of the Canadian Society of Civil Engineering (pp. 2088-2097). Quebec City, QC: Curran Associates, Inc.

Benjamin, J. R., & Cornell, C. A. (1970). Probability, Statistics, and Decision for Civil Engineers. (pp. 466-475, 667) New York: McGraw-Hill Book Company.

Bennett, S. D., & Stam III, A. C. (1996). The Duration of Interstate Wars, 1816-1985. American Political Science Association, Vol. 90, No. 2 (Jun., 1996), pp. 239-257.

Brassington, B., ETS Consulting. (2014). RE: Seeking reference for data presented in ILO publication: "Safety in the supply chain in relation to packing of containers" ISBN 978-92-2-124227-7. Pitstone, Buckinghamshire, United Kingdom. Multiple Private Communications between Jan 2014 to Apr 2014. Contact info for ETS Consulting available at: http://ets-consulting.org/

canada.com. (2013, September 10). *Timeline: Canadian deaths in Afghanistan.* Retrieved from Canada.com: http://www.canada.com/news/Timeline+Canadian+deaths+Afghanistan/1037437/story.htm.

Canadian Defence Academy, C. (2007). Leadership in the Canadian Forces, Leading People. Ottawa, ON, Canada: Her Majesty the Queen in Right of Canada.

Chettoe, C. S. (1948). The Military Classification of Bridges in Great Britain. The Civil Engineer in War, A Symposium of Papers on War-Time Engineering Problems, Volume 1 Airfield, Roads, Railways, and Bridges (pp. 360-364). London, Britain: The Institution of Civil Engineer.

CIRIA. (1977). Rationalisation of safety and serviceability factors in structural codes. London, UK: Construction Industry Research and Information Association.

Clair, C. D. (1993). Lessons in Combat Service Support Tactical Mobility: The Afghanistan Conflict, Falklands War and Operation Desert Shield/Desert Storm.

Monograph. Fort Leavenworth, KS: School of Advance Military Studies, United States Army Command and General Staff College.

Collier, P., Hoeffler, A., & Söderbom, M. (2004). On the Duration of Civil War. Journal of Peace Resarch, Vol. 41, No. 3 (May, 2004), pp. 253-273.

Cremona, C. (2011). Structural Performance, Probability-based Assessment. (pp. 81-124) Hoboken, NJ: John Wiley & Sons, Inc.

CSA. (1981). Guidelines for the Development of Limit States Design, CSA Special Publication S408-1981. Rexdale, ON: Canadian Standards Association.

CSA. (2006a). Canadian Highway Bridge Design Code, CAN/CSA-S6-06. Rexdale, ON: Canadian Standards Association.

CSA. (2006b). Commentary on CAN/CSA-S6-06, Canadian Highway Bridge Design Code. Rexdale, ON, Canada: Canadian Standards Association.

CSA. (2011). Guidelines for the development of limit states design standards, S408-11. Mississauga, ON: Canadian Standards Association.

Defense Industry Daily. (2013, August 07). Defense Industry Daily. Retrieved April 14, 2014, from http://www.defenseindustrydaily.com/canada-looks-to-upgrade-its-armor-in-afghanistan-05190/

DND. (1997). Data Summary, Light Armoured Vehicle (LAV), Wheeled, 8x8, Diesel (Bilingual), C-30-650-000/MA-001. Ottawa, ON: Department of National Defence.

DND. (1999). Operating, Maintenance and Illustrated Parts Instructions for Pallet Loading System Trailer, C-30-874-000/MS-000. Ottawa, ON: Department of National Defence.

DND. (2003). B-GL-321-007/FP-001, LAV Company Tactics. Ottawa, ON: Government of Canada.

DND. (2005). Chief Review Services, Evaluation of DND/CF Ammunition Safety Program - 1258-101-2 (CRS).

DND. (2006a). Data Summary, Armoured Recovery Vehicle Taurus, C-30-733-000/MA-001. Ottawa, ON: Department of National Defence.

DND. (2006b). Data Summary, Armoured Engineer Vehicle Badger. C-30-734-000/MA-001. Ottawa, ON: Department of National Defence.

DND. (2006c). Data Summary, Tank Leopard C2 MBT (Bilingual). C-30-731-000/MA-001. Ottawa, ON: DND/MDN Canada.

DND. (2006d). Data Summary, Truck, Cargo, 10 Tons, 6x6, HLVW, Model H808 with Self-Recovery Winch (Bilingual), C-30-406-000/MA-000. Ottawa, ON: DND/MDN Canada.

DND. (2007a). Manual for Military Nonstandard Fixed Bridges, B-GL-361-014/FP-001. Ottawa, ON: Not Published.

DND. (2007b). Risk Management for CF Operations, Change 1, B-GJ-005-502/FP-000. Ottawa, ON: Department of National Defence.

DND. (2007c). Armoured Heavy Support Vehicle System (00001203). Statement of Operational Requirements.

DND. (2010a). Data Summary, Chassis, Light Armoured Vehicle (LAV), Reconnaissance (Recce), Wheeled, 8x8, Diesel (Bilingual), C-30-600-A00-/MA-001. Ottawa, ON: Department of National Defence.

DND. (2010b). Data Summary, Light Armoured Vehicle (LAV), Wheeled, 8x8, Diesel, Bison Ambulance (Bilingual), C-30-656-000/MA-001. Ottawa, ON: DND/MDN Canada.

DND. (2011a). Cargo / Gun Tractor Vehicle Data Summary, C-30-B80-002/MA-001. Ottawa, ON: Government of Canada.

DND. (2011b). Data Summary, Carrier, Personnel, Full Tracked, Armoured, M113A3 with AN/MWG-505, C-30-775-000/MA-001. Ottawa, ON: DND/MDN Canada.

DND. (2011c). Data Summary, Chassis, Light Armoured Vehicle (LAV), Armoured Personnel Carrier (APC), Wheeled, 8x8, Diesel, C-30-560-000/MA-001. Ottawa, ON: Department of National Defence.

DND. (2011d). Palletized Loading System Vehicle (C-20-B80-003/MA-001). Ottawa, ON, Canada: Department of National Defence.

DND. (2011e). Tractor 24 t Data Summary (C-30-B80-004/MA-001). Ottawa, ON: Government of Canada.

Drew, C. (2009, November 15). High Costs Weigh on Troop Debate for Afghan War. New York Times (New York Ed). New York: New York Times.

Dunker, K. F., & Rabbat, B. G. (1990). Highway Bridge Type and Performance. Journal of Performance of Constructed Facilities (ASCE), 4: 161-173.

Engeler, A. (1994). Parallel Tests with a 6 and 7 Roadwheel Tracked Vehicle. 6th European ISTVS Conference, Off Road Vehicles in Theory and Practice Volume II (pp. 603-617). Vienna, Austria: Austrian Armed Forces and Austrian Society of Automotive Engineers.

Entous, A. (2009, November 16). Afghan strategy debate exposes split over price. Reuters. Washington: Reuters. Retrieved March 26, 2014, from http://www.reuters.com/article/2009/11/16/us-afghanistan-usa-costs-analysis-idUSTRE5AF2FK20091116

European Committee for Standardization. (2010). EN 1990:2002+A1 - Eurocode - Basis of structural design. Brussels, Belgium.

Fender, K. J., & Pierce, D. A. (2012). An Analysis of the Operational Costs of Trucking: 2012 Update. Arlington, VA: American Transportation Research Institute.

Genivar. (2012). Drawings, 1, 8, and 9 of Bug River Bridge, CONT No 2012-6015, WP No 6942-10-00, Thunder Bay, ON

Goldberg, M. S. (2010). Death and Injury Rates of U.S. Military Personnel in Iraq. Military Medicine, Vol 175, 4, p. 220-226.

Greider, W. (1999). Fortress America: The American Military and the Consequences of Peace. New York: Public Affairs.

Homberg, H., Berechnung von Brücken und Militärlasten, Band 1, STANAG 2021 Norm für militärische Fahrzeuge und Brückenbelastungen, Werner-Verlag GmbH, Düsseldorf, 1970.

Hornbeck, B., Kluck, J., & Connor, R. (2005). Trilateral Design and Test Code for Military Bridging and Gap Crossing Equipment. Warren, MI: TARDEC Bridging (AMSRD-TAR-E/ELE).

icasualties.org. (2013, June 16). iCasualties.org. Retrieved June 18, 2013, from http://icasualties.org/OEF/Nationality.aspex?hndQry=Canada

Kennedy, D. L., Gagnon, D. P., & Allen, D. E. (1992). Canadian highway bridge evaluation: load and resistance factors. Canadian Journal of Civil Engineering, 19(6): 992-1006.

Kim, Y. J. (2012). Safety assessment of steel-plate girder bridges subjected to military load classification. Engineering Structures, Vol 38, pp. 21-31.

Kim, Y. J., Tanovic, R., & Wight, R. G. (2010). Load configuration and lateral distribution of NATO wheeled military truck for steel I-Girder Bridges. Journal of Bridge Engineering, Vol 15, pp. 740-748.

Kosmatka, J. B. (2011). Dynamic Behaviour of the Composite Army Bridge (CAB): Field Testing. Proceedings of the 8th International Conference on Structural Dynamics (pp. 1559-1565). Leuven, Belgium: EURODYN.

Landherr, J. C. (2008). Dynamic Analysis of a FRP Deployable Box Beam. Kingston, Ontario: Queen's University.

Lenner, R. (2014). Safety Concept and Partial Factors for Military Assessment of Existing Concrete Bridges. Munich, Germany: UNIVERSITÄT DER BUNDESWEHR MÜNCHEN.

Lenner, R., Keuser, M., & Sykora, M. (2013). Assessment of Existing Reinforced Concrete Bridges Exposed to Military Loads. Novak and Vorechovsky: Proceedings of the 11th International Probabilistic Workshop, (p. (not yet published)). Brno.

Leopard Requirements Officer, Director Land Requirements 3-4-3, Department of National Defence. (22 Nov 2013). ATTLA for Air Shipments, Ottawa, ON, Canada. Private communication

Menzies, J. (1997). Bridge failures, hazards and societal risks. In P. C. Das, Safety of Bridges (pp. 36-41). London, UK: Thomas Telford.

Military Today. (n.d.). Western Star. Retrieved November 1, 2012, from military-today.com: http://www.military-today.com/trucks/western_star_m4866s.htm

Morrison Hershfield Ltd. (2012). Ministry of Transportation Bridge Design Training Design Example. Ontario, Canada: Ministry of Transportation, Government of Ontario, Canada.

National Movement and Distribution System Support Center, Department of National Defence. (2012). Request for Info of Equipment/Seacan Weights – Ref Military Traffic Load Calibration Project. Ottawa, ON, Canada. Private communication.

NATO, (2006). Standardization Agreement (STANAG) 2021, 6th Edition. Military Load Classification of Bridges, Ferries, Rafts and Vehicles. Brussels, Belgium.

NATO, (2008). NATO Glossary of Terms and Definitions (English and French), AAP-6(2008). (p. 2-M-1) Brussels, Belgium.

Pinero, J. C. (2001). Lateral Load Distribution Factors for Military Vehicles on Multi-Girder Deck Slab Bridge Systems. Blacksburg, Virginia: Virginia Polytechnic Institute and State University. Retrieved from http://scholar.lib.vt.edu/theses/ available/etd-05252001-141715/unrestricted/Juan-MSThesis.pdf

Robinson, M. J., & Kosmatka, P. E. (2011). Experimental Dynamic Response of a Short-Span Composite Bridge to Military Vehicles. Journal of Bridge Engineering, 2011.16: 166-170.

SNC. (n.d.). SNC Tech Product Brochure - 5.56mm, 7.62mm and 9mm ammunition. Retrieved October 31, 2013, from http://www.gd-otscanada.com/imports/pdf/en/fiche_techniquel.pdf

Statistics Canada. (2012, May 30). Canadian Socioeconomic Database. Retrieved June 18, 2013, from http://www5.statcan.gc.ca/cansim/

Sýkora, M., Holický, M., Lenner, R., & Maňas, P. (2013). Optimum target reliability for bridges considering emergency situations. Proceedings of the 11th International Probabilistic Workshop (pp. 439-450). Brno: Ing. Vladislav Pokorn´y – LITERA.

Trimble, M. D., Cousins, T. E., & Seda-Sanabria, Y. (2003). Field Study of Live Load Distribution Factors and Dynamic Load Allowance on Reinforced Concrete T-Beam Bridges. Washington, DC, United States of America: US Army Corps of Engineers, Engineer Research and Development Center. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a417357.pdf

Transportation Research Board. (2001). *National Cooperative Highway Research Program, Report 454, Calibration of Load Factors for LRFR Bridge Evaluation.* (p. 7) Washington, D.C.: National Academy Press.

US Army. (2014, November 24).*File:Stryker ICV front q.jpg.* Retrieved from Wikimedia Commons: commons.m.wikimedia.org/wiki/File:Stryker_ICV_front_q.jpg

US Army Center for Army Lessons Learned. (2003). The Modern Warrior's Combat Load, Dismounted Operations in Afghanistan April-May 2003.

US Department of the Army. (1998). Risk Management (FM 100-14). Washington, D.C.

US Department of the Army. (2002). Military Nonstandard Fixed Bridging (FM 3-34.343). Washington, D.C.

US Department of the Army. (2003). The Tank and Mechanized Infantry Battalion Task Force (FM 3-90.2). Washington, D.C.

US Department of the Army. (2006). Counterinsurgency Fm 3-24. Washington, DC: Headquarters, Department of the Army.

US Department of the Army. (2008). Engineering Reconnaissance (FM 3-34.170/MCWP 3.17.4). Washington, D.C.

US Department of the Army, & US Department of the Navy. (2004). Operational Terms and Graphics (FM 1-02/MCRP 5-12A). Washington, DC.

Vancata, P. (2014, November 3). *Statistics of the Battle of Britain.* Retrieved from Battle of Britain: http://cz-raf.hyperlink.cz/BoB/stat.html

Walker, A. C., Zintilis, G. M., & Bulson, P. S. (1991). Strength of Damaged Military Bridges. Thin-Walled Structures, Vol 12, pp. 113-128.

Wight, L. T. (1997, June 13). Operational Commander's Risk Assessment: How much Can You Really Afford to Lose? Naval War College - Published Thesis. Newport, RI, United States of America: Defense Technical Information Center. Retrieved from: http://www.dtic.mil/dtic/tr/fulltext/u2/a325249.pdf

Wikipedia.org. (2014a, November 3). *Battle of the Bulge.* Retrieved from Wikipedia.org: http://en.wikipedia.org/wiki/Battle_of_the_Bulge

Wikipedia.org. (2014b, November 3). *Siege of Bastogne.* Retrieved from Wikipedia.org: http://en.wikipedia.org/wiki/Seige_of_Bastogne

WLAV Chassis Management Team Leader, Department of National Defence. (2014). L2-084 CofG Calcs Update.pptx, Ottawa, ON, Canada. Private communication.

Wong, J. Y. (2010). Terramechanics and Off-road Vehicle Engineering, Terrain Behaviour, Off-road Vehicle Performance and Design (2nd Edition). Oxford, United Kingdom: Elsevier.

Appendix A

DND National Material Distribution System Intermodal Shipping Container Mass Data 2006-2012, Departing Afghanistan

Dispatch Date	Mass (kg)
27/Apr/2010	2040
07/May/2007	2041
13/Dec/2010	2041
16/May/2012	2060
26/Aug/2011	2080
03/Nov/2011	2080
	2082
26/Aug/2011	2090
03/Nov/2011	2090
	2093
	2109
24/Feb/2010	2113
	2117
27/Apr/2010	2120
24/Feb/2010	2130
	2136
07/Aug/2012	2141
08/May/2008	2157
16/May/2011	2159
20/Mar/2006	2170
13/Jun/2008	2170
26/Aug/2011	2177
13/Jun/2008	2180
22/Aug/2012	2180
15/Jun/2011	2181
02/Dec/2010	2182
03/Jun/2011	2185
08/May/2008	2186
01/Feb/2012	2188
	2189
05/Dec/2011	2190
	2195
12/Jan/2010	2200
27/Apr/2010	2200
15/Apr/2010	2218
	2218
03/Nov/2011	2230
26/Aug/2011	2230
15/Apr/2010	2232
15/Nov/2011	2240
02/Dec/2010	2241
18/Aug/2011	2242
15/Apr/2010	2250
16/Jun/2011	2259
	2259
12/Jan/2011	2268
	2268
03/Aug/2010	2268
14/Apr/2011	2272
08/May/2008	2273
	2273
22/May/2012	2273
15/Aug/2012	2273
12/Jul/2012	2273
31/Mar/2011	2275
13/Sep/2012	2277
02/Jun/2011	2280
20/Dec/2011	2300
14/Dec/2011	2313
	2313
	2380
27/Apr/2010	2380
23/Feb/2010	2380
	2386
13/Sep/2012	2390
02/Dec/2010	2398
14/Nov/2008	2400
08/Apr/2008	2404
	2445
	2452
	2454
16/May/2011	2477
27/Nov/2009	2495
16/Dec/2009	2500
11/May/2012	2526
21/Dec/2007	2532
14/Dec/2011	2556
01/Dec/2010	2586
27/Jun/2011	2648
05/Oct/2011	2650
23/Sep/2011	2650
30/May/2012	2710
02/Dec/2009	2720
15/Oct/2010	2722
	2722
18/Sep/2007	2729
05/Jun/2012	2737
10/Dec/2009	2745
NULL	2777
19/Dec/2008	2781
	2781
	2785
	2799
31/Mar/2011	2800
	2812
05/Jun/2012	2813
23/May/2012	2816
19/May/2011	2820
	2821
27/Oct/2009	2829
	2830
	2849
01/Dec/2010	2854
01/Oct/2008	2860
	2867
19/Jan/2010	2870
18/May/2011	2871
	2871
	2877
15/Nov/2011	2887
11/May/2012	2889
19/Dec/2008	2889
	2889
	2892
19/Jan/2010	2898
21/Dec/2010	2900
20/Jan/2012	2903
	2903
11/May/2012	2906
06/Aug/2009	2910
04/Jul/2012	2920
09/Jul/2012	2930
25/Feb/2010	2940
15/Apr/2010	2942
	2942
17/Aug/2010	2948
08/Sep/2012	2948
	2950
11/May/2012	2956
12/Dec/2011	2957
17/Mar/2008	2967
13/Nov/2009	2980
29/Jun/2011	2994
	2994
21/Sep/2007	2997
19/Jan/2007	2998
15/Apr/2010	2998
	2998
16/Dec/2009	3000
10/Mar/2006	3012
13/Dec/2010	3016
16/Feb/2010	3020
19/Jan/2007	3030
	3035
28/Jul/2010	3036
08/Sep/2012	3039
	3039
22/Jun/2007	3044
15/Jun/2011	3048
29/Jun/2010	3060
13/Oct/2011	3062
31/Mar/2010	3066
28/Feb/2011	3082
	3084
13/Jul/2006	3084
	3084
19/Dec/2008	3089
14/Dec/2011	3094
	3112
	3114
07/Jun/2011	3114
07/Aug/2012	3120
05/Jul/2006	3121
	3121
29/Mar/2010	3124
15/Jun/2011	3128
	3134
24/Nov/2008	3150
	3155
	3157
02/Feb/2010	3160
08/Jun/2010	3168
19/Sep/2012	3175
	3175
19/Apr/2011	3193
	3193
02/Apr/2009	3195
	3200
	3202
15/Jun/2011	3204
16/Nov/2007	3214
19/May/2011	3216
	3229
	3231
	3232
14/Dec/2011	3239
11/Mar/2009	3240
28/Jul/2011	3240
15/Jun/2011	3241
31/Mar/2008	3245
08/Jun/2010	3247
15/Jun/2011	3250
13/Nov/2009	3266
	3270
17/Sep/2012	3270
	3282
14/Dec/2011	3284
31/Oct/2008	3288
	3300
29/May/2012	3302

Dispatch Date	Mass (kg)
11/Mar/2010	3305
	3315
09/May/2011	3318
	3331
19/Dec/2011	3348
17/Dec/2008	3350
09/Jul/2012	3350
31/Mar/2010	3353
	3357
31/Aug/2011	3360
	3361
07/Jun/2011	3366
	3370
24/Jan/2011	3370
	3377
25/Oct/2010	3380
19/Nov/2009	3380
18/Feb/2009	3383
31/May/2011	3386
13/Jan/2010	3390
19/Jan/2010	3390
31/May/2011	3402
	3402
11/Mar/2009	3410
25/Jul/2006	3410
12/Jul/2010	3411
08/Jan/2009	3413
08/Jun/2010	3417
02/Feb/2010	3420
	3420
	3425
08/Jun/2010	3425
11/Dec/2008	3426
09/Jun/2011	3428
24/Nov/2009	3430
	3431
	3434
28/Oct/2009	3435
	3445
	3448
26/Nov/2009	3449
19/Jan/2010	3450
25/Nov/2009	3450
	3452
29/May/2006	3453
	3456
22/Jun/2007	3461
	3463
09/Sep/2010	3465
13/Nov/2008	3466
	3468
26/Nov/2009	3470
10/Dec/2009	3472
26/May/2010	3475
20/Aug/2012	3480
16/Sep/2010	3482
07/Sep/2010	3487
16/Sep/2010	3487
	3487
27/Aug/2010	3488
24/Nov/2009	3490
09/May/2011	3490
27/Sep/2007	3491
	3493
14/Dec/2011	3496
19/Jan/2010	3500
09/May/2011	3501
09/May/2011	3504
	3504
02/Feb/2010	3510
15/Jun/2011	3512
13/Nov/2009	3520
08/Jun/2010	3520
09/May/2011	3521
15/Jun/2011	3522
09/May/2011	3528
	3529
08/Oct/2008	3530
25/May/2011	3537
03/Oct/2007	3538
09/May/2011	3539
26/Mar/2009	3540
15/Dec/2011	3542
28/Jun/2011	3543
02/Jun/2011	3549
09/May/2011	3551
	3554
09/May/2011	3554
15/Jun/2011	3557
25/May/2011	3557
	3561
25/May/2011	3562
25/May/2011	3563
25/May/2011	3566
03/Oct/2007	3568
15/Jun/2011	3570
25/May/2011	3570
	3572
19/Sep/2006	3574
28/Jun/2011	3579
16/Oct/2008	3582
27/Aug/2010	3583
28/Jun/2011	3584
	3592
25/Jul/2008	3596
09/Nov/2007	3600
26/Feb/2009	3605
16/Jan/2009	3608
04/Jul/2012	3610
24/Mar/2010	3610
11/Dec/2011	3611
	3615
20/Aug/2009	3620
12/Feb/2010	3620
03/Oct/2007	3622
28/Jun/2011	3623
02/Nov/2010	3628
05/Aug/2008	3629
	3629
19/Jun/2008	3629
	3629
22/Jun/2007	3630
08/Jan/2009	3630
02/Feb/2010	3630
	3631
20/Jun/2007	3636
	3638
19/Oct/2011	3638
15/Feb/2012	3640
02/Feb/2010	3640
	3645
29/Mar/2010	3645
26/Mar/2010	3650
26/Mar/2009	3650
12/Jan/2010	3650
08/Oct/2008	3651
16/May/2011	3660
05/Feb/2008	3663
	3663
01/Oct/2007	3665
12/Dec/2011	3665
16/Mar/2009	3666
26/Mar/2009	3668
07/Jun/2011	3670
15/Jan/2009	3674
21/Dec/2011	3676
09/Nov/2007	3680
15/May/2009	3681
27/Feb/2008	3690
21/Jan/2009	3691
	3692
02/Feb/2010	3700
15/May/2007	3701
11/Feb/2008	3703
16/Oct/2008	3705
08/Oct/2008	3708
	3708
04/Dec/2007	3710
11/Dec/2011	3711
	3713
08/Jun/2007	3719
	3719
21/Jan/2009	3726
04/Dec/2007	3730
31/May/2011	3732
25/Jul/2008	3735
15/Apr/2008	3738
25/May/2011	3740
	3742
14/Feb/2012	3747
	3747
03/Oct/2007	3751
26/May/2011	3755
10/Dec/2009	3756
	3756
27/Feb/2008	3757
22/Nov/2006	3760
11/Jan/2008	3770
12/Jul/2010	3774
31/May/2011	3776
29/Sep/2010	3780
02/Dec/2009	3780
21/Jun/2011	3789
27/Jan/2010	3790
11/Dec/2011	3792
	3792
31/May/2011	3799
24/May/2012	3800
15/Oct/2007	3800
18/Feb/2008	3801
07/Jun/2011	3809
24/Nov/2008	3810
	3810
08/Apr/2009	3811
01/Dec/2010	3817
01/Dec/2009	3819
	3819
12/Apr/2011	3830
03/Oct/2007	3830
08/Feb/2011	3835

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
	3840	01/Jun/2011	3962	21/Oct/2011	4068		4171
17/Jun/2010	3840	02/Feb/2010	3970	13/Jan/2010	4069	26/Jan/2011	4173
25/Feb/2010	3840	12/Oct/2012	3970	20/Jan/2011	4070	04/Aug/2010	4173
06/Dec/2011	3842	03/Oct/2007	3970	31/Oct/2008	4076		4173
31/Mar/2011	3842		3974	02/May/2011	4080	17/Dec/2009	4180
07/Jun/2011	3843	14/Dec/2011	3985	22/May/2007	4082	22/Nov/2006	4180
09/Feb/2010	3850	04/Aug/2010	3987		4082	25/Jun/2009	4187
	3856	15/Apr/2010	3989	12/Dec/2011	4084	30/Mar/2011	4190
31/May/2011	3856	29/Apr/2010	3989	26/Oct/2007	4090	26/Jan/2012	4190
	3856	09/Feb/2010	3990	25/Apr/2008	4090	10/Sep/2012	4191
16/May/2011	3856	20/Jan/2010	3990	01/Dec/2009	4091	13/Jul/2010	4194
21/Jan/2011	3856	13/Mar/2009	3991	09/Dec/2010	4097	29/Feb/2008	4195
26/Mar/2010	3859	25/Aug/2011	3992	09/Jun/2011	4098	02/Feb/2010	4200
03/Oct/2007	3861		3992		4098	14/May/2010	4200
15/May/2007	3865	09/May/2011	3993	22/Nov/2006	4100	13/Nov/2009	4200
07/Jun/2011	3868	12/Dec/2011	3996	01/Sep/2010	4105	06/Oct/2009	4202
22/Jun/2007	3874	11/May/2007	4000		4107		4203
03/Oct/2007	3876	11/Dec/2006	4000	16/May/2011	4108	26/May/2010	4210
07/Jun/2011	3878	05/Dec/2011	4002	15/Sep/2009	4108	08/Sep/2012	4218
03/Feb/2010	3880	29/Apr/2010	4004	22/Jun/2007	4110	23/Jan/2007	4220
	3885		4012	17/Oct/2011	4110	20/Jan/2010	4220
07/Jun/2011	3890		4014	28/Jun/2011	4112	15/Jan/2009	4221
29/Jun/2010	3891	21/Oct/2011	4018		4114	03/Jun/2010	4228
15/Dec/2011	3891	10/Dec/2010	4019	13/Jul/2010	4116	13/Dec/2006	4230
03/Oct/2007	3898	09/Feb/2011	4019	10/Aug/2010	4119	26/May/2011	4230
28/Sep/2012	3900	17/Aug/2009	4020	28/Jun/2011	4119	04/Jan/2012	4232
25/Feb/2010	3900	27/Jan/2010	4020	30/Oct/2008	4119		4232
28/Aug/2012	3901		4021	12/May/2011	4120		4232
	3901	15/Jun/2006	4030	10/Jul/2012	4120	03/Oct/2007	4233
02/May/2011	3910	12/Jan/2010	4030		4123	05/Dec/2011	4236
	3915		4032	18/Sep/2009	4128	11/Feb/2008	4238
02/Jul/2009	3920	25/Jan/2011	4037		4128	30/May/2011	4239
01/Sep/2010	3924	01/Dec/2009	4037	08/Aug/2011	4128	02/Sep/2011	4240
03/Oct/2007	3924		4037	12/Jul/2010	4130	10/Feb/2010	4240
19/Jan/2010	3930	15/Apr/2010	4039	19/Jan/2010	4130	28/Jun/2011	4240
03/Oct/2006	3930	29/Apr/2010	4039	14/Aug/2008	4131	02/Dec/2010	4241
16/May/2011	3938		4042	06/Jul/2012	4138	29/Sep/2010	4242
13/Nov/2009	3940	21/Oct/2011	4043	10/Jul/2007	4140	03/Oct/2007	4243
11/Feb/2011	3940		4048	04/Aug/2010	4140		4248
05/Jul/2012	3940	25/Aug/2011	4050	22/Oct/2008	4144	08/Apr/2011	4250
17/May/2010	3941	04/Nov/2011	4050	09/Aug/2006	4146	26/Jan/2011	4253
13/Dec/2011	3942	15/Dec/2011	4051	15/Dec/2011	4150	03/Nov/2011	4254
09/Apr/2008	3946	29/Jun/2010	4052	28/Apr/2010	4150		4255
	3946		4053	12/Oct/2007	4150	10/Sep/2008	4256
24/Mar/2010	3950	23/Dec/2011	4057	10/Aug/2011	4151	08/Oct/2008	4260
04/Jul/2008	3953	29/Apr/2010	4059	26/Oct/2010	4152	13/Jul/2010	4260
27/Jun/2011	3954		4060	11/Dec/2009	4156	22/Oct/2008	4260
	3955	13/Jan/2010	4060	28/May/2007	4160		4262
17/Jun/2010	3959	12/Nov/2006	4060	19/Jan/2010	4170	22/Jun/2007	4264
31/Jan/2007	3960	24/Mar/2010	4065	07/Dec/2011	4171		4264

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
22/Oct/2007	4267	09/Feb/2011	4363	22/Jun/2007	4482		4581
19/Oct/2011	4269		4368	29/Mar/2010	4488		4584
23/Feb/2010	4270	17/Oct/2011	4370		4488	08/Apr/2010	4588
16/Jun/2010	4271	29/Mar/2010	4380	07/May/2007	4490	16/Jul/2012	4590
17/Jul/2008	4272		4389		4491	30/May/2012	4590
15/Dec/2011	4277	23/Mar/2011	4390	23/Mar/2011	4493	31/Mar/2011	4599
13/Nov/2009	4280	04/Feb/2009	4390	29/Jun/2010	4495	12/Jan/2010	4600
01/Jun/2007	4282		4393		4495	27/May/2011	4600
26/Apr/2010	4283		4395	15/Jun/2009	4499	14/Jul/2010	4603
	4289	28/May/2009	4398		4504	19/Nov/2008	4609
08/Oct/2008	4290	26/Jan/2011	4400		4506		4613
28/Jun/2011	4290	22/Jun/2006	4400	13/Aug/2008	4509	20/Jan/2011	4615
22/Jun/2007	4296	21/Nov/2007	4407	26/Jan/2012	4510		4615
23/Feb/2011	4300	25/May/2011	4408	10/Dec/2009	4520	28/Jun/2010	4616
22/Jun/2007	4300	28/Apr/2010	4410	13/Jan/2010	4520	05/Dec/2009	4618
05/Nov/2010	4304		4416	19/Jun/2012	4522	27/Jan/2010	4620
24/Aug/2012	4309	16/Jul/2008	4417	03/Sep/2011	4527	14/Jan/2010	4620
	4309		4418	15/Dec/2011	4527	01/Sep/2010	4627
10/Aug/2010	4309	19/Jan/2010	4420	06/Sep/2011	4529		4627
12/Jul/2010	4310	17/Aug/2009	4423	05/Jun/2008	4530	01/Apr/2011	4629
09/Feb/2010	4310		4427	22/Oct/2008	4530	16/Feb/2010	4630
19/Nov/2007	4316	26/May/2010	4428		4534	09/Jul/2012	4630
11/May/2006	4318	27/Jan/2010	4430	20/Jul/2010	4534	12/Mar/2009	4634
	4318	15/Apr/2009	4430	09/Jul/2012	4535	28/Feb/2007	4637
09/Jun/2011	4320	26/May/2011	4431	27/Aug/2009	4535	20/Jan/2010	4640
09/Feb/2010	4320	17/Aug/2010	4432	22/Jun/2007	4536	28/May/2010	4645
22/Jun/2007	4321	29/Jun/2010	4435		4536	16/Mar/2010	4650
03/Oct/2007	4321		4436	02/Nov/2010	4536	20/Aug/2009	4653
23/Aug/2010	4322	12/Apr/2011	4440	25/Feb/2009	4537	04/May/2010	4658
26/May/2011	4325	17/Dec/2009	4440		4541	03/Jul/2012	4660
16/May/2011	4326	26/May/2011	4443	03/Oct/2007	4548	01/Jun/2010	4660
26/Sep/2007	4326	07/Nov/2011	4445	10/Nov/2006	4549		4661
25/Feb/2009	4328	15/Oct/2010	4445	25/Aug/2011	4550		4663
10/Sep/2008	4329		4445	27/Jan/2010	4550		4667
19/Jan/2010	4330		4445	31/Mar/2010	4552	25/Feb/2009	4668
	4332		4450	03/Dec/2011	4554	01/Apr/2011	4670
30/Mar/2011	4332	15/Feb/2012	4450		4554	12/Nov/2009	4670
22/Jun/2007	4336	26/May/2011	4457	26/May/2010	4562	14/May/2010	4670
08/Apr/2011	4340	13/Jan/2010	4460	05/Feb/2008	4566	13/Dec/2011	4672
04/Oct/2010	4345	04/Nov/2011	4460	02/Dec/2010	4569		4672
26/May/2011	4350		4461	06/Oct/2009	4570		4673
07/Jun/2007	4350	08/Nov/2010	4465	23/Feb/2010	4570		4679
26/Jul/2012	4350	14/Aug/2008	4470	22/Jan/2007	4570	26/Jan/2011	4680
07/Aug/2009	4350		4470	27/Aug/2009	4570		4684
08/Jan/2009	4351	05/Feb/2009	4472	16/Apr/2009	4572	28/Jun/2011	4684
	4352	05/Dec/2011	4473	05/Jul/2012	4575	09/Jul/2012	4685
07/Sep/2006	4355	26/May/2011	4474	12/Dec/2011	4576	05/Jul/2012	4690
	4355	29/Mar/2010	4477	01/Mar/2011	4578		4692
19/Jan/2010	4360	16/Jun/2010	4480	27/Jun/2011	4580		4695
12/May/2011	4360	17/May/2010	4481	10/Aug/2012	4581		4697

Dispatch Date	Mass (kg)
09/Aug/2010	4700
02/Sep/2010	4700
13/Dec/2010	4701
	4702
	4704
27/Jun/2011	4704
12/Dec/2011	4704
11/Dec/2008	4705
	4708
08/Feb/2010	4710
09/Jul/2012	4715
	4717
25/Jan/2010	4720
30/Mar/2011	4720
07/Dec/2011	4721
16/Jun/2008	4722
28/Jun/2011	4730
09/Sep/2009	4731
05/Nov/2008	4732
11/Jan/2012	4736
22/Feb/2010	4738
14/Jun/2010	4738
	4740
12/Dec/2011	4745
19/Nov/2009	4746
08/Apr/2010	4748
	4749
22/Jun/2006	4750
01/Feb/2008	4757
12/Apr/2010	4758
20/Nov/2006	4758
07/Feb/2007	4760
	4761
22/Jun/2007	4763
04/Oct/2010	4763
17/Dec/2008	4768
13/Jan/2010	4768
01/Dec/2010	4770
17/Dec/2008	4773
29/Jun/2010	4775
15/Dec/2011	4776
19/Oct/2011	4779
28/May/2009	4780
	4781
05/Dec/2009	4783
22/Jun/2007	4785
22/Nov/2007	4787
26/May/2010	4788
09/May/2011	4790
19/Feb/2009	4790
24/Nov/2010	4793
22/Aug/2008	4793
03/Oct/2007	4795
	4797
28/May/2009	4799
	4800
	4808
08/Apr/2009	4809
14/Dec/2011	4812
09/May/2011	4813
	4817
06/May/2009	4819
26/Nov/2007	4820
08/Apr/2010	4821
	4824
18/Dec/2008	4826
26/Jan/2011	4828
02/Dec/2009	4830
19/Jan/2010	4830
22/Nov/2007	4830
09/Dec/2011	4839
13/Apr/2010	4839
24/Aug/2010	4840
10/Nov/2009	4840
02/Jul/2009	4844
09/Feb/2011	4844
07/Mar/2007	4847
25/Jan/2007	4848
13/Feb/2009	4850
17/Jun/2010	4850
	4851
22/Nov/2010	4853
09/Aug/2011	4853
	4853
29/Jul/2009	4854
31/Oct/2008	4854
22/Oct/2008	4855
	4858
16/May/2007	4860
11/Feb/2011	4864
29/Mar/2010	4870
23/Nov/2007	4872
16/Apr/2010	4872
	4878
08/Apr/2010	4878
01/Aug/2006	4880
06/Sep/2011	4881
31/Aug/2009	4882
	4883
27/Jan/2010	4890
18/May/2010	4890
	4892
03/Nov/2011	4899
	4899
	4899
16/Aug/2010	4900
22/Aug/2011	4900
27/Apr/2011	4900
	4901
12/Dec/2011	4902
	4903
31/Oct/2007	4910
25/Jul/2006	4910
20/May/2010	4911
04/Jul/2012	4917
14/Jan/2009	4920
20/Jan/2010	4920
	4922
23/Nov/2007	4923
	4924
25/Jun/2009	4924
	4924
09/Aug/2010	4926
06/Aug/2008	4929
20/Jun/2011	4930
25/Jan/2010	4930
	4931
28/Sep/2007	4931
	4933
16/Jan/2008	4934
	4937
16/Aug/2010	4939
	4940
31/Aug/2009	4940
12/Feb/2010	4940
15/Oct/2008	4941
08/Apr/2010	4942
01/Dec/2009	4944
	4945
	4946
	4949
02/Sep/2010	4949
12/Jan/2010	4950
	4958
26/Jan/2011	4959
	4960
07/Jun/2007	4961
25/May/2011	4965
17/Dec/2009	4966
22/Jun/2007	4967
	4967
05/Feb/2010	4970
07/Nov/2007	4970
12/Jan/2010	4970
16/May/2011	4971
02/Nov/2006	4980
10/Nov/2006	4987
09/Sep/2010	4988
05/Jul/2007	4990
	4990
28/Jun/2010	4990
27/Jun/2011	4990
	4990
11/Apr/2007	4990
06/Jul/2011	4995
	4996
20/Dec/2011	5000
15/Mar/2007	5001
	5001
19/Nov/2007	5001
	5008
30/Mar/2011	5010
23/Apr/2007	5010
23/Jun/2010	5011
	5012
	5013
04/Aug/2010	5017
10/Oct/2006	5020
24/Jul/2009	5020
	5020
01/Dec/2009	5026
03/Oct/2007	5027
02/Nov/2011	5030
03/Dec/2008	5030
24/Aug/2011	5030
24/Feb/2011	5035
23/Aug/2007	5036
02/Dec/2010	5039
23/Feb/2010	5040
04/Sep/2008	5040
06/Dec/2007	5041
17/May/2006	5044
	5044
	5046
03/Jan/2012	5049
04/Mar/2011	5050
08/Nov/2007	5050
27/Feb/2008	5050
	5051
23/Nov/2007	5051

Dispatch Date	Mass (kg)
	5053
16/Nov/2007	5056
11/Dec/2008	5056
NULL	5057
01/Sep/2010	5058
30/Mar/2011	5060
16/Jun/2010	5060
26/May/2010	5061
04/Mar/2011	5062
27/Nov/2008	5064
25/May/2011	5069
18/Apr/2011	5070
16/Sep/2010	5074
08/Apr/2010	5075
02/Feb/2011	5076
31/Mar/2011	5080
01/Dec/2009	5080
	5080
	5083
18/Apr/2011	5083
17/Aug/2010	5085
09/Aug/2010	5088
23/Nov/2007	5090
	5096
08/Apr/2010	5098
05/Aug/2010	5099
04/Nov/2011	5100
11/Dec/2008	5100
12/Jul/2010	5100
07/Apr/2011	5100
09/Dec/2011	5100
	5101
09/Dec/2011	5102
07/Dec/2011	5103
04/Jul/2012	5103
25/Jan/2008	5104
12/Jul/2010	5110
03/Jul/2012	5110
	5112
20/Jan/2011	5114
	5117
23/Nov/2007	5119
17/Jun/2010	5120
19/Nov/2009	5120
16/Jun/2008	5122
11/Apr/2011	5123
10/Nov/2006	5123
	5123
02/Jul/2009	5123
28/Aug/2012	5126

Dispatch Date	Mass (kg)
	5126
06/May/2009	5126
11/Jan/2008	5128
07/May/2007	5130
25/Jan/2010	5130
12/Feb/2009	5130
	5137
03/Jun/2011	5140
11/Feb/2010	5140
16/Jan/2008	5142
12/Apr/2010	5146
23/Nov/2007	5148
15/Sep/2010	5148
18/Oct/2011	5150
09/Feb/2010	5150
24/Mar/2010	5151
10/Aug/2011	5153
	5153
28/Oct/2009	5153
23/Mar/2011	5160
18/Dec/2008	5162
09/Feb/2011	5167
17/Jul/2008	5170
09/Feb/2010	5170
04/Aug/2010	5171
	5171
	5172
27/Apr/2011	5175
	5178
01/Dec/2009	5180
16/Jun/2010	5182
	5182
13/Jul/2010	5184
31/Jan/2008	5185
28/Apr/2011	5189
	5189
17/Jul/2008	5190
10/Feb/2011	5190
16/Jun/2011	5194
03/Oct/2006	5194
09/Feb/2011	5198
13/Feb/2009	5198
	5198
23/Mar/2010	5200
13/Jan/2010	5200
03/Oct/2006	5202
03/Oct/2007	5203
	5205
05/Jul/2010	5205
09/Feb/2011	5207

Dispatch Date	Mass (kg)
03/Oct/2007	5208
26/Aug/2011	5210
03/Nov/2011	5210
29/Jun/2010	5212
	5214
27/Mar/2012	5216
22/Jun/2007	5216
23/Nov/2007	5217
08/Apr/2010	5218
11/Dec/2009	5218
	5219
12/Apr/2011	5219
17/Dec/2009	5220
20/Jun/2011	5220
12/Dec/2011	5222
27/Jan/2010	5230
08/Sep/2008	5230
03/Oct/2007	5230
15/Jul/2010	5239
	5239
27/Jan/2010	5240
19/Jan/2010	5240
29/Jun/2010	5241
16/May/2011	5244
23/Nov/2007	5244
16/Apr/2009	5244
29/Oct/2007	5245
08/Mar/2011	5247
	5248
13/Nov/2009	5250
10/Feb/2011	5250
22/Jun/2006	5250
03/Oct/2006	5258
	5259
09/Feb/2010	5260
03/Dec/2008	5260
26/Jan/2011	5260
08/Sep/2012	5262
	5262
05/Feb/2010	5263
	5264
	5266
16/Apr/2009	5268
29/Mar/2010	5268
15/Apr/2008	5268
	5269
10/Feb/2011	5270
05/Aug/2008	5271
04/May/2010	5276
15/Jun/2011	5279

Dispatch Date	Mass (kg)
03/Dec/2011	5280
23/Jun/2011	5280
	5282
08/Apr/2009	5284
17/Dec/2009	5285
26/Jan/2011	5286
11/Dec/2009	5287
11/Feb/2011	5288
29/Mar/2010	5288
11/May/2006	5289
22/Jun/2011	5289
27/Feb/2008	5290
	5290
09/Aug/2010	5290
23/Jun/2011	5290
13/Jan/2010	5290
18/Feb/2011	5292
09/Feb/2011	5298
02/Nov/2011	5300
	5300
10/Feb/2011	5300
22/Aug/2011	5300
11/Dec/2009	5301
	5303
06/Dec/2011	5304
08/Sep/2012	5307
	5307
04/Nov/2011	5310
10/Feb/2011	5310
29/Jun/2010	5310
16/Feb/2010	5310
	5312
25/May/2011	5312
03/Jan/2012	5314
11/Mar/2010	5317
	5318
23/Feb/2010	5320
14/Jul/2010	5322
	5322
01/Mar/2010	5322
	5324
28/Apr/2011	5325
	5325
16/Feb/2011	5328
04/Apr/2008	5328
06/Jul/2011	5330
	5330
09/Nov/2007	5330
04/Mar/2009	5330
25/Feb/2010	5330

Dispatch Date	Mass (kg)
24/Jan/2011	5333
12/Oct/2010	5335
20/May/2010	5338
25/Aug/2011	5340
04/Nov/2011	5340
19/Jan/2011	5342
15/Apr/2010	5342
	5343
16/Nov/2010	5344
30/Nov/2010	5344
11/Dec/2008	5350
26/May/2010	5350
	5350
11/May/2011	5352
	5352
29/Nov/2010	5356
08/Jan/2010	5359
04/Oct/2010	5360
16/Mar/2009	5361
	5362
23/Nov/2007	5365
05/Feb/2009	5366
22/Sep/2006	5370
	5371
27/Nov/2009	5371
	5373
15/Nov/2007	5374
	5375
10/Aug/2012	5380
04/Feb/2011	5380
19/Sep/2006	5380
25/Jan/2011	5380
27/Apr/2011	5380
10/May/2011	5381
16/Mar/2010	5381
26/Jan/2011	5383
	5384
29/Dec/2008	5388
	5389
29/Mar/2010	5389
25/Jun/2009	5389
15/Jan/2007	5390
19/Jan/2010	5390
06/Jun/2007	5391
	5393
29/Mar/2010	5394
11/Mar/2011	5394
08/Sep/2012	5398
	5399
	5400
11/Mar/2009	5400
18/Feb/2011	5400
22/Jun/2007	5402
12/Dec/2011	5404
22/Nov/2010	5408
16/Jul/2009	5409
20/May/2010	5410
27/Jan/2010	5410
	5411
	5416
08/Feb/2010	5416
01/Dec/2010	5417
30/Aug/2010	5419
27/May/2010	5420
	5420
29/Mar/2010	5421
	5423
12/Sep/2008	5430
10/Feb/2011	5430
	5434
08/Apr/2009	5436
08/Apr/2010	5438
08/Apr/2010	5438
08/Oct/2009	5439
	5441
30/Sep/2010	5443
	5443
28/Mar/2011	5443
18/Nov/2010	5443
	5444
	5445
04/Aug/2010	5448
	5448
07/Jan/2008	5448
01/Dec/2009	5448
06/Apr/2011	5450
08/Apr/2010	5450
17/Jul/2008	5452
04/May/2012	5452
	5455
05/Feb/2009	5459
04/Nov/2011	5460
22/Jun/2011	5460
13/Jan/2010	5460
21/Feb/2006	5461
29/Mar/2010	5467
26/Jan/2011	5468
06/Feb/2012	5468
23/Aug/2010	5470
	5471
26/Jan/2011	5473
10/Jul/2009	5476
12/Nov/2009	5479
19/Dec/2011	5479
24/Nov/2010	5480
15/Dec/2010	5481
09/Aug/2010	5484
	5484
09/Mar/2011	5485
27/Aug/2009	5486
	5486
06/Apr/2011	5487
08/Sep/2012	5489
	5489
17/Oct/2007	5489
08/May/2007	5490
20/Nov/2006	5490
14/Jul/2010	5491
	5495
	5498
07/May/2007	5500
21/Aug/2007	5500
08/Oct/2010	5502
24/Aug/2010	5502
	5504
08/Apr/2010	5505
01/Dec/2008	5507
06/Jan/2010	5508
27/Jan/2010	5510
	5511
	5513
05/Oct/2009	5515
	5515
06/Dec/2011	5517
04/Mar/2011	5518
	5518
15/Jan/2007	5520
14/Oct/2009	5520
	5520
04/Sep/2008	5523
12/Apr/2010	5523
	5525
30/May/2011	5525
12/Nov/2010	5527
18/Nov/2008	5528
	5529
03/Nov/2011	5530
25/Aug/2011	5530
05/Feb/2009	5530
15/Oct/2010	5534
	5534
	5535
	5536
13/Aug/2008	5539
19/Jan/2010	5540
12/Jan/2010	5540
	5543
	5545
13/Jan/2011	5548
03/Dec/2010	5549
25/Feb/2010	5550
03/Sep/2011	5552
08/Feb/2007	5555
11/Feb/2008	5556
14/Dec/2011	5557
26/May/2010	5557
	5559
07/Jan/2010	5560
	5564
23/Jun/2011	5564
	5566
10/Jun/2008	5566
01/Sep/2011	5569
16/Mar/2010	5570
	5570
13/Aug/2008	5571
27/Nov/2008	5571
10/Mar/2010	5574
12/Apr/2010	5578
08/Sep/2012	5579
	5579
23/Apr/2008	5580
25/Aug/2011	5580
03/Nov/2011	5580
22/Mar/2011	5581
	5582
	5582
05/Aug/2010	5583
	5584
08/Apr/2010	5584
03/Oct/2007	5588
22/Jun/2007	5588
	5588
	5588
28/Sep/2012	5590
02/Apr/2008	5590
	5593
04/May/2010	5595
29/Dec/2008	5596
05/Dec/2011	5597

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
01/Dec/2008	5597		5679	07/Jan/2011	5742		5817
29/Mar/2011	5599	07/Dec/2009	5680	19/Oct/2010	5747	04/May/2010	5818
	5600	05/Dec/2011	5681	22/Feb/2011	5750	04/Mar/2011	5818
17/Dec/2008	5601	30/Mar/2011	5683	16/Sep/2010	5751	09/Mar/2011	5820
	5602	11/Feb/2008	5688		5752	15/Sep/2011	5820
14/Jul/2010	5606		5688		5754	08/Feb/2010	5826
04/May/2012	5606	04/Mar/2010	5690		5758	23/Nov/2006	5830
22/Aug/2008	5610	02/Feb/2011	5692	11/Feb/2011	5759	16/Jun/2010	5834
08/Jun/2010	5610	25/Jan/2012	5693	18/Jun/2007	5760	22/Mar/2011	5838
11/Feb/2011	5610		5693		5761	26/Sep/2012	5840
21/Jul/2010	5611		5695	30/Jul/2012	5761		5842
	5611	16/Aug/2010	5696	10/Mar/2008	5761		5845
	5613	06/Jan/2012	5697	08/Apr/2010	5764	12/Dec/2011	5849
22/Jun/2007	5616	04/Jul/2012	5698	15/Nov/2006	5765	17/Feb/2011	5850
15/Dec/2010	5619	27/Aug/2009	5699	02/Jun/2006	5766	11/May/2006	5851
28/May/2009	5620		5699	10/Aug/2010	5767		5851
02/Apr/2008	5620	09/Jul/2012	5700	08/Apr/2010	5769	31/May/2010	5853
22/Apr/2009	5620	23/Apr/2007	5700	17/Feb/2012	5770		5854
29/Sep/2006	5625		5702	17/Oct/2011	5770		5858
	5625		5702	12/Jan/2010	5770	17/Jun/2010	5860
	5626	26/Jan/2011	5702	25/May/2011	5771	03/Jun/2010	5860
10/May/2011	5628	30/Nov/2010	5704	09/Nov/2010	5774	09/Jun/2010	5861
04/Mar/2011	5629	04/Feb/2011	5705		5774	11/Dec/2008	5864
05/Dec/2006	5630	26/Nov/2007	5707	16/Jun/2010	5775	23/Sep/2011	5864
17/Dec/2009	5630	11/Dec/2011	5709	09/Sep/2010	5780		5865
07/Aug/2008	5634	08/Apr/2010	5713	27/Nov/2009	5780	29/Mar/2010	5866
29/Mar/2010	5637	03/Oct/2007	5713		5786	27/Nov/2009	5867
	5638	07/Dec/2011	5714	07/Dec/2011	5786	24/Nov/2009	5868
16/Dec/2008	5640	19/Oct/2010	5714	07/Jan/2008	5786	18/Nov/2009	5870
	5640	19/Nov/2007	5715	06/Oct/2008	5790	05/Jul/2012	5870
14/Jan/2009	5647		5715	09/Nov/2010	5792		5872
	5647	08/Sep/2012	5715	02/Sep/2010	5793	11/Feb/2011	5872
11/Jan/2007	5649		5715	22/Jun/2011	5796	26/Nov/2007	5873
27/Jan/2010	5650		5716		5796	03/Oct/2007	5875
27/Aug/2009	5654	26/Jan/2011	5718	13/Jan/2011	5798	29/Mar/2010	5875
31/May/2011	5657	08/Jan/2010	5720	02/Feb/2011	5799	29/Nov/2010	5876
	5659		5720	04/Jul/2012	5800	27/Feb/2008	5878
01/Dec/2010	5660	16/Mar/2011	5720	24/Jan/2011	5800	01/Dec/2009	5879
14/Sep/2011	5660		5724	08/Apr/2010	5802		5879
09/Aug/2011	5661	05/Feb/2009	5725	07/Jan/2008	5806	07/Jan/2010	5880
	5661	25/Jun/2010	5729	11/May/2011	5806	16/Mar/2011	5884
	5663		5729		5806	06/Jan/2012	5888
05/Feb/2008	5664	02/Jun/2010	5730		5807	09/Aug/2011	5888
28/Sep/2007	5666	18/Jun/2007	5730		5808	20/Jun/2008	5888
05/Feb/2010	5669		5731	17/Jun/2010	5810	15/Jul/2011	5889
01/Jun/2010	5670	14/Dec/2011	5733	02/Dec/2009	5810	14/Aug/2008	5890
	5670	28/Mar/2012	5734	14/Oct/2008	5811	17/Aug/2010	5890
18/Nov/2010	5670		5736		5811	18/May/2007	5891
16/May/2007	5674	02/Nov/2012	5740		5813	17/Aug/2010	5892
10/Dec/2010	5677	26/Nov/2009	5740	14/Dec/2011	5815	27/Feb/2008	5895

Dispatch Date	Mass (kg)
16/Jun/2010	5895
20/Jan/2011	5897
	5897
23/Mar/2011	5897
07/Dec/2011	5898
11/May/2010	5898
21/Jul/2010	5899
08/Jul/2011	5900
21/Aug/2007	5900
28/Sep/2009	5901
	5901
	5902
06/May/2009	5903
	5904
06/Dec/2011	5906
17/May/2010	5906
08/Apr/2010	5907
	5908
27/Aug/2009	5909
31/May/2010	5910
20/Jan/2010	5910
01/Apr/2011	5910
	5910
12/Apr/2010	5912
03/Dec/2011	5915
	5915
16/Jul/2008	5915
25/Nov/2009	5920
26/Jun/2007	5920
26/Oct/2010	5922
10/Mar/2008	5925
12/Dec/2011	5928
	5929
01/Aug/2006	5930
07/Sep/2011	5933
27/Nov/2008	5935
	5935
	5938
15/Sep/2010	5942
	5942
25/Aug/2006	5943
13/Jun/2011	5947
	5949
22/Mar/2011	5950
15/Nov/2006	5951
	5951
01/Sep/2011	5956
05/Dec/2007	5956
27/Aug/2009	5957
	5958
	5958
29/Jan/2010	5960
07/Dec/2006	5961
04/Nov/2009	5962
	5963
	5963
04/Jul/2011	5965
	5965
15/Jun/2011	5967
12/Jun/2009	5968
22/Oct/2007	5970
	5972
22/Jun/2007	5974
	5974
27/Aug/2009	5974
04/Jul/2011	5976
	5978
13/Jan/2010	5980
02/Feb/2010	5980
	5981
15/Jun/2011	5983
19/Oct/2011	5984
25/Jan/2007	5987
23/Jun/2010	5987
	5987
17/Oct/2007	5988
	5990
28/Jun/2010	5990
07/Feb/2007	5990
04/Feb/2011	5991
07/Mar/2006	5997
	5997
	5999
21/Aug/2007	6000
27/Jan/2010	6000
28/Apr/2010	6004
07/Jan/2011	6005
	6008
12/Apr/2010	6010
22/Aug/2011	6010
04/Nov/2011	6010
12/Oct/2010	6015
06/Nov/2012	6017
15/Sep/2009	6018
25/Nov/2009	6020
	6022
11/Dec/2007	6024
12/Dec/2011	6024
	6026
22/Mar/2011	6028
05/Feb/2009	6029
26/Apr/2010	6030
16/Feb/2010	6030
06/Apr/2011	6030
	6031
17/Aug/2010	6031
10/Nov/2006	6032
05/Apr/2011	6033
08/Apr/2011	6033
03/Dec/2011	6033
11/May/2010	6035
	6037
	6040
10/Feb/2010	6040
12/Dec/2011	6044
22/Oct/2007	6044
09/Aug/2010	6048
	6049
22/Dec/2010	6050
11/Feb/2008	6055
	6056
	6058
20/Apr/2011	6059
14/Aug/2008	6060
03/Jun/2010	6060
	6060
05/Dec/2008	6062
25/Jan/2011	6063
17/Nov/2010	6064
12/Oct/2010	6067
19/Nov/2007	6068
06/Feb/2008	6069
25/Feb/2010	6070
18/Dec/2008	6077
24/Jan/2007	6078
30/Aug/2006	6078
	6078
29/Nov/2007	6078
02/May/2011	6080
23/Sep/2011	6080
	6083
	6085
22/Jun/2007	6087
	6087
22/Jun/2011	6090
16/Jul/2009	6091
	6092
05/Feb/2008	6094
18/Jun/2012	6096
26/Oct/2010	6099
02/Feb/2010	6100
	6101
	6103
13/Nov/2008	6104
18/Nov/2009	6110
07/Jun/2011	6110
11/Feb/2008	6112
	6114
	6117
11/May/2010	6118
02/May/2011	6120
20/Nov/2007	6122
22/Jun/2007	6124
	6124
01/Sep/2010	6126
19/Oct/2010	6126
10/Jul/2009	6127
29/Dec/2008	6128
02/May/2011	6130
11/Dec/2011	6131
	6133
13/Mar/2012	6133
	6133
	6139
26/Nov/2009	6140
15/Feb/2012	6140
16/May/2007	6140
10/Mar/2006	6142
12/Apr/2010	6143
01/Feb/2008	6147
15/Jun/2010	6148
17/Dec/2009	6150
10/Sep/2012	6150
	6153
11/Feb/2011	6156
08/Feb/2010	6160
27/Nov/2008	6162
	6162
25/Jul/2012	6163
25/Jul/2008	6166
	6167
17/Sep/2010	6169
	6169
28/Jun/2010	6170
19/Nov/2009	6170
	6171
20/Oct/2010	6172
16/Nov/2007	6177
02/May/2011	6180
10/Nov/2006	6181

Dispatch Date	Mass (kg)
19/Nov/2009	6190
	6192
11/Jan/2007	6193
21/Aug/2007	6200
	6201
24/Apr/2012	6210
08/Mar/2011	6210
16/Dec/2008	6214
08/Sep/2012	6214
	6215
25/Jul/2008	6216
	6217
28/Oct/2009	6218
21/Jan/2009	6220
22/Dec/2010	6220
	6223
03/Dec/2011	6227
20/Jan/2010	6230
07/Jan/2008	6236
	6237
11/Mar/2009	6240
22/Sep/2006	6240
	6241
23/Sep/2010	6243
25/Feb/2010	6250
10/Nov/2006	6259
	6260
28/May/2010	6260
13/Jul/2010	6260
22/Feb/2010	6263
	6263
04/Jul/2012	6270
08/Dec/2009	6270
	6271
03/Feb/2010	6275
20/Nov/2006	6276
15/Sep/2009	6277
18/Oct/2006	6280
	6280
	6282
	6285
11/Mar/2009	6290
11/Feb/2011	6290
03/Aug/2006	6300
12/May/2006	6305
	6307
12/Jan/2010	6310
13/Jan/2010	6310
06/Feb/2008	6312
	6314
09/Feb/2010	6316
29/Oct/2007	6316
01/Oct/2007	6318
27/Feb/2008	6320
15/Jun/2009	6326
	6328
23/Mar/2012	6330
	6337
01/Mar/2011	6340
10/Sep/2012	6348
01/Aug/2008	6350
06/Sep/2007	6350
22/May/2007	6350
	6350
10/Aug/2011	6359
25/Feb/2010	6360
	6362
11/Feb/2008	6364
16/Jun/2010	6368
11/Jan/2012	6373
09/Nov/2010	6376
27/Apr/2011	6380
19/May/2011	6385
19/Jul/2010	6386
17/Jun/2010	6390
27/Jan/2010	6390
13/Aug/2008	6391
30/Sep/2010	6392
22/Jun/2012	6396
22/Dec/2010	6396
	6396
10/Nov/2006	6397
17/Oct/2011	6400
17/Dec/2009	6400
	6405
10/Nov/2006	6405
	6407
	6408
02/Feb/2010	6410
17/Jan/2007	6410
	6412
05/Dec/2011	6416
10/Feb/2011	6416
	6416
10/Feb/2011	6418
24/Nov/2008	6420
15/Sep/2011	6420
12/Dec/2011	6422
29/Dec/2010	6423
	6427
05/Nov/2008	6428
	6430
18/Oct/2010	6430
15/Sep/2011	6432
05/Nov/2008	6435
	6437
15/Jun/2011	6437
09/Jul/2012	6438
03/Jun/2010	6439
05/Dec/2011	6440
27/Jan/2010	6440
08/Sep/2012	6441
	6441
11/Feb/2008	6446
	6447
09/Jun/2011	6450
27/Jan/2010	6450
26/Jan/2011	6452
	6452
06/Dec/2011	6455
05/Nov/2008	6459
01/Dec/2009	6459
24/Apr/2012	6460
02/Feb/2010	6460
	6461
16/Jul/2008	6466
08/Apr/2010	6468
	6468
12/Jul/2010	6470
27/Jan/2010	6470
15/Nov/2007	6472
	6473
16/Jul/2009	6474
16/Mar/2010	6479
20/Aug/2012	6480
17/Feb/2010	6480
30/Aug/2011	6486
	6486
25/Sep/2009	6488
27/Jan/2010	6490
	6498
21/Aug/2007	6500
	6500
25/Apr/2008	6510
06/Mar/2007	6510
	6514
10/Feb/2011	6518
	6518
04/Oct/2012	6520
NULL	6523
	6527
24/Nov/2009	6530
22/Dec/2010	6531
08/Sep/2012	6532
	6532
	6535
	6536
02/Dec/2009	6540
	6541
	6543
01/Mar/2011	6544
09/Jul/2012	6544
	6545
	6548
23/Sep/2010	6550
	6552
25/Oct/2010	6554
	6566
09/Jun/2010	6568
09/Jun/2010	6568
	6568
31/Mar/2009	6568
23/Sep/2010	6570
16/Mar/2009	6574
28/Sep/2009	6577
11/Sep/2008	6578
05/Jan/2012	6579
	6579
18/Oct/2010	6580
	6584
	6586
18/Jan/2010	6588
05/Feb/2009	6588
27/Jan/2010	6590
10/Mar/2010	6590
23/Aug/2011	6590
17/Sep/2008	6591
	6593
15/Dec/2010	6599
	6600
22/Jun/2011	6600
	6602
	6604
	6607
13/May/2010	6608
	6609
18/Jan/2010	6610
	6611
25/Jul/2008	6618
02/Feb/2010	6620

Dispatch Date	Mass (kg)
08/Jun/2009	6622
31/Jul/2006	6623
	6623
	6623
	6624
17/Aug/2010	6630
03/Sep/2011	6632
13/Nov/2008	6636
	6636
	6641
08/Apr/2009	6642
22/Jun/2011	6650
22/Aug/2008	6651
	6658
	6659
16/Feb/2011	6660
	6666
22/Sep/2009	6668
18/Jan/2010	6668
04/Jul/2012	6670
27/May/2010	6670
05/Dec/2011	6677
09/Mar/2011	6678
	6679
10/Feb/2010	6680
29/Mar/2010	6680
06/Oct/2010	6686
11/Dec/2008	6689
11/Mar/2009	6690
07/May/2007	6690
23/Mar/2012	6690
21/Sep/2006	6695
	6695
	6700
13/Dec/2011	6700
27/Jan/2010	6700
	6701
21/Sep/2006	6704
08/Feb/2007	6707
03/Dec/2009	6710
07/Jan/2010	6711
29/Nov/2010	6713
	6713
	6714
	6716
	6720
17/Feb/2010	6720
21/Sep/2006	6722
	6725
	6727
31/Oct/2007	6730
27/Jan/2010	6730
21/Sep/2006	6731
	6731
14/Oct/2010	6739
16/Mar/2011	6739
16/Mar/2010	6740
23/Jan/2007	6740
11/Oct/2007	6741
	6743
28/Aug/2009	6745
08/Apr/2009	6749
26/Feb/2009	6750
10/Feb/2012	6759
	6759
07/Dec/2009	6760
	6763
	6765
01/May/2009	6766
16/May/2011	6770
03/Oct/2007	6774
06/Jun/2008	6778
	6779
08/Feb/2007	6779
02/Feb/2010	6780
	6784
28/Sep/2006	6786
29/Dec/2008	6786
	6788
17/Jan/2007	6790
16/May/2008	6790
	6790
17/Dec/2007	6800
07/Jan/2010	6800
25/Jan/2010	6800
25/Jul/2012	6803
11/Mar/2011	6804
05/Dec/2011	6804
	6804
	6808
12/Dec/2011	6810
26/May/2010	6810
17/Jan/2007	6810
12/Nov/2009	6813
	6814
	6818
	6820
03/Jul/2012	6820
14/Aug/2008	6820
	6822
07/Jun/2007	6828
05/Oct/2007	6830
21/Jul/2008	6830
17/Feb/2011	6830
	6833
11/Dec/2008	6834
16/Jun/2008	6836
05/Feb/2008	6839
04/Jul/2012	6840
27/May/2010	6840
10/Nov/2006	6846
19/Oct/2010	6848
05/Oct/2010	6849
30/Aug/2010	6850
02/Nov/2011	6850
	6856
31/Aug/2009	6860
	6865
11/Mar/2011	6867
	6867
19/Apr/2011	6870
04/Aug/2010	6870
15/Dec/2008	6870
16/Feb/2010	6870
	6879
25/Aug/2011	6880
02/Nov/2011	6880
29/Jan/2009	6882
13/Jul/2010	6889
13/Jan/2010	6890
18/Feb/2011	6891
03/Sep/2011	6895
	6895
	6896
02/Sep/2010	6900
	6901
	6901
12/Apr/2011	6905
10/Oct/2006	6910
04/Feb/2011	6910
18/Jun/2007	6911
	6911
06/Dec/2008	6913
	6915
29/Mar/2010	6918
10/Oct/2006	6920
	6922
17/Dec/2009	6924
	6929
10/Mar/2008	6929
17/Oct/2006	6930
27/Sep/2006	6931
11/May/2010	6931
16/Jan/2012	6933
07/Mar/2012	6940
08/Sep/2012	6940
	6940
16/Jun/2010	6944
	6945
	6949
	6949
21/Jan/2011	6950
27/Apr/2010	6950
	6956
06/Sep/2011	6958
07/Dec/2009	6960
04/Jul/2012	6960
11/Sep/2006	6963
17/Oct/2006	6970
28/Mar/2012	6970
12/Apr/2011	6972
	6972
25/Aug/2006	6972
	6976
02/Mar/2011	6979
07/Aug/2008	6985
	6985
	6988
22/Jul/2008	6990
	6990
18/Sep/2007	6990
01/Feb/2008	6992
15/Nov/2010	6995
	7000
	7001
12/Oct/2006	7004
07/Dec/2009	7005
03/Aug/2006	7008
02/Feb/2010	7010
14/May/2007	7010
12/Nov/2010	7013
	7015
05/May/2010	7020
29/Sep/2006	7022
27/May/2010	7024
03/Sep/2008	7030
29/Oct/2007	7030
27/Sep/2006	7031
	7031
	7033

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
15/Mar/2007	7034	19/Sep/2006	7150	01/Mar/2010	7234		7341
28/Jan/2008	7038	03/Dec/2009	7150	08/Sep/2012	7239	17/Sep/2009	7342
28/Oct/2009	7039		7151	03/Dec/2009	7240	24/Mar/2010	7345
12/Feb/2008	7040		7153	11/Feb/2011	7240	22/Mar/2011	7345
07/Dec/2009	7040	29/Sep/2010	7154	12/Jul/2010	7240	12/Sep/2008	7348
	7042	05/Dec/2011	7154		7242		7348
26/Jul/2012	7050		7155	20/Jan/2010	7245	13/Jul/2010	7350
14/Dec/2009	7050	16/Mar/2010	7159	27/Sep/2006	7248	11/Oct/2006	7354
23/Sep/2011	7060	22/Apr/2009	7160	17/Jul/2008	7250	09/Jul/2012	7354
	7060		7165	26/Jul/2012	7250	06/Feb/2012	7357
	7063	02/Feb/2011	7166		7251	28/Sep/2012	7360
07/Dec/2006	7063	03/Sep/2011	7167		7255	27/Jan/2010	7360
	7069		7167	25/Aug/2010	7257	02/Feb/2011	7360
05/Dec/2006	7070	09/Jul/2012	7169	15/Apr/2010	7258		7362
07/Dec/2009	7070		7169		7258	09/Jul/2012	7364
	7076	18/Oct/2011	7170	14/Dec/2009	7258		7369
	7076	03/Jun/2010	7170		7258	23/Apr/2008	7370
07/Apr/2008	7080	03/Oct/2006	7172		7260	07/Dec/2009	7370
14/Dec/2009	7080	21/Dec/2010	7173	15/Aug/2006	7260		7371
22/Jun/2012	7085		7174	17/Dec/2009	7260	22/Oct/2007	7374
09/Jul/2012	7089	14/Sep/2009	7175	23/Mar/2011	7268		7376
	7090	23/Jun/2010	7176	30/Aug/2010	7270	03/Feb/2010	7378
28/Sep/2007	7090	03/Jun/2010	7180	07/Dec/2009	7270	03/Dec/2009	7380
06/Apr/2011	7090	08/Sep/2008	7180	09/Jul/2012	7274		7382
04/Jul/2012	7098		7180		7278	08/Apr/2010	7383
02/Jun/2010	7100	22/Oct/2007	7183	02/Apr/2008	7280	06/Sep/2011	7389
	7101		7183	13/Nov/2009	7280	13/Nov/2009	7390
	7103	21/Dec/2010	7186	04/Jun/2010	7280	07/May/2007	7390
04/Apr/2008	7107	05/Jul/2012	7188		7283		7391
07/Jun/2010	7110	12/Jul/2010	7190	09/Jul/2012	7284	03/Dec/2009	7400
27/Jan/2010	7110	05/Feb/2008	7190		7285	24/Dec/2007	7400
03/Dec/2011	7110		7192	04/Jul/2012	7289	17/May/2010	7407
	7115	09/Jul/2012	7194	26/Feb/2007	7290	01/Sep/2010	7407
04/Jul/2012	7120	18/Oct/2011	7199		7296		7407
03/Dec/2009	7120	20/Jan/2010	7200	04/Dec/2009	7300	02/Feb/2010	7410
	7126	07/Jun/2010	7200	17/Aug/2010	7301	16/May/2008	7410
04/Dec/2009	7130		7201		7303		7414
15/Jul/2010	7135	04/Jul/2012	7208	03/Jul/2012	7304	10/Jan/2007	7416
	7135	NULL	7209		7305		7416
01/Sep/2010	7140	15/Apr/2010	7210		7307	10/Mar/2010	7420
14/Nov/2007	7140	12/Jul/2010	7210	14/Nov/2007	7310	08/Jun/2010	7420
17/Dec/2009	7140	16/Jul/2008	7212	14/Oct/2008	7310	20/Feb/2006	7421
01/Mar/2011	7140	21/Dec/2010	7212	21/Dec/2010	7316		7423
	7142		7212	02/Feb/2011	7317	06/Jul/2011	7427
11/Oct/2006	7146		7217	05/Nov/2010	7319	07/Dec/2009	7430
	7146	12/Jul/2010	7220	07/Jun/2010	7320		7434
25/Feb/2008	7148	04/Sep/2008	7220	07/Nov/2011	7320		7436
25/Feb/2008	7148	28/Sep/2012	7220	16/Feb/2010	7330	09/Aug/2011	7439
29/Sep/2006	7149	03/Oct/2007	7230	17/Nov/2010	7338		7439
09/Jul/2012	7149	22/Jun/2012	7230	09/Feb/2010	7340	15/Apr/2010	7440

Dispatch Date	Mass (kg)
	7446
	7446
	7448
29/Jun/2010	7449
16/Feb/2010	7450
	7453
09/Sep/2010	7455
15/Apr/2010	7460
11/Mar/2009	7460
	7464
20/Feb/2006	7466
21/Dec/2010	7468
12/Jul/2010	7470
10/Mar/2010	7475
20/Sep/2006	7480
21/Sep/2006	7484
	7484
	7489
20/Jan/2010	7490
03/Dec/2009	7490
	7491
	7493
05/Dec/2007	7494
04/Aug/2010	7500
27/Apr/2010	7500
	7500
10/Nov/2006	7502
	7505
20/Nov/2006	7505
	7509
07/Dec/2009	7510
	7516
04/Dec/2009	7520
07/Dec/2009	7521
	7521
	7522
	7525
05/Nov/2008	7530
	7530
	7530
03/May/2010	7530
	7537
09/Jun/2011	7540
17/Dec/2009	7540
23/Mar/2012	7540
24/Oct/2007	7543
	7544
12/Jul/2010	7550
27/Nov/2009	7550
28/Mar/2008	7550
	7552
	7555
10/May/2011	7560
27/May/2010	7560
	7566
13/Jan/2010	7569
06/Nov/2006	7570
07/Dec/2009	7570
24/Jan/2011	7578
	7580
	7590
06/Jul/2011	7590
07/Dec/2009	7590
	7591
31/Jan/2007	7600
14/Dec/2009	7600
14/Aug/2008	7601
01/Feb/2008	7602
20/Apr/2007	7602
28/Aug/2008	7602
17/May/2010	7606
19/Oct/2010	7606
	7607
11/Dec/2007	7609
04/Dec/2009	7610
13/Jan/2010	7610
	7614
	7616
09/Jul/2012	7619
03/Dec/2009	7620
03/Mar/2008	7620
31/Mar/2008	7620
20/Feb/2006	7620
	7625
27/Sep/2006	7630
04/Dec/2009	7630
08/Jun/2010	7630
	7632
03/Dec/2009	7632
08/Apr/2010	7634
27/Sep/2006	7639
09/Jun/2011	7639
09/Jul/2012	7639
04/Dec/2009	7640
05/Sep/2008	7640
	7643
26/Feb/2009	7648
05/Jul/2012	7649
17/Feb/2010	7650
	7650
23/Mar/2009	7650
	7652
05/Aug/2010	7653
07/Dec/2009	7660
21/Jun/2010	7660
19/Nov/2009	7661
27/Sep/2006	7666
09/Mar/2009	7670
02/Feb/2010	7670
10/Feb/2009	7670
03/Oct/2007	7672
	7677
06/Nov/2006	7680
27/Jan/2010	7680
25/Jun/2007	7684
20/Feb/2006	7684
24/Nov/2009	7690
	7698
11/Feb/2008	7698
15/Jul/2010	7700
03/Oct/2006	7702
	7703
18/Oct/2010	7710
22/Apr/2008	7711
23/Jun/2011	7712
05/Feb/2009	7716
17/Mar/2009	7720
29/Dec/2008	7722
13/Sep/2010	7726
	7729
06/Nov/2006	7730
13/Dec/2006	7730
05/May/2011	7731
	7734
03/Oct/2006	7734
29/Sep/2006	7738
	7738
26/Aug/2011	7740
03/Nov/2011	7740
13/Jan/2010	7741
	7741
03/Mar/2010	7743
30/Mar/2011	7747
	7749
13/Dec/2006	7750
16/Mar/2010	7751
09/Aug/2006	7757
19/Jan/2010	7760
22/Oct/2009	7761
29/Sep/2006	7766
	7766
14/Aug/2008	7770
22/Oct/2009	7770
13/Dec/2006	7770
03/Jul/2009	7771
02/Sep/2010	7771
16/Jun/2010	7772
	7772
05/Jan/2012	7777
22/Nov/2011	7779
25/Feb/2010	7780
18/Jun/2010	7783
20/Feb/2006	7784
28/Oct/2009	7784
	7786
22/Feb/2010	7788
29/Jun/2010	7790
14/Jan/2010	7790
	7791
	7793
20/Feb/2006	7793
	7795
19/Aug/2010	7797
	7797
08/Jun/2010	7800
26/Feb/2008	7800
01/Dec/2009	7802
	7802
20/Feb/2006	7802
	7804
	7806
	7806
28/May/2010	7808
19/Jan/2010	7810
09/Oct/2009	7811
16/Jun/2010	7816
	7820
03/Feb/2010	7820
07/Nov/2011	7826
19/Nov/2009	7830
13/Jan/2010	7830
	7836
02/Feb/2010	7840
14/Jan/2010	7840
	7847
17/Jun/2010	7849
09/Feb/2010	7850
05/Feb/2009	7854
	7854
	7855

Dispatch Date	Mass (kg)
20/Jan/2010	7860
31/Aug/2009	7860
	7861
	7863
	7865
20/Feb/2006	7865
07/May/2007	7870
	7870
18/Nov/2008	7870
	7872
24/Sep/2008	7878
	7879
10/Nov/2006	7880
03/Oct/2007	7880
	7886
13/Nov/2007	7888
26/May/2006	7888
10/Jul/2006	7888
	7888
19/Nov/2009	7890
03/Oct/2007	7890
	7895
	7899
26/Jan/2011	7900
	7904
05/Oct/2010	7906
02/Nov/2006	7910
26/Oct/2012	7910
13/Jan/2010	7910
	7915
27/Jan/2010	7920
10/Nov/2006	7924
28/Mar/2012	7926
	7927
18/Jan/2010	7927
26/Jan/2011	7930
	7931
22/Jun/2007	7938
27/Feb/2008	7939
30/Aug/2010	7940
09/Feb/2010	7940
	7941
	7947
20/Feb/2006	7947
08/Jun/2010	7950
05/May/2010	7950
29/May/2006	7960
22/Jan/2009	7960
22/May/2007	7960
	7963
25/Mar/2008	7970
18/Jun/2010	7970
26/Feb/2009	7973
03/Jul/2009	7980
26/Jan/2011	7981
14/Apr/2011	7981
	7983
NULL	7985
26/Feb/2008	7990
19/Feb/2009	7992
09/Aug/2011	8000
25/Feb/2010	8000
26/Sep/2008	8008
07/Feb/2008	8010
18/Nov/2009	8020
15/Feb/2011	8024
	8024
05/Oct/2010	8028
28/Sep/2006	8029
22/Jun/2006	8029
17/Aug/2010	8030
03/Jul/2012	8030
18/Aug/2006	8040
17/Aug/2010	8042
09/Feb/2010	8050
	8051
	8058
17/Feb/2010	8060
11/Jan/2007	8060
	8060
	8067
15/Feb/2010	8070
17/Apr/2007	8070
	8074
	8074
08/Feb/2011	8076
	8079
09/Feb/2010	8080
	8081
17/Aug/2010	8085
	8085
	8088
27/Jan/2010	8090
19/Dec/2007	8090
23/Feb/2010	8100
09/Sep/2008	8100
19/Nov/2009	8110
19/Sep/2006	8110
	8113
27/Feb/2008	8116
23/Oct/2007	8119
08/Sep/2012	8119
10/Oct/2006	8120
12/Apr/2011	8120
17/Feb/2010	8120
	8122
	8126
15/Aug/2006	8130
23/Feb/2010	8130
	8138
10/Oct/2006	8140
09/Feb/2010	8140
25/Jun/2007	8148
09/Feb/2010	8150
08/Feb/2010	8153
	8156
16/Aug/2006	8160
12/Jan/2010	8160
15/Apr/2010	8165
	8165
29/Apr/2010	8165
	8167
19/Nov/2009	8170
29/May/2006	8171
	8172
24/Dec/2007	8172
	8174
09/Feb/2010	8180
	8181
04/Jul/2012	8188
13/Jan/2010	8190
25/Feb/2010	8190
09/Aug/2010	8193
	8194
	8199
31/May/2006	8200
16/Jun/2008	8200
23/Feb/2010	8200
28/Sep/2006	8210
09/Feb/2010	8215
24/Jan/2007	8220
12/Jan/2010	8230
12/May/2008	8237
30/Aug/2010	8240
09/Feb/2010	8240
	8244
31/Oct/2007	8250
26/Oct/2007	8255
	8255
18/Nov/2010	8268
	8269
06/Sep/2011	8274
11/Jan/2010	8275
17/Jan/2007	8280
21/Apr/2011	8290
13/Sep/2012	8292
09/Aug/2010	8300
08/Sep/2012	8301
	8301
22/Jun/2011	8303
	8303
	8304
	8307
	8308
18/Aug/2006	8310
01/Feb/2010	8310
25/Mar/2008	8310
23/Feb/2010	8320
25/Mar/2008	8320
08/Apr/2010	8323
27/Sep/2006	8328
09/Jun/2011	8330
09/Feb/2010	8330
14/Jul/2010	8333
	8333
21/Feb/2006	8337
05/Jul/2012	8340
10/Nov/2006	8340
26/Mar/2009	8346
	8346
	8348
29/Oct/2007	8349
23/Jun/2011	8350
03/Jul/2012	8359
17/Feb/2011	8360
16/Sep/2010	8364
	8364
22/Feb/2010	8370
	8371
	8373
09/Nov/2007	8376
03/Oct/2006	8376
07/Nov/2011	8379
16/Aug/2010	8386
07/Nov/2011	8387
01/Mar/2010	8390
21/Mar/2012	8392
18/Jan/2010	8392
	8396
01/Feb/2010	8400

Dispatch Date	Mass (kg)
	8401
	8403
	8418
10/May/2011	8420
02/Feb/2010	8420
	8426
07/Dec/2009	8428
19/Aug/2009	8430
10/Mar/2010	8436
08/Sep/2012	8437
	8437
24/Mar/2011	8439
	8439
05/Mar/2009	8440
	8441
09/Nov/2007	8444
01/Feb/2010	8448
10/Mar/2010	8449
16/Nov/2010	8449
13/Dec/2007	8451
22/Sep/2006	8455
	8455
02/Sep/2010	8460
26/Nov/2009	8460
	8482
	8485
	8487
03/Feb/2010	8490
16/Jul/2010	8496
	8496
	8498
25/May/2011	8498
26/Oct/2012	8500
22/Sep/2006	8500
	8507
20/Aug/2009	8512
	8514
16/May/2007	8515
03/Feb/2010	8520
	8521
16/Apr/2008	8527
01/Feb/2010	8528
	8528
	8532
	8534
	8538
	8539
03/May/2010	8540
	8544
03/May/2010	8550
	8550
	8552
18/Aug/2011	8565
	8568
27/Jan/2010	8570
18/Apr/2011	8590
22/Sep/2006	8591
	8591
03/Oct/2007	8593
	8593
	8598
03/May/2010	8600
15/Dec/2011	8609
16/Mar/2012	8610
04/Apr/2007	8610
29/Sep/2010	8618
	8618
	8621
	8625
28/Oct/2009	8630
03/Dec/2009	8630
05/Nov/2008	8635
05/Jul/2012	8636
26/Jul/2006	8640
20/Dec/2010	8642
20/Jun/2008	8645
19/Jan/2010	8650
	8657
21/Dec/2007	8657
	8659
16/Mar/2012	8660
27/Apr/2011	8660
18/Nov/2008	8661
09/Nov/2010	8663
10/Sep/2012	8664
	8668
03/Dec/2009	8680
	8686
	8689
17/Sep/2010	8689
10/Feb/2011	8690
	8695
13/Jan/2011	8700
	8700
21/Apr/2008	8700
17/Aug/2012	8709
	8709
07/Jun/2010	8710
01/Feb/2010	8712
	8716
09/Sep/2010	8719
03/Dec/2009	8720
	8729
04/Dec/2009	8730
14/Dec/2009	8730
03/Sep/2010	8732
	8734
	8736
16/Mar/2012	8740
25/Jan/2007	8750
16/Mar/2012	8750
20/Dec/2010	8760
21/Apr/2009	8760
	8766
11/Oct/2007	8766
	8768
02/Feb/2010	8770
06/Aug/2009	8771
	8784
13/Nov/2007	8785
26/Aug/2011	8790
	8793
09/Mar/2011	8794
03/Aug/2006	8795
	8798
01/Mar/2007	8799
	8800
19/Sep/2006	8800
06/Jan/2010	8800
	8807
	8809
	8811
13/Jan/2011	8817
28/Feb/2011	8820
29/Mar/2010	8828
	8829
09/Jul/2012	8830
14/Dec/2007	8830
28/Jun/2012	8831
23/Jul/2012	8840
28/Jun/2012	8841
	8843
01/Sep/2010	8845
	8850
NULL	8850
	8852
	8856
17/Sep/2010	8857
25/Sep/2009	8862
31/Mar/2011	8864
NULL	8865
25/Jan/2007	8870
	8870
	8886
12/Apr/2011	8890
17/Feb/2010	8890
	8891
05/Aug/2010	8895
	8897
28/May/2010	8899
04/Sep/2008	8900
24/Mar/2010	8903
28/Sep/2010	8907
06/Dec/2011	8911
	8918
23/Feb/2010	8920
	8920
18/Jul/2011	8920
04/Mar/2011	8930
28/Apr/2010	8930
16/Aug/2010	8943
04/Mar/2009	8950
08/Aug/2012	8950
22/Feb/2010	8953
	8954
10/Mar/2010	8963
29/Aug/2007	8967
09/Jul/2012	8970
NULL	8980
20/Apr/2010	8980
24/Aug/2012	8981
	8981
15/Mar/2012	8984
	8986
22/Feb/2010	8988
25/Sep/2009	8990
17/Apr/2008	9000
11/Dec/2006	9000
18/Feb/2011	9000
	9006
06/Jul/2011	9009
	9011
29/Aug/2006	9018
09/Sep/2010	9018
08/Aug/2012	9030
09/Nov/2010	9031
	9033
NULL	9035
	9036
25/Jun/2010	9038

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
NULL	9050	29/Nov/2010	9177		9394		9622
12/Jan/2010	9050	08/Feb/2009	9181	21/Apr/2009	9400	26/Nov/2009	9630
16/Sep/2010	9057	05/Oct/2010	9188	24/Sep/2008	9400		9639
12/Jan/2010	9057	07/Dec/2007	9189		9403	18/Apr/2011	9640
18/Feb/2011	9070	06/Feb/2009	9189	17/Aug/2010	9403		9643
12/Oct/2010	9071	06/Sep/2011	9190	17/Feb/2011	9410		9648
24/Feb/2010	9072	01/Aug/2012	9200	14/Oct/2009	9410	29/Dec/2010	9650
10/Mar/2010	9072	04/Feb/2011	9200	02/Sep/2010	9412		9650
07/Oct/2010	9074	10/Jul/2008	9210		9412	07/Dec/2007	9657
04/Nov/2008	9081		9213	28/Apr/2008	9429	19/Sep/2006	9660
	9083	06/Oct/2010	9215	24/Nov/2008	9430	02/Sep/2010	9662
03/Feb/2009	9086	18/Feb/2008	9222		9433	19/Mar/2008	9670
	9086	01/Dec/2008	9230		9435		9675
03/Feb/2009	9088	17/Feb/2011	9234	02/Feb/2009	9450		9682
02/Feb/2009	9089	02/Feb/2009	9250	24/Nov/2010	9450		9689
20/Feb/2009	9090		9253		9451	22/Feb/2010	9690
03/Feb/2009	9095	06/Feb/2009	9262	02/Feb/2011	9460	12/Jul/2010	9700
07/Feb/2009	9099		9265	13/Jul/2011	9470	20/Dec/2010	9701
05/Oct/2010	9099	NULL	9265		9473		9705
14/Aug/2008	9100		9267	07/Jan/2010	9476	08/Sep/2012	9707
09/Nov/2008	9104	08/Oct/2010	9276	22/Jul/2011	9480	20/Dec/2010	9708
	9104		9276	22/Jul/2011	9490	19/Nov/2009	9710
07/Oct/2010	9108		9278	16/Feb/2010	9490	31/Jan/2007	9711
12/Feb/2009	9110	19/Nov/2009	9280		9494		9712
	9115		9281		9498	26/Jul/2012	9720
03/Feb/2009	9117		9283	22/Jul/2011	9500	23/Feb/2010	9720
	9117	20/Jan/2011	9284	17/Jan/2007	9500		9725
28/Jan/2009	9119	09/Nov/2008	9285		9501	22/Feb/2010	9730
09/Feb/2011	9120	11/Jun/2010	9285	07/Jun/2010	9510	10/Oct/2006	9740
	9122		9287	28/Jun/2012	9517	13/Jan/2010	9740
06/Oct/2011	9126	12/Jul/2007	9299	05/Oct/2010	9526	02/Dec/2009	9740
15/Mar/2012	9127	26/Jul/2006	9300		9526		9748
20/Jan/2010	9130	06/Nov/2008	9301	23/Jun/2011	9530	27/Oct/2008	9750
26/Feb/2010	9139		9308		9535	02/Nov/2011	9750
08/Oct/2010	9140		9310	03/Oct/2007	9540	26/Mar/2012	9752
	9142	06/Oct/2010	9315	26/Nov/2009	9540	06/Oct/2010	9752
07/Feb/2009	9145	03/Feb/2009	9317		9546	03/Jul/2012	9760
03/Oct/2007	9149	28/Apr/2008	9318	01/Sep/2011	9550		9775
03/Mar/2011	9150	04/Jan/2010	9320		9560	03/Sep/2010	9788
17/Feb/2011	9160	22/Feb/2010	9340		9566		9791
28/Jun/2012	9160	01/Feb/2010	9344	17/Aug/2010	9570	07/Mar/2012	9797
02/Oct/2010	9160		9360	15/Jul/2010	9580		9798
	9160	03/Jul/2012	9360	18/Feb/2011	9590	12/Feb/2008	9800
08/Oct/2010	9162	16/Aug/2010	9368	22/Mar/2011	9593		9802
25/Feb/2007	9163	11/Dec/2011	9368	31/Aug/2009	9594		9823
08/Sep/2012	9163	25/Jan/2010	9380		9596	29/Nov/2010	9849
	9163	02/Apr/2009	9380	26/Feb/2007	9614		9852
12/Feb/2009	9170	06/Nov/2008	9381	05/Oct/2010	9616		9866
12/May/2008	9170	29/Jun/2010	9388		9616	31/Aug/2009	9867
	9176	03/Sep/2010	9389	07/Jun/2010	9620		9868

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
26/Feb/2008	9870	29/Jan/2010	10090	07/Sep/2011	10360		10606
	9879		10102	28/Feb/2007	10366	19/Nov/2009	10610
28/Sep/2012	9880	04/Oct/2010	10110	18/Aug/2006	10370		10628
	9888	01/Mar/2007	10115		10378	07/Dec/2009	10640
23/Jan/2008	9890	19/Nov/2009	10130	03/Nov/2010	10381	09/Jun/2011	10640
10/Feb/2010	9890		10132	24/Jan/2011	10400	02/Feb/2010	10640
	9895	04/Jan/2010	10138		10403		10641
	9897	NULL	10145	07/Nov/2011	10406	06/Oct/2010	10660
	9897	12/Jan/2010	10150	30/Mar/2011	10416		10660
	9900	18/Jun/2008	10157	27/Apr/2011	10426	29/Jan/2010	10660
30/Apr/2007	9900	20/Dec/2010	10164	09/Nov/2010	10426	28/Jun/2007	10660
25/Feb/2010	9900	04/Jan/2010	10175	05/Feb/2010	10428	08/Nov/2010	10670
	9903	12/Jul/2010	10180	24/Oct/2011	10431	31/Mar/2011	10679
	9909	01/Oct/2008	10183		10433	25/Feb/2010	10680
07/Jan/2010	9910		10186	23/Jun/2007	10433	26/Aug/2011	10680
	9911	02/Feb/2010	10190	27/Jan/2010	10440	27/Jan/2010	10690
	9920	22/Nov/2010	10197	06/Jul/2011	10440	12/Jul/2010	10690
19/Feb/2009	9926	14/Feb/2007	10200	19/Nov/2009	10450	01/May/2008	10700
	9927		10204	10/Jul/2009	10460	06/Jan/2010	10705
08/Sep/2012	9934	06/Oct/2010	10206	03/Nov/2010	10461	22/Feb/2011	10710
	9938	22/Sep/2010	10208	03/Nov/2011	10470	19/Nov/2009	10720
11/Mar/2009	9940	12/Oct/2010	10210	07/May/2011	10470		10725
04/Mar/2011	9940	29/Jan/2010	10210	09/Nov/2010	10481	25/Oct/2010	10740
31/Aug/2009	9946	18/Jun/2008	10218		10485	02/Feb/2010	10740
	9952	29/Jan/2010	10230	12/Jan/2011	10485		10743
	9957		10235	05/Feb/2010	10490	12/Jul/2010	10750
	9966		10239	24/Jul/2009	10490		10750
	9968	26/Nov/2009	10240		10495	01/May/2008	10760
31/Aug/2009	9969		10244	12/Jun/2012	10500		10773
08/Dec/2010	9970	08/Sep/2012	10251	03/Nov/2010	10521	12/Oct/2010	10773
	9975	07/Nov/2011	10256		10523	21/Apr/2009	10780
08/Sep/2012	9979		10258		10531		10793
	9979	29/Dec/2010	10260	12/Jun/2012	10550	08/Sep/2012	10796
21/Mar/2012	9980		10260	19/Nov/2009	10550	08/Nov/2010	10800
24/Jul/2009	9984	10/Jul/2009	10269	26/Aug/2011	10560		10805
19/Oct/2012	10000	29/Jan/2010	10270	04/Nov/2011	10560	04/Mar/2010	10810
25/Feb/2010	10010		10279	04/Jun/2010	10560		10814
26/May/2010	10018	29/Jan/2010	10280	22/Nov/2010	10572		10818
23/Feb/2010	10020		10285	26/Aug/2011	10580	18/Jul/2011	10820
01/Apr/2011	10020	26/Nov/2009	10290	25/Feb/2010	10580	19/Nov/2009	10822
25/Jun/2009	10021	03/Nov/2010	10291		10585	11/Mar/2009	10850
	10029	02/Nov/2011	10300		10587	18/Nov/2009	10850
10/Feb/2010	10030	24/Aug/2011	10300	09/Jul/2012	10589	01/Feb/2010	10860
01/Jun/2011	10038	NULL	10303	13/Jan/2010	10590		10868
22/Oct/2010	10050	06/Oct/2010	10308	13/Nov/2009	10590		10868
	10061	04/Jul/2012	10310		10591	15/May/2009	10886
	10068		10319		10599	08/Sep/2012	10886
	10070		10328	14/Sep/2010	10599		10886
22/Oct/2010	10070	29/Nov/2010	10333		10601	19/Nov/2009	10910
	10086		10342		10603	13/Jan/2010	10910

Dispatch Date	Mass (kg)
02/Feb/2010	10920
01/May/2008	10920
	10920
09/Jul/2012	10939
13/Jul/2011	10943
	10948
	10954
	10975
21/Apr/2009	10980
	10988
19/Nov/2009	10990
19/Oct/2010	11000
23/Feb/2010	11010
01/May/2008	11020
13/Jan/2010	11030
22/Oct/2010	11030
	11038
26/Aug/2011	11040
04/Nov/2011	11040
	11047
	11049
01/May/2008	11050
18/Nov/2009	11060
03/Nov/2011	11090
12/Sep/2011	11090
	11104
09/Jul/2012	11110
06/Oct/2010	11113
	11124
08/Feb/2007	11137
13/Jan/2010	11140
20/Feb/2006	11140
12/Apr/2011	11150
17/Dec/2009	11150
14/Oct/2008	11160
	11174
09/Jul/2012	11180
	11202
05/Nov/2012	11204
26/Nov/2009	11206
12/Jan/2010	11210
29/Apr/2010	11220
04/Nov/2011	11220
13/Jul/2011	11229
	11229
25/Aug/2011	11230
09/Feb/2010	11230
08/Aug/2012	11240
	11245
13/Jul/2011	11249
	11249
19/Nov/2009	11250
	11266
13/Jul/2011	11267
	11268
09/Sep/2010	11270
	11281
13/Jan/2010	11290
13/Jul/2011	11293
18/Feb/2011	11300
18/Jan/2011	11305
14/Dec/2009	11320
14/Sep/2010	11320
31/May/2011	11340
	11340
26/Jun/2008	11340
	11363
02/Feb/2011	11375
21/Apr/2008	11385
13/Jul/2011	11390
	11394
05/Jul/2012	11400
	11401
10/Nov/2006	11418
05/Jul/2012	11430
13/Jul/2011	11476
04/Jan/2010	11483
18/Feb/2011	11485
01/Dec/2008	11500
18/Feb/2011	11503
18/Nov/2009	11510
17/Feb/2011	11512
29/Sep/2010	11540
08/Dec/2010	11558
17/Feb/2010	11580
08/Dec/2008	11600
26/Jun/2008	11610
07/Mar/2012	11612
	11612
	11617
24/Oct/2011	11619
27/Jun/2011	11620
NULL	11627
12/Apr/2011	11660
17/Feb/2010	11660
28/Nov/2011	11690
	11716
	11730
	11738
	11741
06/Jan/2010	11750
20/Feb/2006	11766
29/Sep/2010	11770
	11773
12/May/2008	11780
14/Jun/2006	11790
14/Feb/2007	11790
	11791
08/Sep/2012	11794
	11794
	11805
12/Oct/2010	11830
	11852
05/Jul/2012	11880
	11884
09/Jul/2012	11900
27/Aug/2008	11910
	11925
13/Jul/2011	11930
	11932
	11932
07/Feb/2007	11940
13/Aug/2008	11950
	11964
	11966
	11975
28/Mar/2006	11989
	11991
	11993
	11998
02/Nov/2011	12040
24/Aug/2011	12040
07/Jun/2007	12048
07/Feb/2007	12050
05/Nov/2012	12066
	12066
22/Oct/2010	12070
	12072
14/Jun/2006	12090
29/Jan/2010	12100
07/Mar/2007	12107
24/Aug/2011	12110
02/Nov/2011	12110
	12122
22/Nov/2007	12130
02/Sep/2010	12134
30/Nov/2007	12140
16/Jul/2010	12156
21/Oct/2009	12160
08/Aug/2012	12180
04/Dec/2007	12210
	12213
	12215
31/Jul/2006	12230
04/Aug/2010	12240
10/Feb/2010	12240
08/Sep/2012	12247
	12247
14/Jun/2006	12270
	12283
19/Sep/2006	12290
	12299
24/Aug/2011	12320
02/Nov/2011	12320
NULL	12327
08/Sep/2012	12338
02/Feb/2010	12340
	12349
31/Jul/2006	12356
04/Jul/2012	12360
21/Oct/2008	12372
01/Mar/2011	12390
	12397
15/Dec/2010	12411
04/Dec/2007	12430
11/Nov/2006	12440
10/Oct/2006	12450
09/Jul/2008	12460
01/May/2008	12480
	12481
30/Apr/2007	12489
	12519
06/Aug/2009	12520
05/Nov/2010	12530
06/Nov/2012	12531
	12537
	12560
04/Mar/2011	12570
	12585
30/Nov/2007	12590
	12592
13/Nov/2006	12600
	12605
	12610
21/Oct/2009	12680
17/Feb/2010	12680
15/Sep/2011	12690
06/Aug/2009	12690
22/Feb/2011	12700
02/Feb/2010	12700

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
	12701		13204		14232	15/Sep/2011	15876
02/Feb/2010	12710		13239	09/Dec/2008	14242	18/Apr/2007	16000
10/Sep/2012	12715		13245	17/Sep/2008	14288	24/Oct/2011	16057
06/Nov/2012	12715		13336	01/Aug/2008	14340		16244
	12786	12/Jan/2011	13401	01/Oct/2008	14389	18/Apr/2007	16280
02/Feb/2010	12810	15/Oct/2008	13420	21/Oct/2008	14420	NULL	16308
	12823		13426		14443		16663
	12832	24/Oct/2011	13426		14456	14/Jul/2010	16817
	12839		13463	12/Apr/2011	14510	05/Nov/2012	16874
09/Feb/2010	12850	22/Oct/2010	13530	17/Feb/2010	14510		17028
15/Apr/2010	12859		13558		14558	22/Nov/2007	17030
07/Dec/2009	12860	07/May/2012	13608	08/Sep/2012	14560		17237
15/Apr/2010	12869		13628		14608	14/Jul/2010	17271
02/Dec/2009	12870	15/Jun/2010	13665	21/Apr/2009	14618		17459
02/Dec/2009	12890		13665	17/Feb/2010	14690		17486
	12891	24/Oct/2011	13717	NULL	14733		17781
03/Jun/2011	12900		13737	01/Oct/2008	14813	24/Oct/2011	18012
02/Dec/2009	12910		13758	04/Jul/2012	14890	06/Oct/2010	18144
	12918	24/Sep/2008	13784		14982	22/Oct/2008	18530
18/Jun/2008	12947		13810	26/Apr/2011	15105	24/Oct/2011	19006
30/Apr/2010	12970	24/Sep/2008	13862	NULL	15190	12/Jan/2011	21128
23/Apr/2010	12970		13885		15200	NULL	21355
21/Oct/2009	13000	22/Oct/2008	13950		15225	24/Dec/2007	21792
15/May/2008	13020		14107	06/Feb/2007	15270	03/May/2007	22560
15/Oct/2008	13030	05/Nov/2012	14152		15333	24/Dec/2007	22700
13/Feb/2007	13038		14152		15336	NULL	23275
23/Apr/2010	13041	20/Jan/2010	14160		15383	07/Nov/2011	28506
30/Apr/2010	13059		14164		15502	NULL	28817
23/Apr/2010	13060	01/Oct/2008	14188	NULL	15520	07/Nov/2011	29371
	13154	02/Sep/2010	14198		15740	06/Aug/2010	30482
02/Sep/2010	13177		14213	07/Feb/2007	15760		

Entries ommitted due to not being 6.1m (20') intermodal shipping containers or suspected erroneous entry

Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)	Dispatch Date	Mass (kg)
11/Jul/2007	0	02/Dec/2009	966		1467		1817
18/Aug/2011	1	25/Oct/2010	1032		1484		1845
02/Dec/2009	11		1046		1565		1871
09/Jun/2011	45		1064	21/Feb/2012	1588		1873
15/Feb/2011	91	14/Aug/2009	1128		1608	25/Feb/2010	1920
09/Jun/2011	227		1134		1645		1928
10/Sep/2008	454		1202		1662		1955
19/Jan/2010	534		1254		1701		1996
10/Jan/2011	544		1278		1774		2012
	708	17/Sep/2012	1280		1794		2014
04/Sep/2009	726		1315		1810	16/Sep/2008	68040
03/Dec/2009	751	19/Jan/2010	1365	29/Nov/2007	1814	26/Oct/2007	87763
25/Jan/2007	800	24/May/2007	1370	22/Mar/2007	1814	10/Feb/2010	100299
	800		1386	16/Apr/2010	1814		
13/Dec/2010	907		1454		1814		

Appendix B

Shipping Container Eccentricity

Table B.1 – Proportion of shipping containers with greater than 5% eccentricity

Grouping	Percent of Total Population for Grouping	Number of Lifts	Percent Greater than 5% Eccentricity	Percent Less than 5% Eccentricity
< 5 tonne	8.5%	603	50.9%	49.1%
5 - 10 tonne	9.6%	685	21.8%	78.2%
10 - 15 tonne	6.9%	493	13.6%	86.4%
15 - 20 tonne	12.3%	878	16.6%	83.4%
20 - 25 tonne	24.9%	1,771	13.7%	86.3%
25 - 30 tonne	22.7%	1,613	17.5%	82.5%
30 + tonne	15.1%	1,078	2.8%	97.2%
Global	100%	7,121	17.2%	82.8%

Table B.2 – Best-fit for intermodal container eccentricities to half-normal distribution

Container Population (Half-Normal Distribution, Best Fit σ)	Eccentricity (m)	Cumulative probability (data)	Cumulative probability (Best Fit)
< 5 tonnes (no fit)	0	0.00	N/A
	0.305	0.49	N/A
	0.329	0.75	N/A
5 – 10 tonnes ($\sigma = 0.250$ m)	0	0.00	0.00
	0.305	0.78	0.78
	0.415	0.89	0.90
10 – 15 tonnes ($\sigma = 0.214$ m)	0	0.00	0.00
	0.305	0.86	0.85
	0.482	0.93	0.98
15 – 20 tonnes ($\sigma = 0.226$ m)	0	0.00	0.00
	0.305	0.83	0.83
	0.397	0.92	0.93
20 – 25 tonnes ($\sigma = 0.207$ m)	0	0.00	0.00
	0.305	0.86	0.86
	0.384	0.93	0.94
25 – 30 tonnes ($\sigma = 0.238$ m)	0	0.00	0.00
	0.305	0.83	0.81
	0.470	0.91	0.95
> 30 tonnes ($\sigma = 0.140$ m)	0	0.00	0.00
	0.305	0.97	0.97
	0.610	0.99	1.00
Overall ($\sigma = 0.226$ m)	0	0.00	0.00
	0.305	0.83	0.82
	0.409	0.91	0.93

Appendix C

DND National Material Distribution System Vehicle “Weight” Data 2006-2012, Depart and Arrive Afghanistan, Armoured Heavy Support Vehicle System (AHSVS)

DND National Material Distribution System Vehicle Weight 2006-2012, Dep & Arr Afghanistan, Amoured Heavy Support Vehicle System (AHSVS)

Dispatch Date	CFR	Mass (kg)
PLS		
21/Oct/2011	69915	25,564
26/Oct/2011	69916	24,384
15/Dec/2011	69917	23,832
28/Aug/2011	69918	23,394
02/Aug/2011	69919	25,375
15/Dec/2011	69920	25,825
15/Dec/2011	69921	25,365
09/May/2012	69922	25,945
28/Sep/2011	69923	24,636
28/Sep/2011	69924	24,715
25/Sep/2011	69926	24,555
27/Sep/2011	69927	24,555
01/Nov/2011	69928	24,690
02/10/2011	69929	24,705
29/Sep/2011	69930	24,275
15/Dec/2011	69932	23,445
15/10/2011	69933	22,414
27/Sep/2011	69934	26,655
26/Sep/2011	69935	24,635
03/Nov/2011	69936	24,505
12/Nov/2011	69937	26,615
01/Dec/2011	69938	27,755
23/Dec/2011	69939	24,834
24/Aug/2011	69940	25,664
23/Dec/2011	69941	28,745
23/Dec/2011	69943	24,604
16/Aug/2011	69944	24,054
15/Dec/2011	69945	25,655
15/Oct/2011	69946	24,125
23/Dec/2011	69947	27,655

Dispatch Date	CFR	Mass (kg)
Cargo gun tractor for M777		
26/Sep/2011	69957	23,404
23/Dec/2011	69959	23,355
15/Dec/2011	69960	24,525
25/Sep/2011	69961	23,555
15/Dec/2011	69965	24,786
15/Dec/2011	69967	24,475
28/Aug/2011	69970	24,555
15/Dec/2011	69973	24,676
Cargo with crane		
26/Aug/2011	69955	24,394
30/Sep/2011	69956	23,495
24/Aug/2011	69958	24,638
15/Dec/2011	69962	24,625
28/Jul/2011	69963	24,685
08/Sep/2011	69964	24,404
08/Sep/2011	69966	25,464
15/Dec/2011	69968	23,986
15/Dec/2011	69969	24,825
09/Aug/2008	69971	24,300
15/Dec/2011	69986	24,404
01/Sep/2011	69987	24,844
15/Dec/2011	69988	24,935
15/Dec/2011	69989	25,205

Entry ommitted due to adnormally low mass given vehicle type

Dispatch Date	CFR	Mass (kg)
Cargo with crane		
15/May/2010	69956	21,319

Appendix D

DND National Material Distribution System Vehicle “Weight” Data 2006-2012, Depart and Arrive Afghanistan, Light Armoured Vehicle III – Infantry Section Carrier (LAV III-ISC)

DND National Materials Distribution System Vehicle Weight 2006-2012, Dep & Arr Afghanistan
LAV III-ISC and LAV III APC w/RWS

Dispatch Date	CFR	Vehicle Description	Mass (kg)
LAV III: Nominal Curb Weight =13,702 kg			
13/Sep/2011	95130	LIGHT ARMORED VEHICLE, AR	12,302
19/Jul/2007	31185	Light Armored Vehicle, ARM	13,472
19/Jul/2007	40229	LAV APC ISC 3.25 STEERING	13,608
22/Apr/2009	30057	LAV APC ISC 3.25 STEERING	13,662
23/Nov/2008	40200	LAV APC ISC 3.25 STEERING	13,710
09/Feb/2008	30223	LAV APC ISC 3.25 STEERING	13,744
23/Nov/2008	31143	LAV APC ISC 3.25 STEERING	13,860
25/Aug/2011	95121	LIGHT ARMORED VEHICLE, AR	13,962
11/Jul/2007	31151	LAV APC ISC 8x8 DIESEL	14,062
27/Sep/2011	30219	Light Armored Vehicle, ARM	14,604
25/Sep/2011	31137	LAV APC ISC 8x8 DIESEL	14,664
28/Nov/2010	29993	Light Armored Vehicle, ARM	14,684
23/Oct/2011	30004	Light Armored Vehicle, ARM	14,714
23/Nov/2010	30003	Light Armored Vehicle, ARM	14,744
21/Nov/2010	30075	Light Armored Vehicle, ARM	14,775
29/Jan/2007	30142	LAV APC ISC 3.25 STEERING	14,778
28/Oct/2011	30212	LAV APC ISC 3.25 STEERING	14,813
31/Oct/2011	96510	LIGHT ARMORED VEHICLE, AR	14,814
27/Feb/2007	40208	LAV APC ISC 3.25 STEERING	14,828
19/Nov/2011	31119	Light Armored Vehicle, ARM	15,143
29/Jan/2007	40231	LAV APC ISC 3.25 STEERING	15,368
29/Sep/2011	30218	Light Armored Vehicle, ARM	15,464
22/Feb/2007	30200	LAV APC ISC 3.25 STEERING	15,504
30/Sep/2011	85918	LIGHT ARMORED VEHICLE, AR	15,684
28/Jun/2007	31182	Light Armored Vehicle, ARM	15,740
29/Apr/2006	30023	Light Armored Vehicle, ARM	15,899
29/Aug/2011	30208	Light Armored Vehicle, ARM	15,923
20/Nov/2011	30074	Light Armored Vehicle, ARM	16,083
18/Apr/2007	40246	LAV APC ISC 8x8 DIESEL	16,103
01/Mar/2007	30045	Light Armored Vehicle, ARM	16,157
19/Mar/2007	31129	LAV APC ISC 3.25 STEERING	16,266
29/Aug/2011	30213	Light Armored Vehicle, ARM	16,294
22/Sep/2011	42018	Light Armored Vehicle, ARM	16,333
15/Aug/2011	31135	Light Armored Vehicle, ARM	16,413
22/Aug/2009	40241	LAV APC ISC 3.25 STEERING	16,420
10/May/2007	303138	LAV APC ISC 3.25 STEERING	16,511
23/Sep/2011	30023	Light Armored Vehicle, ARM	16,553
22/Mar/2007	40209	LAV APC ISC 3.25 STEERING	16,556
17/Mar/2007	31144	LIGHT ARMORED VEHICLE, AR	16,645
12/Sep/2011	56180	LIGHT ARMORED VEHICLE, AR	16,665
14/Mar/2007	31187	LAV APC ISC 3.25 STEERING	16,701
24/Aug/2011	15002	Light Armored Vehicle, ARM	16,703
24/Jul/2007	40231	LAV APC ISC 3.25 STEERING	16,720
26/Dec/2006	30142	LAV APC ISC 3.25 STEERING	16,729
22/Sep/2011	94479	LIGHT ARMORED VEHICLE, AR	16,734
21/Aug/2011	96514	LIGHT ARMORED VEHICLE, AR	16,783
22/Nov/2011	30221	Light Armored Vehicle, ARM	16,912
20/Aug/2011	40284	Light Armored Vehicle, ARM	16,984
26/Sep/2011	96509	LIGHT ARMORED VEHICLE, AR	16,994
20/Aug/2011	40259	Light Armored Vehicle, ARM	17,043
25/Apr/2006	30055	Light Armored Vehicle, ARM	17,092
21/Oct/2011	30006	Light Armored Vehicle, ARM	17,204
21/Aug/2011	30044	Light Armored Vehicle, ARM	17,353
24/Aug/2011	94438	LIGHT ARMORED VEHICLE, AR	17,393
01/May/2006	30139	LAV APC ISC 3.25 STEERING	17,400
07/Aug/2011	30073	Light Armored Vehicle, ARM	17,434
21/Mar/2007	30065	LAV APC ISC 3.25 STEERING	17,563
20/Aug/2011	96761	LIGHT ARMORED VEHICLE, AR	17,573
17/Mar/2007	30197	LAV APC ISC 3.25 STEERING	17,745
21/Jan/2011	30041	LAV APC ISC 3.25 STEERING	17,781
19/Aug/2011	96507	Light Armored Vehicle, ARM	17,784
23/Aug/2011	30092	Light Armored Vehicle, ARM	17,933
29/Aug/2011	40278	Light Armored Vehicle, ARM	17,944
21/Sep/2011	40253	LAV APC ISC 8x8 DIESEL	18,023
24/Aug/2011	31128	LAV APC ISC 3.25 STEERING	18,113
29/Aug/2011	85989	Light Armored Vehicle, ARM	18,115
28/Jul/2011	31120	LAV APC ISC 8x8 DIESEL	18,253
09/Aug/2011	40217	Light Armored Vehicle, ARM	18,295
20/Aug/2011	40263	Light Armored Vehicle, ARM	18,324
02/Oct/2010	40267	LAV APC ISC 8x8 DIESEL	18,357
11/Sep/2011	31117	Light Armored Vehicle, ARM	18,444
30/Aug/2011	94429	LIGHT ARMORED VEHICLE, AR	18,873
18/Sep/2010	31186	LAV APC ISC 3.25 STEERING	18,974
20/Aug/2011	30114	Light Armored Vehicle, ARM	19,174
07/Dec/2010	30135	LAV APC ISC 3.25 STEERING	19,600
23/Aug/2011	30233	Light Armored Vehicle, ARM	19,663
13/Aug/2011	30012	Light Armored Vehicle, ARM	19,813

Dispatch Date	CFR	Vehicle Description	Mass (kg)
LAV III APC W/RWS: Nominal Curb Weight = 18,375 kg			
27/Sep/2011	40418	LAV III APC W/RWS	17,185
20/Oct/2011	40411	LAV III APC W/RWS	17,213
21/Oct/2011	40417	LAV III APC W/RWS	17,229
03/Sep/2011	40413	LAV III APC W/RWS	17,265
21/Oct/2011	40423	LAV III APC W/RWS	17,313
13/Oct/2011	40415	LAV III APC W/RWS	17,354
27/Sep/2011	40410	LAV III APC W/RWS	17,375
14/Sep/2011	40407	LAV III APC W/RWS	17,822
21/Sep/2011	40406	LAV III APC W/RWS	17,844
17/Oct/2011	40408	LAV III APC W/RWS	17,853
24/Sep/2011	40414	LAV III APC W/RWS	18,143
16/Sep/2011	40412	LAV III APC W/RWS	18,653
22/Oct/2011	40420	LAV III APC W/RWS	18,703
19/Oct/2011	40421	LAV III APC W/RWS	18,804
23/Sep/2011	40422	LAV III APC W/RWS	18,954
13/Sep/2011	40416	LAV III APC W/RWS	18,963
24/Sep/2011	40404	LAV III APC W/RWS	20,353

Appendix E

Weight Bias Coefficient and Variability in Relation to Payload Weight Fraction

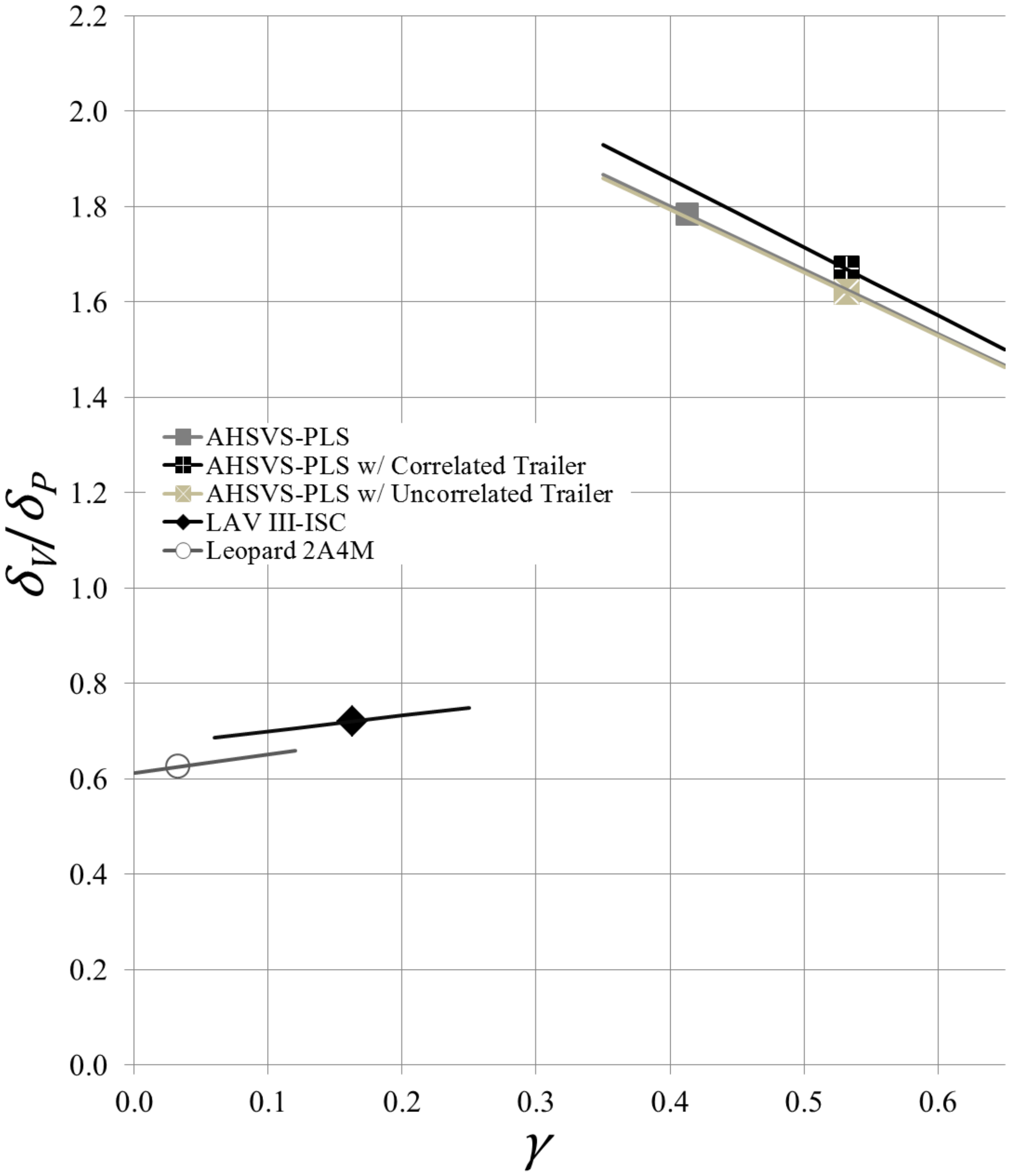


Figure E.1 - Event weight statistical parameters versus payload weight fraction for bias coefficient

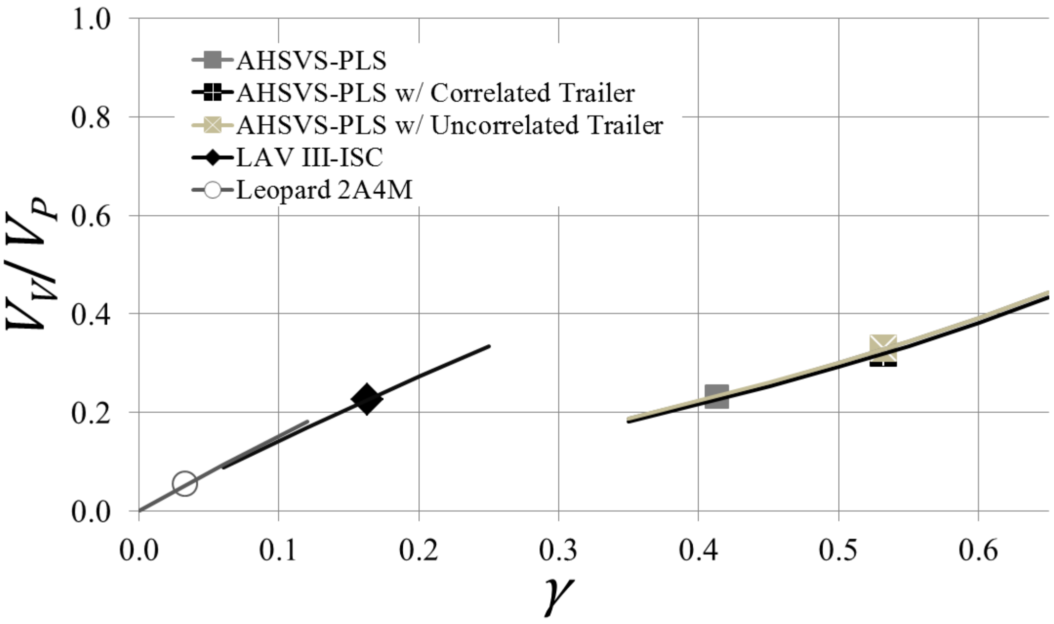


Figure E.2 - Event statistical parameters versus payload weight fraction for CoV

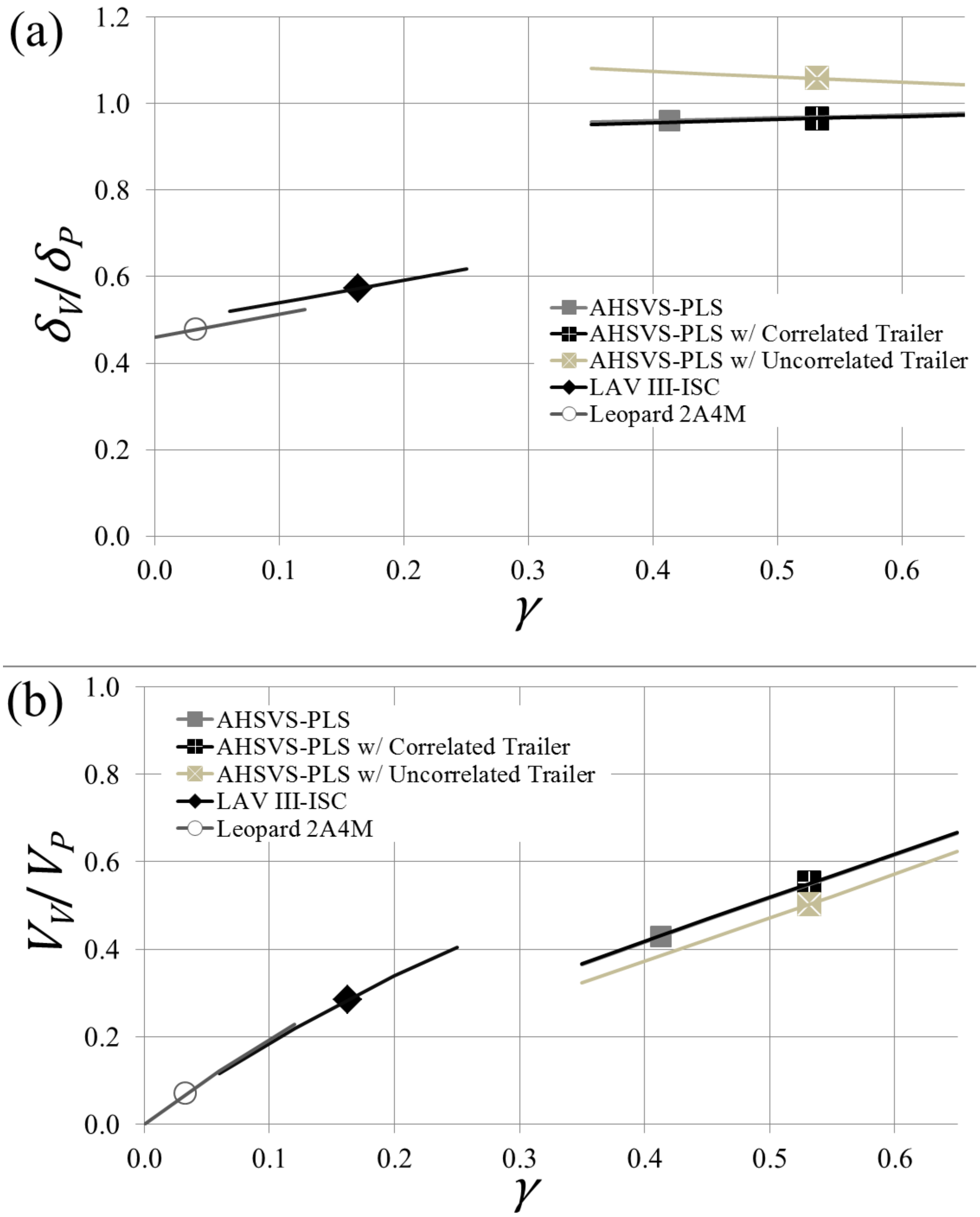


Figure E.3 – Maximum annual weight statistical parameters ($n = 100$ veh/yr) versus payload weight fraction: (a) bias coefficient; (b) CoV

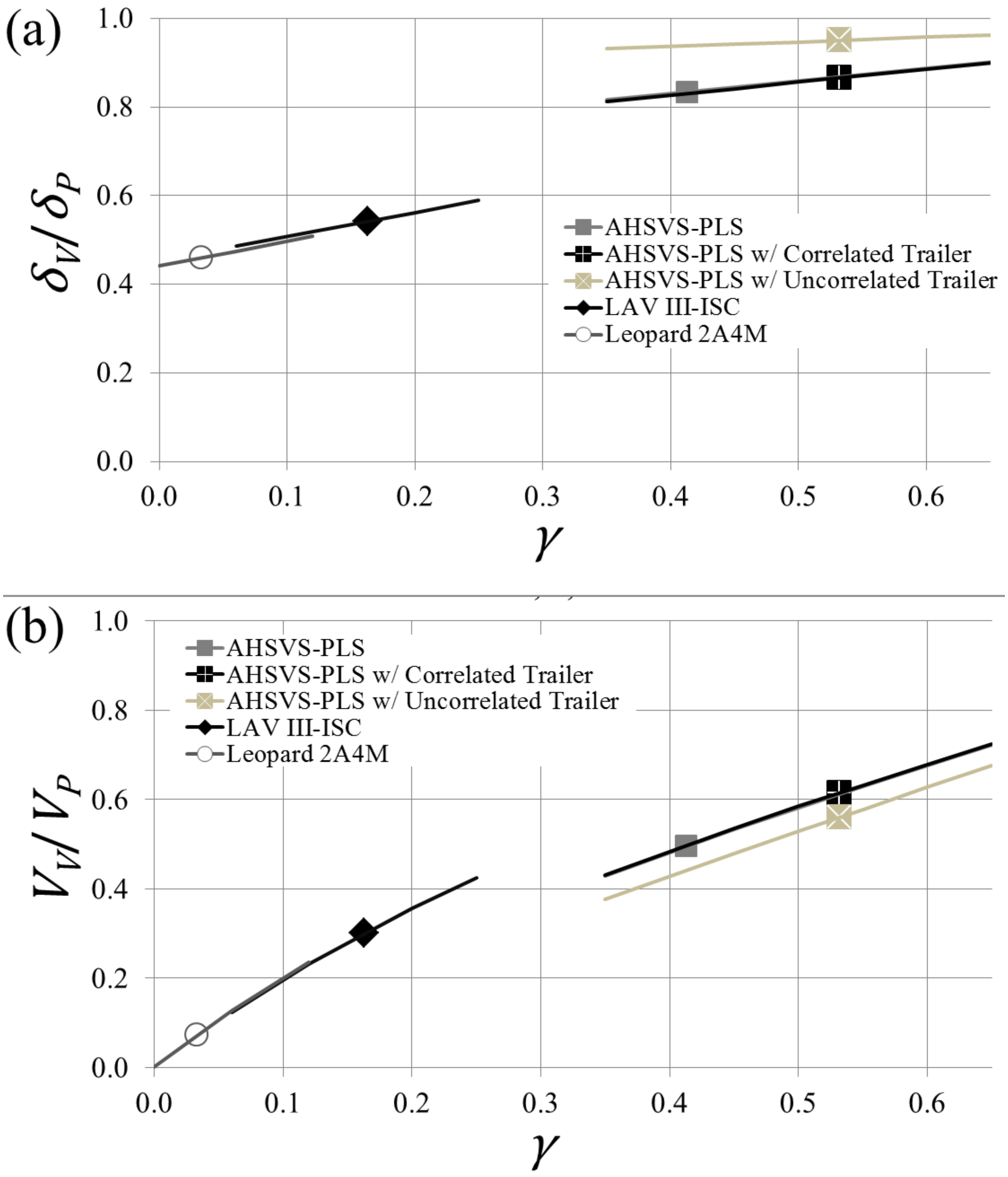


Figure E.4 – Maximum annual weight statistical parameters (n = 1,000 veh/yr) versus payload weight fraction: (a) bias coefficient; (b) CoV

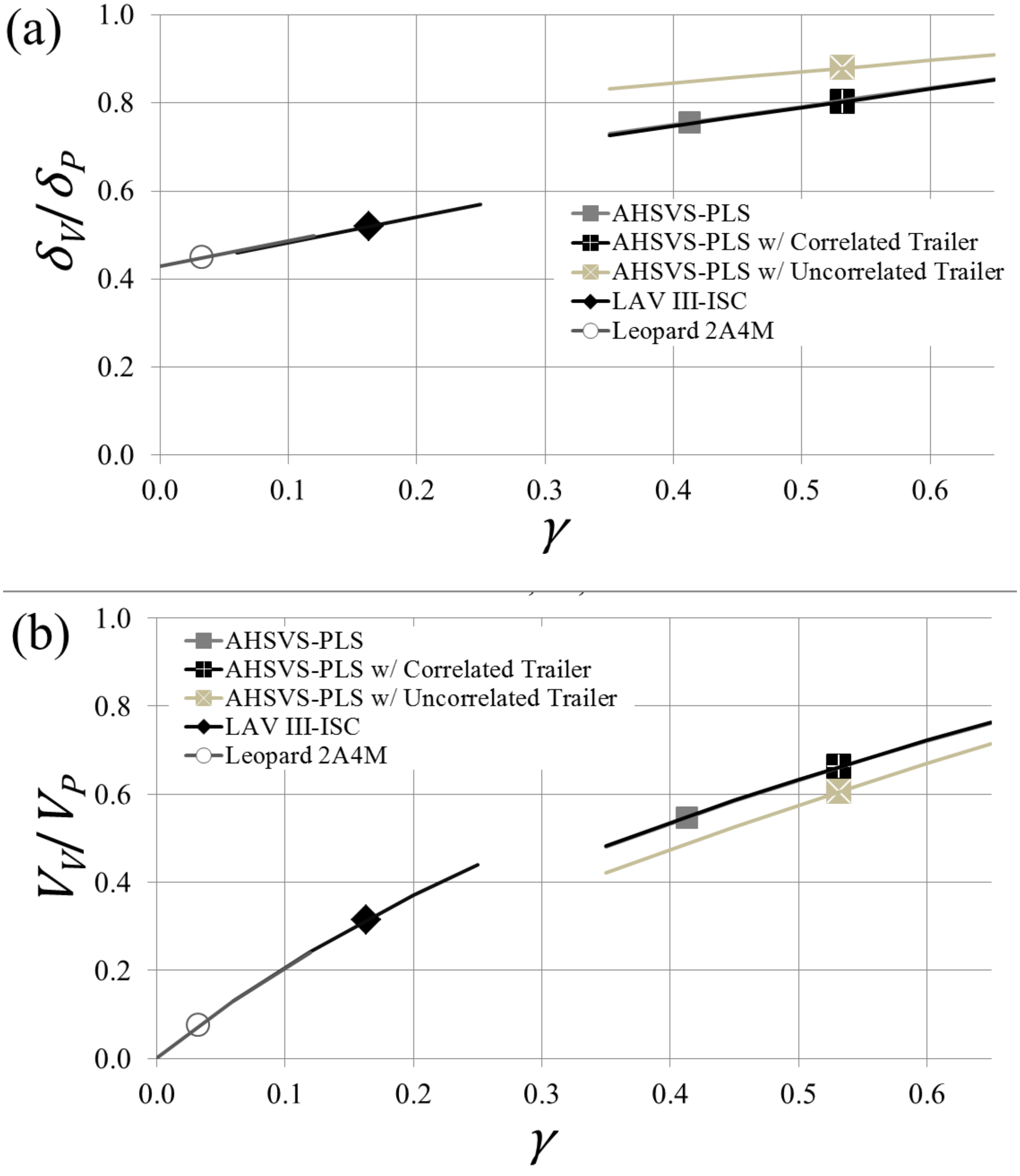


Figure E.5 – Maximum annual weight statistical parameters ($n = 10{,}000$ veh/yr) versus payload weight fraction: (a) bias coefficient; (b) CoV

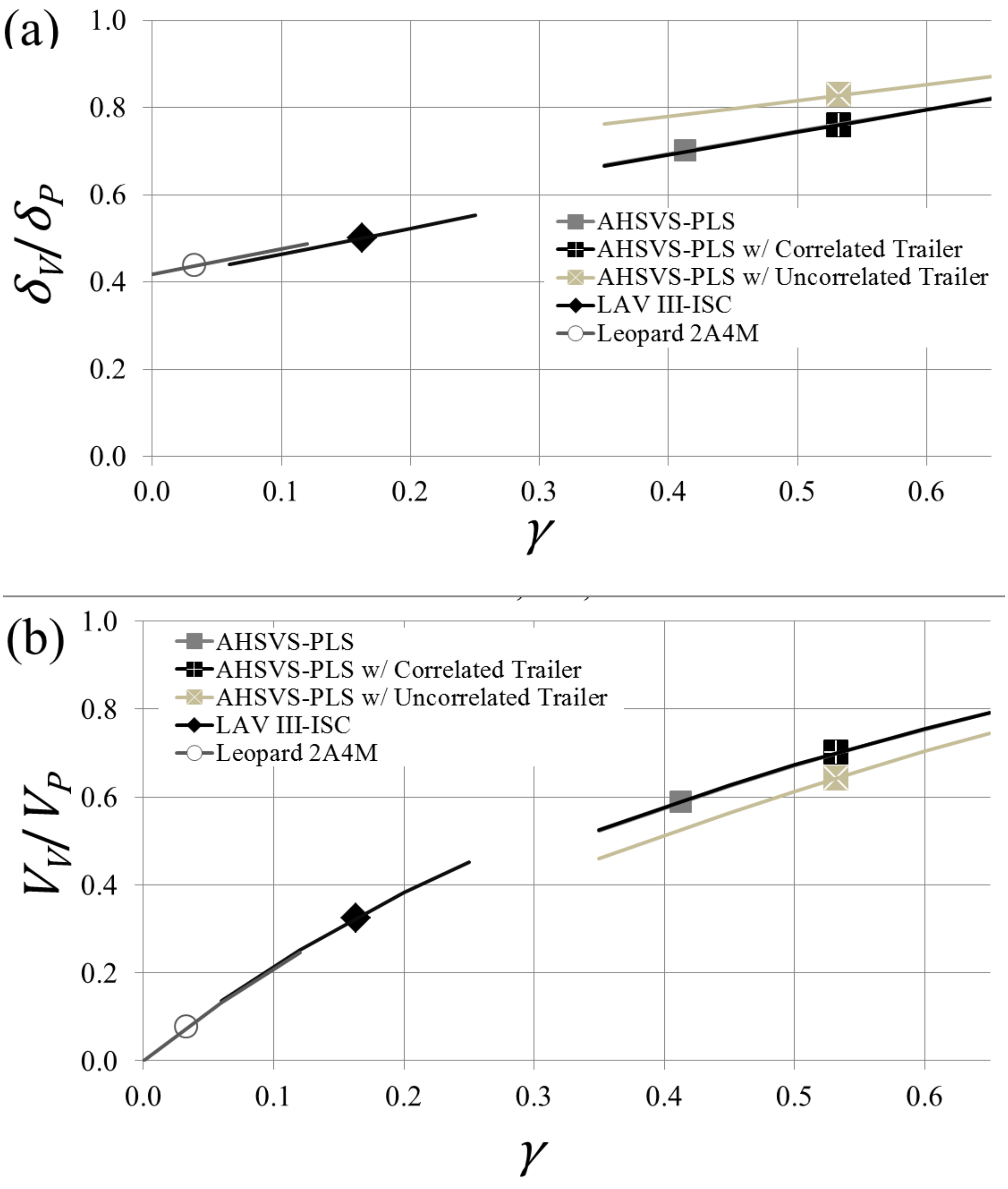


Figure E.6 – Maximum annual weight statistical parameters ($n = 100{,}000$ veh/yr) versus payload weight fraction: (a) bias coefficient; (b) CoV

Appendix F

Comparison of Lateral Load Distribution Amplification Factors from: CSA (2006a), AASHTO LRFD Bridge (2012), and Pinero (2001)

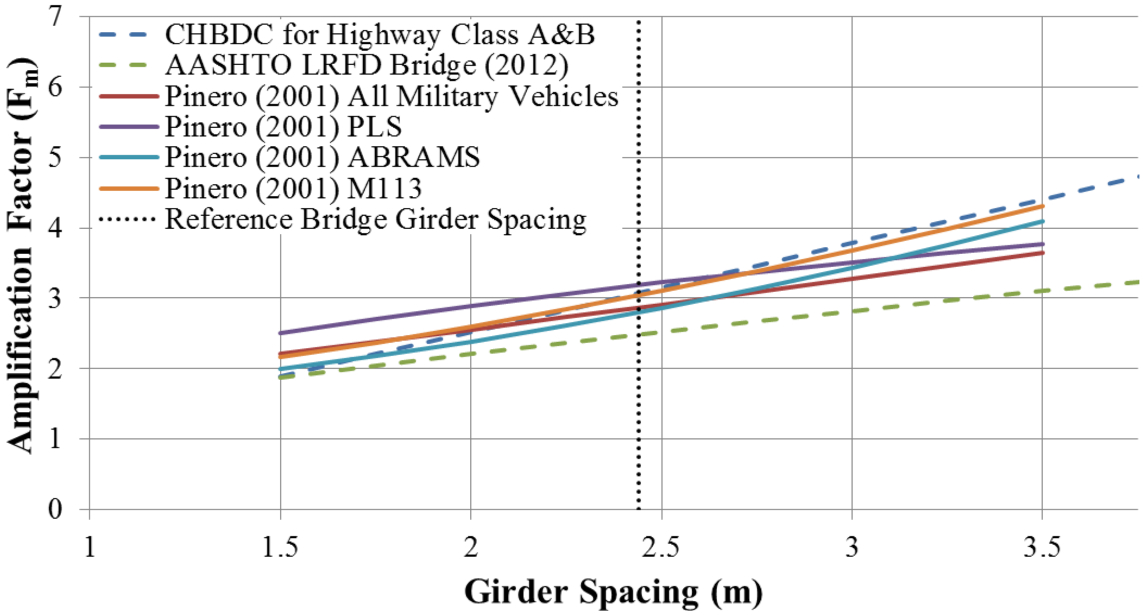


Figure F.1 - Amplification factor versus girder spacing: *All Beam Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

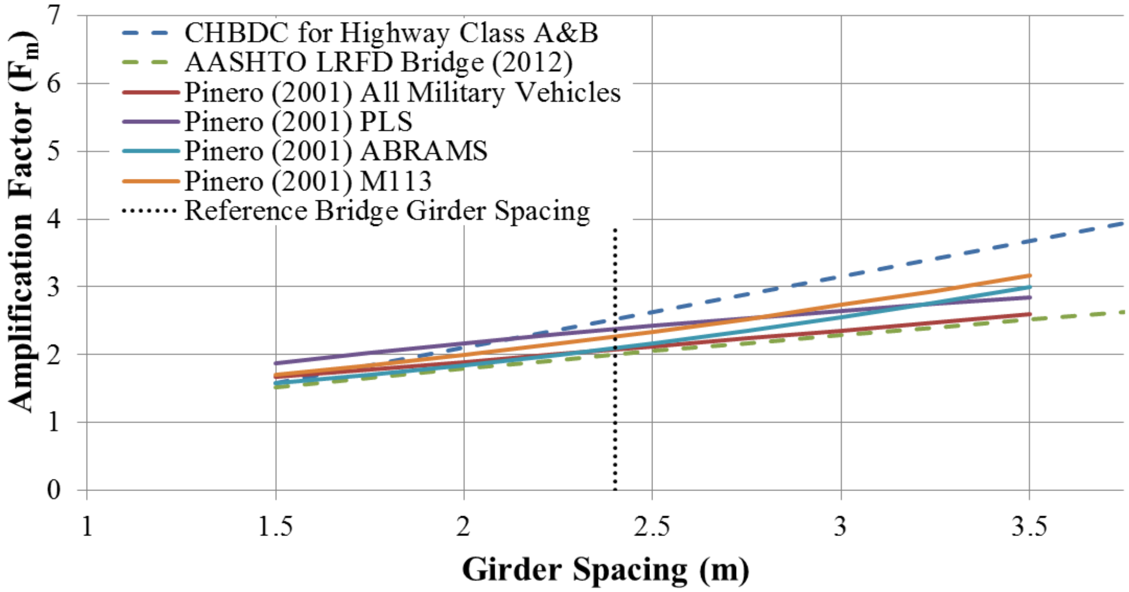


Figure F.2 - Amplification factor versus girder spacing: *All Beam Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison-Hershfield, 2012)

Figure F.3 - Amplification factor versus girder spacing: *Steel Girder Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

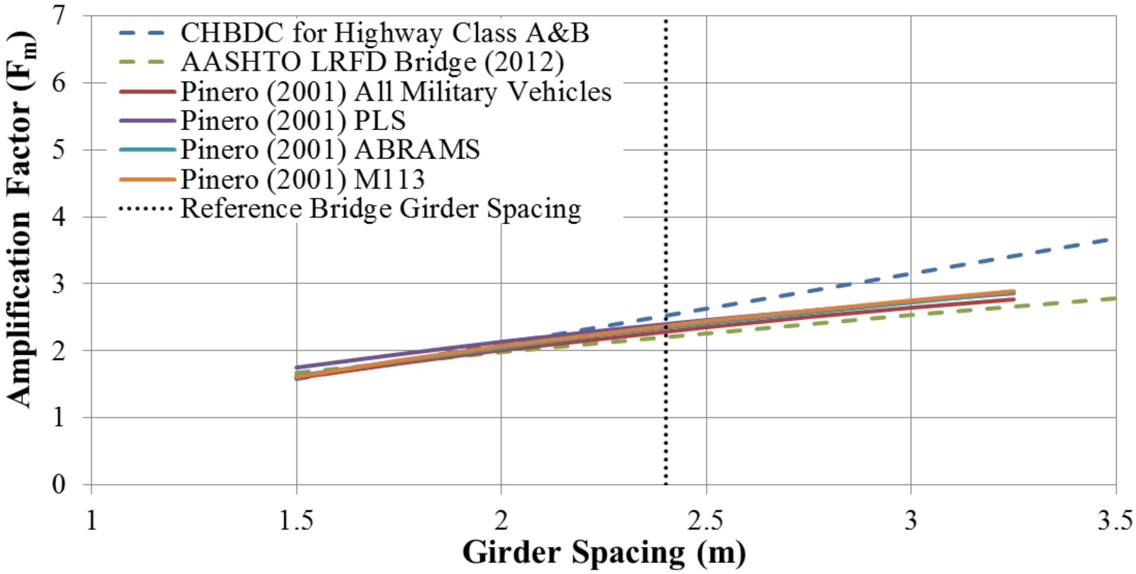


Figure F.4 - Amplification factor versus girder spacing: *Pre-stressed Concrete Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison-Hershfield, 2012)

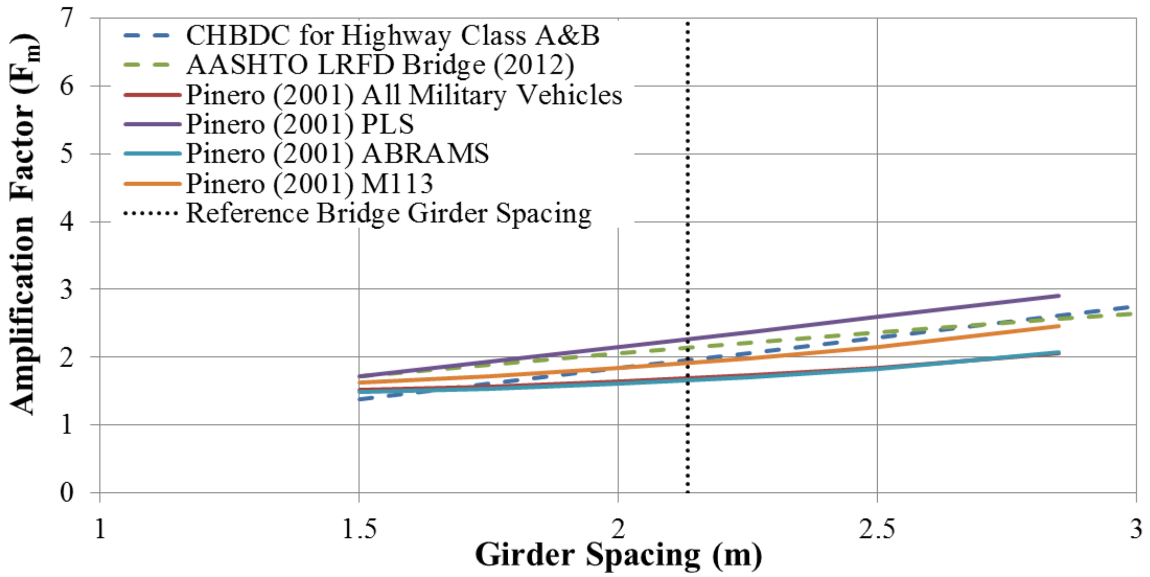


Figure F.5 - Amplification factor versus girder spacing: *Concrete T-beam Bridges* (Pinero, 2001), 12 m concrete T-beam (Franklin) (Trimble, Cousins and Seda-Sanabria, 2003)

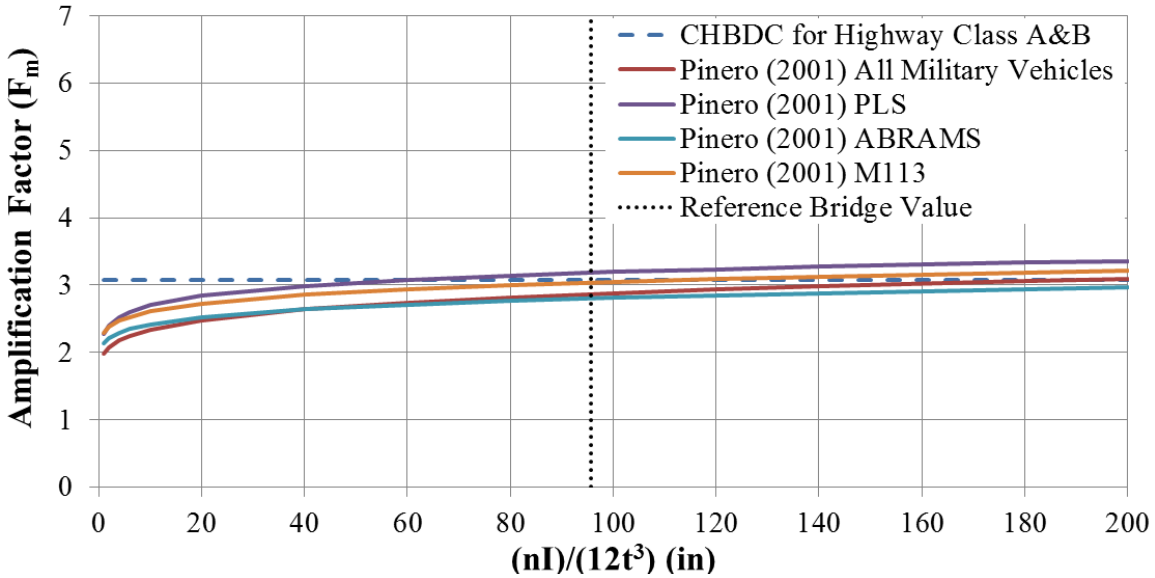


Figure F.6 - Amplification factor versus stiffness: *All Beam Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

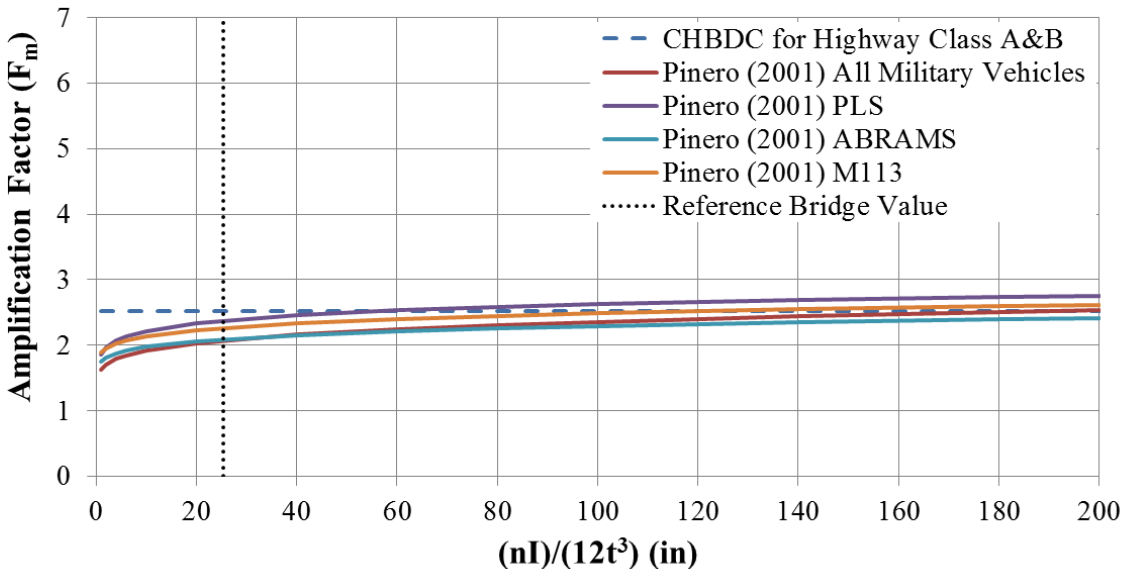


Figure F.7 - Amplification factor versus stiffness: *All Beam Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison Hershfield Ltd., 2012)

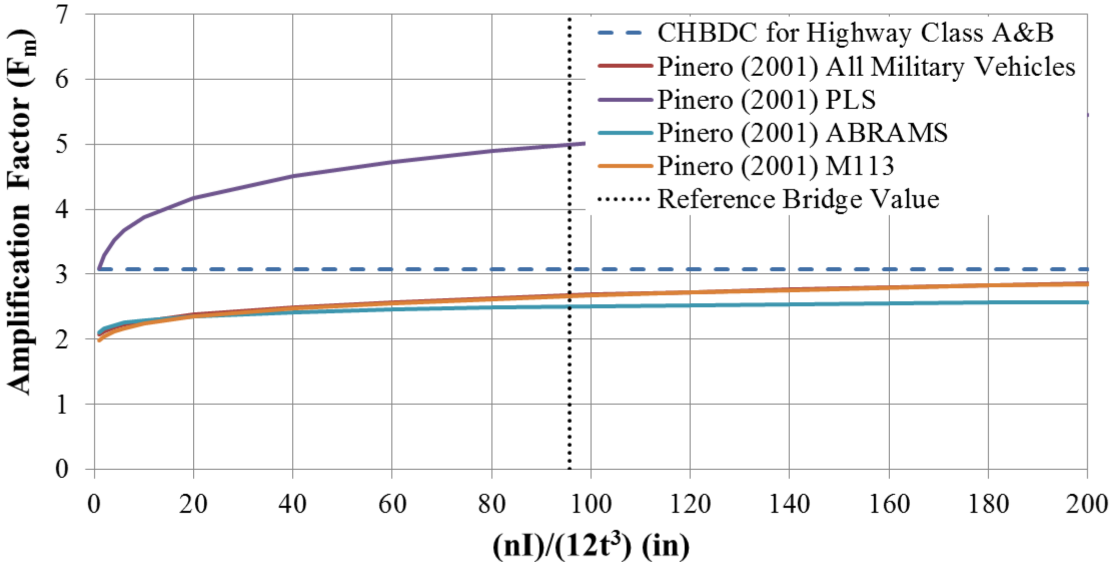


Figure F.8 - Amplification factor versus stiffness: *Steel Girder Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

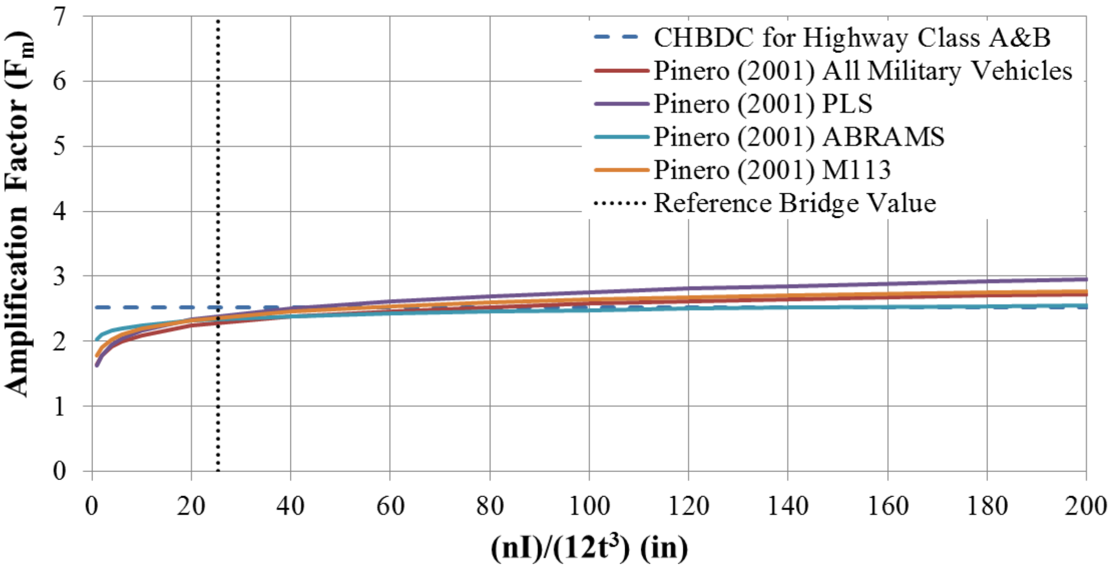


Figure F.9 - Amplification factor versus stiffness: *Pre-stressed Concrete Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison Hershfield Ltd., 2012)

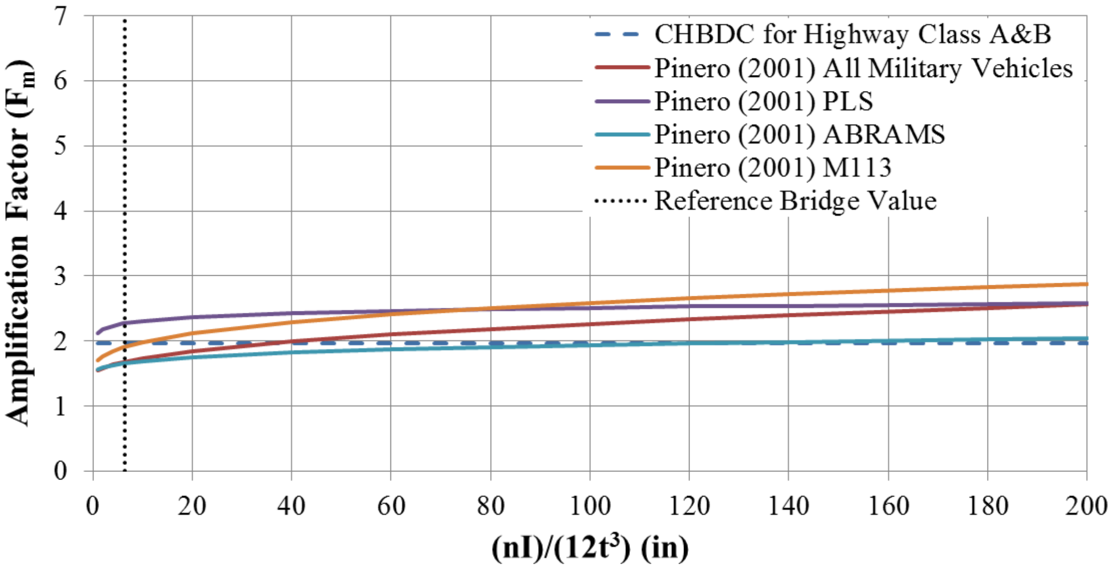


Figure F.10 - Amplification factor versus stiffness: *Concrete T-beam Bridges* (Pinero, 2001), 12 m concrete T-beam (Franklin) (Trimble, Cousins and Seda-Sanabria, 2003)

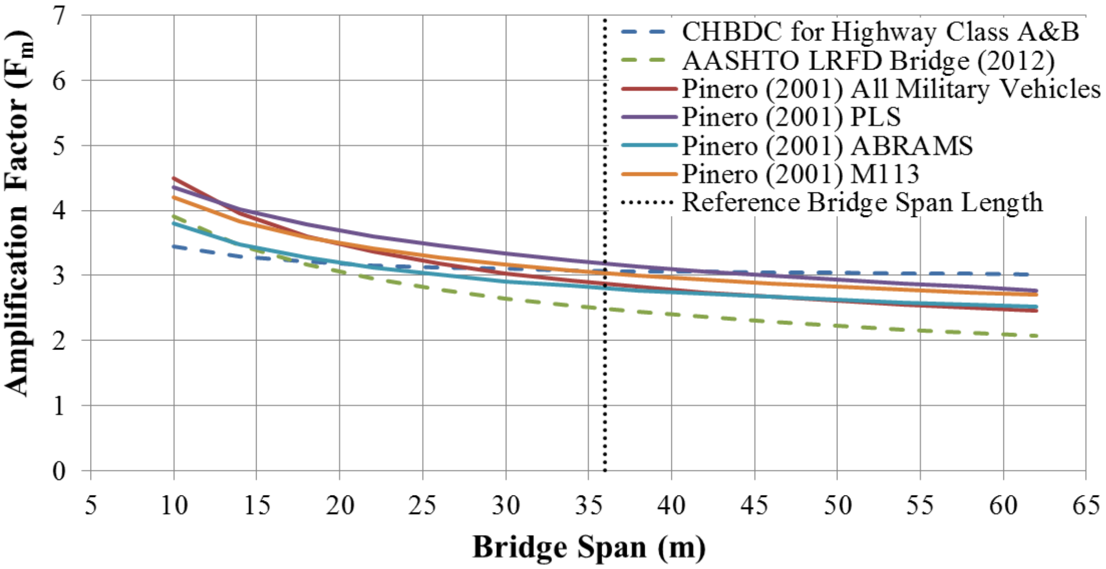


Figure F.11 - Amplification factor versus span: *All Beam Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

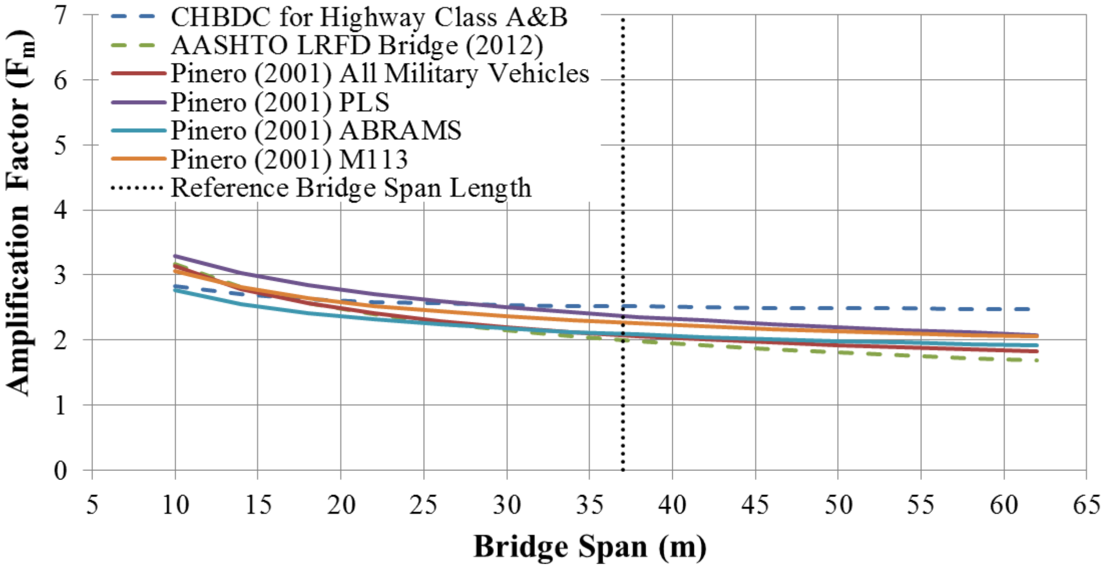


Figure F.12 - Amplification factor versus span: *All Beam Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison Hershfield Ltd., 2012)

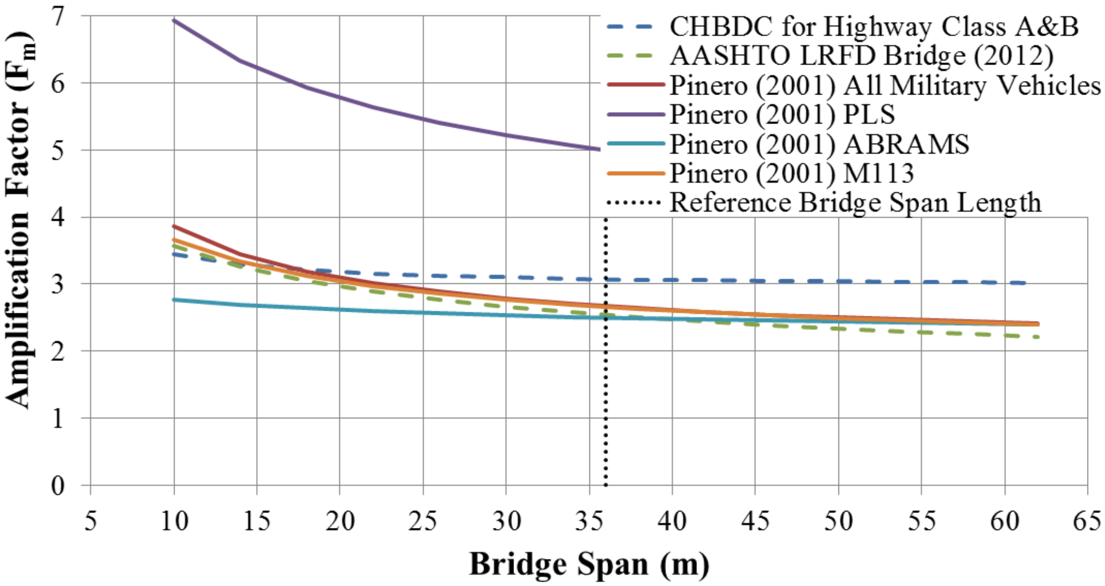


Figure F.13 - Amplification factor versus span: *Steel Girder Bridges* (Pinero, 2001), 36 m steel girder bridge (Kim, Tanovic, & Wight, 2010)

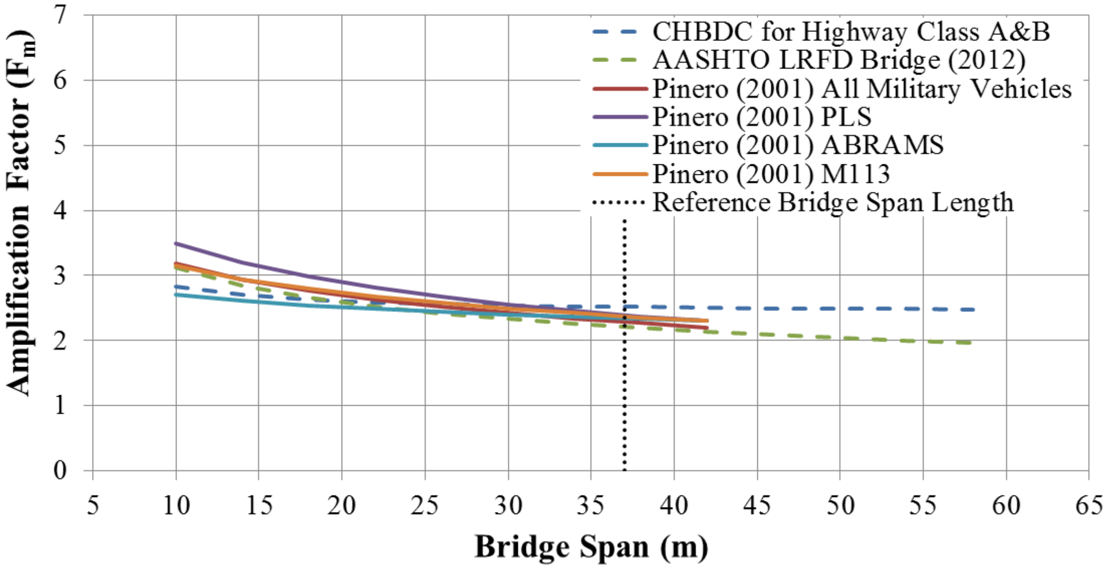


Figure F.14 - Amplification factor versus span: *Pre-stressed Concrete Bridges* (Pinero, 2001), 37 m steel CPCI girder bridge (Morrison Hershfield Ltd., 2012)

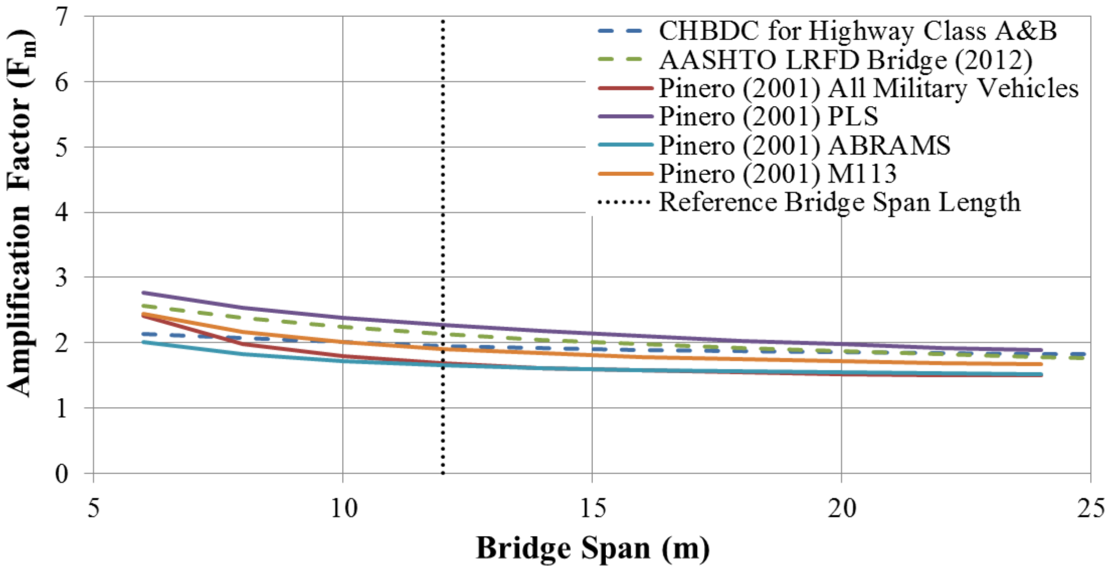


Figure F.15 - Amplification factor versus span: *Concrete T-beam Bridges* (Pinero, 2001), 12 m concrete T-beam (Franklin) (Trimble, Cousins and Seda-Sanabria, 2003)

Appendix G

Load Effect Bias Coefficient and CoV on Bridges for AHSVS-PLS (Transport), LAV III-ISC (Armoured Personnel Carrier), and Leopard 2A4M Tank

Table G.1 - Load effects for AHSVS-PLS, short spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.698	0.187	0.668	0.160	0.844	0.195	0.753	0.216
	Pinero (2001)	0.751	0.187	0.718	0.160	0.907	0.195	0.809	0.216
100	CSA (2006a)	0.904	0.199	0.865	0.173	1.093	0.207	0.975	0.227
	Pinero (2001)	0.972	0.199	0.930	0.173	1.175	0.207	1.049	0.227
1,000	CSA (2006a)	1.096	0.191	1.048	0.164	1.325	0.199	1.182	0.220
	Pinero (2001)	1.179	0.191	1.127	0.164	1.424	0.199	1.271	0.220
10,000	CSA (2006a)	1.312	0.185	1.255	0.157	1.585	0.194	1.414	0.215
	Pinero (2001)	1.410	0.185	1.349	0.157	1.705	0.194	1.521	0.215
100,000	CSA (2006a)	1.530	0.179	1.463	0.150	1.849	0.188	1.650	0.209
	Pinero (2001)	1.645	0.179	1.573	0.150	1.988	0.188	1.774	0.209

Table G.2 - Load effects for AHSVS-PLS, other spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.655	0.187	0.626	0.160	0.791	0.195	0.706	0.216
	Pinero (2001)	0.704	0.187	0.673	0.160	0.851	0.195	0.759	0.216
100	CSA (2006a)	0.882	0.176	0.844	0.147	1.066	0.185	0.951	0.207
	Pinero (2001)	0.949	0.176	0.907	0.147	1.146	0.185	1.023	0.207
1,000	CSA (2006a)	0.997	0.173	0.953	0.142	1.205	0.182	1.075	0.204
	Pinero (2001)	1.072	0.173	1.025	0.142	1.295	0.182	1.156	0.204
10,000	CSA (2006a)	1.119	0.172	1.070	0.141	1.353	0.181	1.207	0.203
	Pinero (2001)	1.203	0.172	1.151	0.141	1.454	0.181	1.298	0.203
100,000	CSA (2006a)	1.239	0.170	1.185	0.139	1.497	0.179	1.336	0.201
	Pinero (2001)	1.332	0.170	1.274	0.139	1.610	0.179	1.436	0.201

Table G.3 - Load effects for AHSVS-PLS and trailer, uncorrelated container, short spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.676	0.187	0.647	0.160	0.817	0.195	0.729	0.216
	Pinero (2001)	0.727	0.187	0.695	0.160	0.878	0.195	0.784	0.216
100	CSA (2006a)	0.900	0.206	0.861	0.181	1.088	0.213	0.971	0.232
	Pinero (2001)	0.968	0.206	0.926	0.181	1.170	0.213	1.044	0.232
1,000	CSA (2006a)	1.098	0.190	1.050	0.162	1.327	0.197	1.184	0.218
	Pinero (2001)	1.180	0.190	1.129	0.162	1.427	0.197	1.273	0.218
10,000	CSA (2006a)	1.303	0.183	1.246	0.154	1.575	0.191	1.405	0.212
	Pinero (2001)	1.401	0.183	1.340	0.154	1.694	0.191	1.511	0.212
100,000	CSA (2006a)	1.505	0.178	1.440	0.148	1.819	0.186	1.622	0.208
	Pinero (2001)	1.618	0.178	1.548	0.148	1.956	0.186	1.745	0.208

Table G.4 - Load effects for AHSVS-PLS and trailer, uncorrelated container, other spans

DLA		CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.595	0.187	0.569	0.160	0.719	0.195	0.641	0.216
	Pinero (2001)	0.639	0.187	0.612	0.160	0.773	0.195	0.689	0.216
100	CSA (2006a)	0.789	0.172	0.755	0.142	0.953	0.181	0.851	0.203
	Pinero (2001)	0.848	0.172	0.811	0.142	1.025	0.181	0.915	0.203
1,000	CSA (2006a)	0.876	0.170	0.838	0.139	1.059	0.179	0.945	0.202
	Pinero (2001)	0.942	0.170	0.901	0.139	1.139	0.179	1.016	0.202
10,000	CSA (2006a)	0.962	0.169	0.920	0.137	1.162	0.177	1.037	0.200
	Pinero (2001)	1.034	0.169	0.989	0.137	1.250	0.177	1.115	0.200
100,000	CSA (2006a)	1.048	0.167	1.003	0.136	1.267	0.176	1.130	0.199
	Pinero (2001)	1.127	0.167	1.078	0.136	1.362	0.176	1.215	0.199

Table G.5 - Load effects for AHSVS-PLS and trailer fully correlated container, short spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.670	0.209	0.641	0.185	0.810	0.217	0.722	0.236
	Pinero (2001)	0.720	0.209	0.689	0.185	0.871	0.217	0.777	0.236
100	CSA (2006a)	0.901	0.199	0.862	0.173	1.089	0.207	0.971	0.227
	Pinero (2001)	0.969	0.199	0.927	0.173	1.171	0.207	1.045	0.227
1,000	CSA (2006a)	1.098	0.191	1.050	0.164	1.327	0.199	1.184	0.220
	Pinero (2001)	1.180	0.191	1.129	0.164	1.427	0.199	1.273	0.220
10,000	CSA (2006a)	1.303	0.182	1.246	0.153	1.575	0.190	1.405	0.212
	Pinero (2001)	1.401	0.182	1.340	0.153	1.694	0.190	1.511	0.212
100,000	CSA (2006a)	1.502	0.177	1.436	0.148	1.815	0.186	1.619	0.208
	Pinero (2001)	1.615	0.177	1.544	0.148	1.952	0.186	1.741	0.208

Table G.6 - Load effects for AHSVS-PLS and trailer, fully correlated container, other spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.595	0.209	0.570	0.185	0.720	0.217	0.642	0.236
	Pinero (2001)	0.640	0.209	0.612	0.185	0.774	0.217	0.690	0.236
100	CSA (2006a)	0.894	0.186	0.855	0.159	1.081	0.195	0.964	0.216
	Pinero (2001)	0.961	0.186	0.920	0.159	1.162	0.195	1.037	0.216
1,000	CSA (2006a)	1.036	0.178	0.991	0.149	1.252	0.187	1.117	0.209
	Pinero (2001)	1.114	0.178	1.066	0.149	1.347	0.187	1.201	0.209
10,000	CSA (2006a)	1.201	0.177	1.149	0.147	1.452	0.185	1.295	0.207
	Pinero (2001)	1.292	0.177	1.236	0.147	1.561	0.185	1.393	0.207
100,000	CSA (2006a)	1.358	0.173	1.299	0.143	1.641	0.182	1.464	0.204
	Pinero (2001)	1.460	0.173	1.397	0.143	1.765	0.182	1.574	0.204

Table G.7 - Load effects for LAV III-ISC Case (1), short spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	1.051	0.168	1.005	0.137	1.270	0.177	1.133	0.200
	Pinero (2001)	1.130	0.168	1.081	0.137	1.366	0.177	1.218	0.200
100	CSA (2006a)	1.181	0.162	1.129	0.129	1.427	0.171	1.273	0.195
	Pinero (2001)	1.270	0.162	1.214	0.129	1.535	0.171	1.369	0.195
1,000	CSA (2006a)	1.218	0.162	1.165	0.129	1.472	0.171	1.313	0.194
	Pinero (2001)	1.309	0.162	1.252	0.129	1.582	0.171	1.412	0.194
10,000	CSA (2006a)	1.247	0.162	1.193	0.128	1.508	0.171	1.345	0.194
	Pinero (2001)	1.341	0.162	1.283	0.128	1.621	0.171	1.446	0.194
100,000	CSA (2006a)	1.277	0.162	1.222	0.128	1.544	0.171	1.377	0.194
	Pinero (2001)	1.374	0.162	1.314	0.128	1.660	0.171	1.481	0.194

Table G.8 - Load effects for LAV III-ISC Case (1), other spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.928	0.164	0.888	0.131	1.122	0.173	1.001	0.196
	Pinero (2001)	0.998	0.164	0.955	0.131	1.207	0.173	1.076	0.196
100	CSA (2006a)	0.999	0.161	0.956	0.128	1.208	0.171	1.078	0.194
	Pinero (2001)	1.075	0.161	1.028	0.128	1.299	0.171	1.159	0.194
1,000	CSA (2006a)	1.019	0.161	0.975	0.128	1.232	0.171	1.099	0.194
	Pinero (2001)	1.096	0.161	1.048	0.128	1.324	0.171	1.181	0.194
10,000	CSA (2006a)	1.036	0.161	0.991	0.128	1.252	0.171	1.117	0.194
	Pinero (2001)	1.114	0.161	1.066	0.128	1.347	0.171	1.201	0.194
100,000	CSA (2006a)	1.053	0.161	1.007	0.128	1.273	0.171	1.136	0.194
	Pinero (2001)	1.133	0.161	1.083	0.128	1.369	0.171	1.221	0.194

Table G.9 - Load effects for LAV III-ISC Case (2), short spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	1.046	0.177	1.001	0.147	1.265	0.185	1.128	0.207
	Pinero (2001)	1.125	0.177	1.076	0.147	1.360	0.185	1.213	0.207
100	CSA (2006a)	1.245	0.164	1.191	0.132	1.505	0.173	1.342	0.197
	Pinero (2001)	1.339	0.164	1.280	0.132	1.618	0.173	1.443	0.197
1,000	CSA (2006a)	1.310	0.163	1.253	0.131	1.583	0.173	1.412	0.196
	Pinero (2001)	1.409	0.163	1.347	0.131	1.702	0.173	1.519	0.196
10,000	CSA (2006a)	1.376	0.163	1.316	0.131	1.663	0.172	1.483	0.196
	Pinero (2001)	1.479	0.163	1.415	0.131	1.788	0.172	1.595	0.196
100,000	CSA (2006a)	1.441	0.163	1.378	0.130	1.742	0.172	1.554	0.196
	Pinero (2001)	1.549	0.163	1.482	0.130	1.873	0.172	1.671	0.196

Table G.10 - Load effects for LAV III-ISC Case (2), other spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.924	0.177	0.884	0.147	1.117	0.185	0.996	0.207
	Pinero (2001)	0.994	0.177	0.950	0.147	1.201	0.185	1.071	0.207
100	CSA (2006a)	1.107	0.164	1.059	0.132	1.338	0.173	1.194	0.197
	Pinero (2001)	1.190	0.164	1.139	0.132	1.439	0.173	1.284	0.197
1,000	CSA (2006a)	1.166	0.163	1.115	0.130	1.410	0.172	1.257	0.196
	Pinero (2001)	1.254	0.163	1.199	0.130	1.516	0.172	1.352	0.196
10,000	CSA (2006a)	1.220	0.163	1.167	0.130	1.475	0.172	1.316	0.196
	Pinero (2001)	1.312	0.163	1.255	0.130	1.586	0.172	1.415	0.196
100,000	CSA (2006a)	1.275	0.163	1.219	0.130	1.541	0.172	1.375	0.195
	Pinero (2001)	1.371	0.163	1.311	0.130	1.657	0.172	1.478	0.195

Table G.11 - Load effects for LAV III-ISC Case (3), short spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.889	0.177	0.850	0.147	1.074	0.185	0.959	0.207
	Pinero (2001)	0.956	0.177	0.914	0.147	1.155	0.185	1.031	0.207
100	CSA (2006a)	1.058	0.164	1.012	0.132	1.278	0.173	1.140	0.197
	Pinero (2001)	1.137	0.164	1.088	0.132	1.374	0.173	1.226	0.197
1,000	CSA (2006a)	1.113	0.163	1.065	0.130	1.345	0.172	1.200	0.196
	Pinero (2001)	1.197	0.163	1.145	0.130	1.447	0.172	1.291	0.196
10,000	CSA (2006a)	1.162	0.163	1.111	0.130	1.404	0.172	1.253	0.195
	Pinero (2001)	1.249	0.163	1.195	0.130	1.510	0.172	1.347	0.195
100,000	CSA (2006a)	1.210	0.163	1.157	0.130	1.462	0.172	1.304	0.195
	Pinero (2001)	1.301	0.162	1.244	0.130	1.572	0.172	1.403	0.195

Table G.12 - Load effects for LAV III-ISC Case (3), other spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.774	0.177	0.741	0.147	0.936	0.185	0.835	0.207
	Pinero (2001)	0.833	0.177	0.796	0.147	1.006	0.185	0.898	0.207
100	CSA (2006a)	0.927	0.164	0.887	0.132	1.121	0.173	1.000	0.197
	Pinero (2001)	0.997	0.164	0.954	0.132	1.205	0.173	1.075	0.197
1,000	CSA (2006a)	0.976	0.163	0.934	0.130	1.180	0.172	1.053	0.196
	Pinero (2001)	1.050	0.163	1.004	0.130	1.269	0.172	1.132	0.196
10,000	CSA (2006a)	1.021	0.163	0.976	0.130	1.234	0.172	1.101	0.195
	Pinero (2001)	1.098	0.163	1.050	0.130	1.327	0.172	1.183	0.195
100,000	CSA (2006a)	1.065	0.163	1.019	0.130	1.288	0.172	1.149	0.195
	Pinero (2001)	1.145	0.163	1.096	0.130	1.384	0.172	1.235	0.195

Table G.13 - Load effects for Leopard 2A4M, Short and Other Spans

	DLA	CSA (2006b)		Trimble, Cousins and Seda-Sanabria (2003)					
				Franklin		Patrick		Both	
Annual Traffic Rate	Lateral Load Distribution	Bias	CoV	Bias	CoV	Bias	CoV	Bias	CoV
Event	CSA (2006a)	0.873	0.161	0.835	0.128	1.055	0.171	0.941	0.194
	Pinero (2001)	0.938	0.129	0.898	0.083	1.134	0.140	1.012	0.168
100	CSA (2006a)	0.889	0.161	0.850	0.128	1.074	0.170	0.959	0.194
	Pinero (2001)	0.956	0.128	0.914	0.083	1.155	0.140	1.031	0.168
1,000	CSA (2006a)	0.892	0.161	0.853	0.128	1.078	0.170	0.961	0.194
	Pinero (2001)	0.959	0.128	0.917	0.083	1.159	0.140	1.034	0.168
10,000	CSA (2006a)	0.894	0.161	0.855	0.128	1.081	0.170	0.964	0.194
	Pinero (2001)	0.961	0.128	0.920	0.083	1.162	0.140	1.037	0.168
100,000	CSA (2006a)	0.896	0.161	0.857	0.128	1.083	0.170	0.966	0.194
	Pinero (2001)	0.963	0.128	0.921	0.083	1.164	0.140	1.039	0.168

Appendix H

Example Bridges used for Load Factor Calibration

H.1 – Morrison and Hershfield Ltd. (2012), 37 m CPCI Grider (x5) Bridge

H.1.1 – Cross Section of Interior Girder (Mid Span)

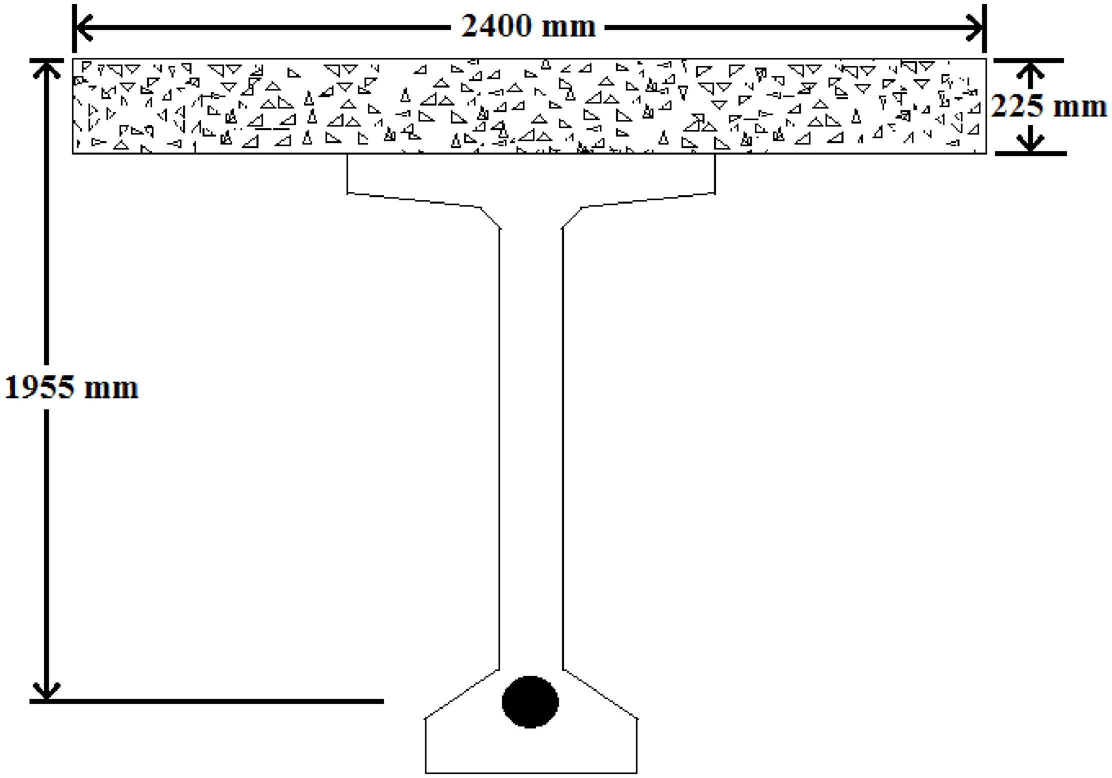


Figure H.1 – Cross Section of interior girder (mid-span) Morrison and Hershfield Ltd. (2012), 37 m CPCI grider (x5) bridge

H.1.2 – Section Parameters

Span Length, $L = 37$ m

Number of Girder, 5

Girder Spacing, $S = 2400$ mm

Effective Flange Width, $b_f = 2400$ mm

Concrete Strength of Deck, $f_c{}' = 30$ MPa

Strands Ultimate Stress, $f_{pu} = 1860$ MPa

Area of Pre-Stressing, $A_{ps} = 4{,}540$ mm^2

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

$\alpha_1 = 0.805$, $\beta_1 = 0.895$ (for deck)

H.1.3 – Dead Load

Dead loads, per interior girder:

$D_1 = \text{CPCI Girder} = 13.8\ \text{kN/m}$

$D_2 = \text{Deck Slab } + \text{Haunch} + \text{Barrier}$

$= 13.01\ \text{kN/m} + 1.64\ \text{kN/m} + 2.97\ \text{kN/m} = 17.62\ \text{kN/m}$

$D_3 = \text{Asphalt} = 4.65\ \text{kN/m}$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(13.8\ \text{kN/m}) \cdot (37\text{m})^2}{8} = 2{,}361.5\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(17.62\ \text{kN/m}) \cdot (37\text{m})^2}{8} = 3{,}015.2\ \text{kN} \cdot \text{m}$$

$$M_{D_3} = \frac{D_3 \cdot L^2}{8} = \frac{(4.65\ \text{kN/m}) \cdot (37\text{m})^2}{8} = 795.7\ \text{kN} \cdot \text{m}$$

H.1.4 – Vehicle Live Load

Table H.1 – Vehicle live load moment at mid-span of interior girder

<table>
<tr><td colspan="6">L_1 (kNm)
CSA (2006a): $F_m = 2.71$
Pinero (2001): $F_m = 2.08$</td></tr>
<tr><td colspan="2">AHSVS-PLS</td><td colspan="2">LAV III-ISC</td><td colspan="2">Leopard 2A4M</td></tr>
<tr><td rowspan="2">No Trailer</td><td>Trailer</td><td rowspan="2">Case (1) / (2)</td><td rowspan="2">Case (3)</td><td colspan="2">Lateral Load Dist.</td></tr>
<tr><td>Uncorrelated / Correlated</td><td>Pinero (2001)</td><td>CSA (2006a)</td></tr>
<tr><td>1,663</td><td>2,566</td><td>916</td><td>1,093</td><td>2,156</td><td>2,809</td></tr>
</table>

H.1.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate factored value of c/d_p, where c is the distance from the extreme compression fiber to the neutral axis and d_p is the depth of centroid of pre-stress from extreme compression fiber.

$$c/d_p = \frac{\phi_p A_{ps} f_{pu}}{\alpha_1 \phi_c \beta_1 f_c{}' b_f d_p + \phi_p k_p A_{ps} f_{pu}}$$

$$= \frac{(0.95)(4{,}540)(1{,}860)}{(0.805)(0.75)(0.895)(30)(2{,}400)(1{,}955) + (0.95)(0.28)(4{,}540)(1{,}860)}$$

$$= 0.102$$

Check if compression is in slab:

$$c = 0.102 d_p = (0.102)(1955\text{ mm}) = 199\text{ mm} < 225\text{ mm}, \quad \therefore\ \text{OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(199\text{ mm}) = 178\text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860\text{ MPa})\big(1 - (0.28)(0.102)\big) = 1{,}807\text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_f} = \phi_p A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (0.95)(4{,}540\text{ mm}^2)(1{,}807\text{ MPa})\left((1{,}955\text{ mm}) - \frac{(178\text{ mm})}{2}\right)$$

$$= 14{,}543\text{ kN}\cdot\text{m}$$

Calculate specified value of c/d_p:

$$c/d_p = \frac{A_{ps}f_{pu}}{\alpha_1\beta_1 f_c{}' b_f d_p - k_p A_{ps} f_{pu}}$$

$$= \frac{(4{,}540)(1{,}860)}{(0.805)(0.895)(30)(2{,}400)(1{,}955) + (0.28)(4{,}540)(1{,}860)}$$

$$= 0.081$$

Check if compression is in slab:

$$c = 0.081 d_p = (0.081)(1955 \text{ mm}) = 159 \text{ mm} < 225 \text{ mm}, \quad \therefore \text{ OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(159 \text{ mm}) = 142 \text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860 \text{ MPa})\big(1 - (0.28)(0.081)\big) = 1{,}818 \text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_s} = A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (4{,}540 \text{ mm}^2)(1{,}818 \text{ MPa})\left((1{,}955 \text{ mm}) - \frac{(142 \text{ mm})}{2}\right)$$

$$= 15{,}550 \text{ kN} \cdot \text{m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{14{,}543\ \mathrm{kN \cdot m}}{15{,}550\ \mathrm{kN \cdot m}} = 0.935$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias and CoV, ω_p must be calculated:

$$\omega_p \approx 0.85\frac{a}{d_p} = 0.85\frac{(142\ \mathrm{mm\ to\ }179\ \mathrm{mm})}{1955\ \mathrm{mm}} = 0.062\ \mathrm{to}\ 0.078$$

$$\therefore\ \omega_p < 0.15 \rightarrow \delta_R = 1.06, V_R = 0.05$$

H.2 - Trimble, Cousins and Seda-Sanabria (2003), 12 m Concrete T-Beam (x4), Bridge

H.2.1 – Cross Section of Interior Girder

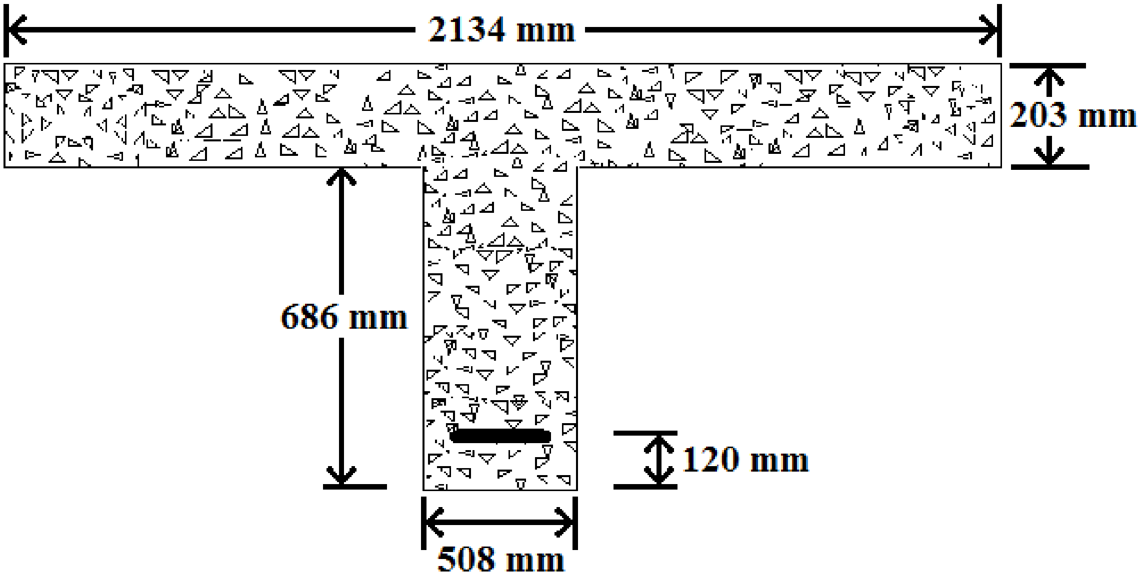


Figure H.2 - Cross Section of interior girder (mid-span) Trimble, Cousins and Seda-Sanabria (2003), 12 m concrete T-beam (x4), bridge

H.2.2 – Section Parameters

Span Length, $L = 12$ m Number of Girder, 4

Girder Spacing, $S = 2{,}134\ \text{mm}$	Area of Steel, $A_s = 8{,}190\ \text{mm}^2$
Effective Flange Width, $b_f = 2{,}134\ \text{mm}$	Density of Steel, $\gamma_s = 77\ \ \text{kN/m}^3$
Concrete Strength $f_c{}' = 27.6\ \text{MPa}$	Density of Concrete, $\gamma_c = 24\ \ \text{kN/m}^3$
Steel Yield Stress, $F_y = 414\ \text{MPa}$	$\alpha_1 = 0.809$, $\beta_1 = 0.901$ (for deck)

Area of concrete, $A_c = 203\ \text{mm} \cdot 2{,}134\ \text{mm} + 508\ \text{mm} \cdot 686\ \text{mm} = 781{,}690\ \text{mm}^2$

Area of Beam, $A_{beam} = 348{,}488\ \text{mm}^2$

Area of Deck, $A_{slab} = 433{,}202\ \text{mm}^2$

H.2.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = A_{beam} \cdot \gamma_c = (0.3485\ \text{m}^2)(24\ \ \text{kN/m}^3) = 8.36\ \ \text{kN/m}$$

$$D_2 = A_{slab} \cdot \gamma_c = (0.4332\ \text{m}^2)(24\ \ \text{kN/m}^3) = 10.4\ \ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(8.36\ \ \text{kN/m}) \cdot (12\text{m})^2}{8} = 150.5\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(10.4\ \ \text{kN/m}) \cdot (12\text{m})^2}{8} = 187.2\ \text{kN} \cdot \text{m}$$

H.2.4 – Vehicle Live Load

Table H.2 - Vehicle live load moment at mid-span of interior girder

L_1 (kNm) CSA (2006a): $F_m = 2.10$ Pinero (2001): $F_m = 1.63$					
AHSVS-PLS		LAV III-ISC		Leopard 2A4M	
No Trailer	Trailer	Case (1) / (2)	Case (3)	Lateral Load Dist.	
	Uncorrelated / Correlated			Pinero (2001)	CSA (2006a)
364	377	244	291	583	751

H.2.5 – Calculation of Factored, Unfactored Resistance, and $\boldsymbol{\phi}$

Note: a is taken from surface of concrete.

Calculate a for factored material resistance, a_f, by assuming a_f is in the flange of the T-beam:

$$a_f = \frac{\phi_s A_s F_y}{\phi_c \alpha_1 f_c{}' b} = \frac{(0.90)(8{,}190\text{ mm}^2)(414\text{ MPa})}{(0.75)(0.809)(27.6\text{ MPa})(2{,}134\text{ mm})} = 85\text{ mm}$$

Calculate factored moment arm, d_f, between centroid of compression and tension:

$$d_f = (\text{Steel Depth}) - \frac{a}{2} = 203\text{ mm} + 686\text{ mm} - 120\text{ mm} - \frac{85\text{ mm}}{2} = 727\text{ mm}$$

Calculate the factored plastic moment resistance, M_{r_f} of the section:

$$M_{r_f} = \phi_s A_s F_y d_f = (0.9)(8{,}190\text{ mm}^2)(414\text{ MPa})(727\text{ mm}) = 2{,}218.5\text{ kN}\cdot\text{m}$$

Calculate a for specified material resistance, a_s, by assuming a_s is in the flange of the T-beam:

$$a_s = \frac{A_s F_y}{\alpha_1 f_c{}' b} = \frac{(8{,}190\text{ mm}^2)(414\text{ MPa})}{(0.809)(27.6\text{ MPa})(2{,}134\text{ mm})} = 71\text{ mm}$$

Calculate specified moment arm, d_f, between centroid of compression and tension:

$$d_f = (\text{Steel Depth}) - \frac{a}{2} = 203\text{ mm} + 686\text{ mm} - 120\text{ mm} - \frac{71\text{ mm}}{2} = 734\text{ mm}$$

Calculate the specified plastic moment resistance, M_{r_s} of the section:

$$M_{r_s} = A_s F_y d_f = (8{,}190\text{ mm}^2)(414\text{ MPa})(734\text{ mm}) = 2{,}488.7\text{ kN}\cdot\text{m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{2{,}218.5\text{ kN}\cdot\text{m}}{2{,}488.7\text{ kN}\cdot\text{m}} = 0.891$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, the reinforcement ratio, ρ, and balance ratio, ρ_b, must be calculated:

$$\rho = \frac{A_s}{A_c} = \frac{8{,}190\text{ mm}^2}{781{,}690\text{ mm}^2} = 0.01$$

$$\rho_b = \frac{0.85\beta_1 f_c{}'}{F_y}\left(\frac{700}{700 + F_y}\right) = \frac{0.85(0.901)(27.6\text{ MPa})}{(414\text{ MPa})}\left(\frac{700}{700 + (414\text{ MPa})}\right) = 0.032$$

$$0.4\rho_b = 0.4(0.032) = 0.013 > \ \rho = 0.01 \rightarrow \delta_R = 1.04, V_R = 0.08$$

H.3 – DND (2007a), Example from Section F2.2, 21.95 m Steel-Stringer (x5), Bridge

H.3.1 – Cross Section of Bridge (excerpts from Figure F-2 of DND (2007a))

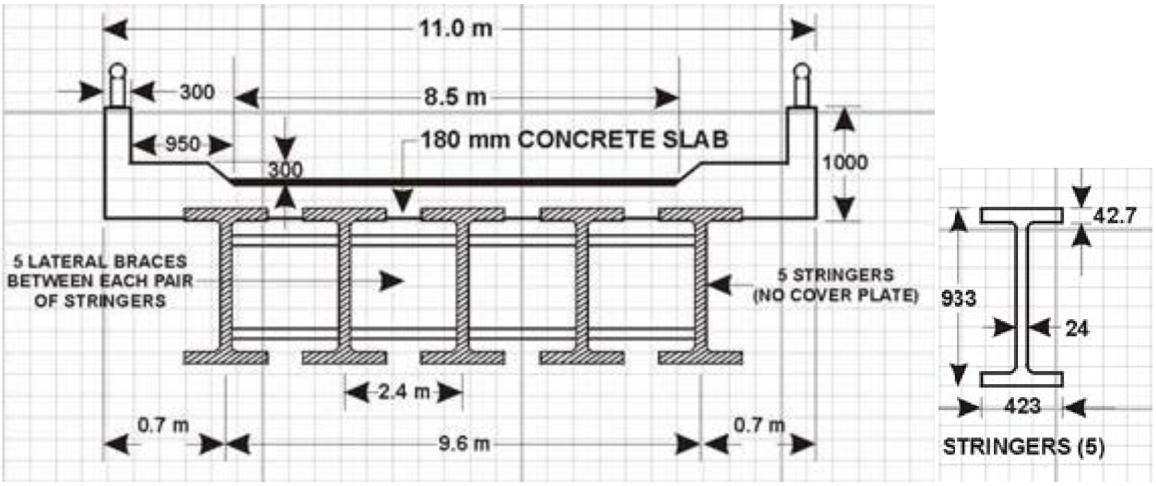


Figure H.3 - Cross Section of Bridge (DND, 2007a), 21.95 m steel-stringer (x5)

H.3.2 – Section Parameters

Span Length, $L = 21.95$ m	Steel Section Dead Load, $D = 4.39$ kN/m
Number of Girder, 5	Plastic Modulus, $Z_x = 21 \times 10^6$ mm^3
Girder Spacing, $S = 2{,}400$ mm	Density of Concrete, $\gamma_c = 24$ kN/m^3
Steel Yield Stress, $F_y = 210$ MPa	Steel Section is Class 1

H.3.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = \frac{5 \times (\text{Stringers}) + 2 \times (\text{Curbs}) + (\text{Braces})}{5}$$

$$= \frac{(21.95\ \text{kN/m}) + (25.49\ \text{kN/m}) + (0.82\,\text{kN/m})}{5} = 9.65\ \text{kN/m}$$

$$D_2 = \frac{(\text{Deck}) + (\text{Rails})}{5} = \frac{(47.52\ \text{kN/m}) + (0.30\ \text{kN/m})}{5} = 9.56\ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(9.65\ \text{kN/m}) \cdot (21.95\text{m})^2}{8} = 581.2\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(9.56\ \text{kN/m}) \cdot (21.95\text{m})^2}{8} = 575.8\ \text{kN} \cdot \text{m}$$

H.3.4 – Vehicle Live Load

Table H.3 - Vehicle live load moment at mid-span of interior girder

<table>
<tr><td colspan="6">L_1 (kNm)
CSA (2006a): $F_m = 2.78$
Pinero (2001): $F_m = 2.37$</td></tr>
<tr><td colspan="2">AHSVS-PLS</td><td colspan="2">LAV III-ISC</td><td colspan="2">Leopard 2A4M</td></tr>
<tr><td rowspan="2">No Trailer</td><td>Trailer</td><td rowspan="2">Case (1) / (2)</td><td rowspan="2">Case (3)</td><td colspan="2">Lateral Load Dist.</td></tr>
<tr><td>Uncorrelated / Correlated</td><td>Pinero (2001)</td><td>CSA (2006a)</td></tr>
<tr><td>909</td><td>1,118</td><td>529</td><td>632</td><td>1,386</td><td>1,625</td></tr>
</table>

H.3.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate the factored plastic moment resistance, M_{r_f} of the section:

$$M_{r_f} = \phi_s F_y Z_x = (0.95)(210\ \text{MPa})(21 \times 10^6\ \text{mm}^3) = 4{,}190\ \text{kN} \cdot \text{m}$$

Calculate the specified plastic moment resistance, M_{r_s} of the section:

$$M_{r_s} = F_y Z_x = (210\ \text{MPa})(21 \times 10^6\ \text{mm}^3) = 4{,}410\ \text{kN} \cdot \text{m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{4{,}190\ \text{kN} \cdot \text{m}}{4{,}410\ \text{kN} \cdot \text{m}} = 0.95$$

H.4 – DND (2007a), Example from Section F2.3, 24.38 m Steel-Composite (x4), Bridge

H.4.1 – Cross Section of Bridge (excerpts from Figure F-3 of DND (2007a))

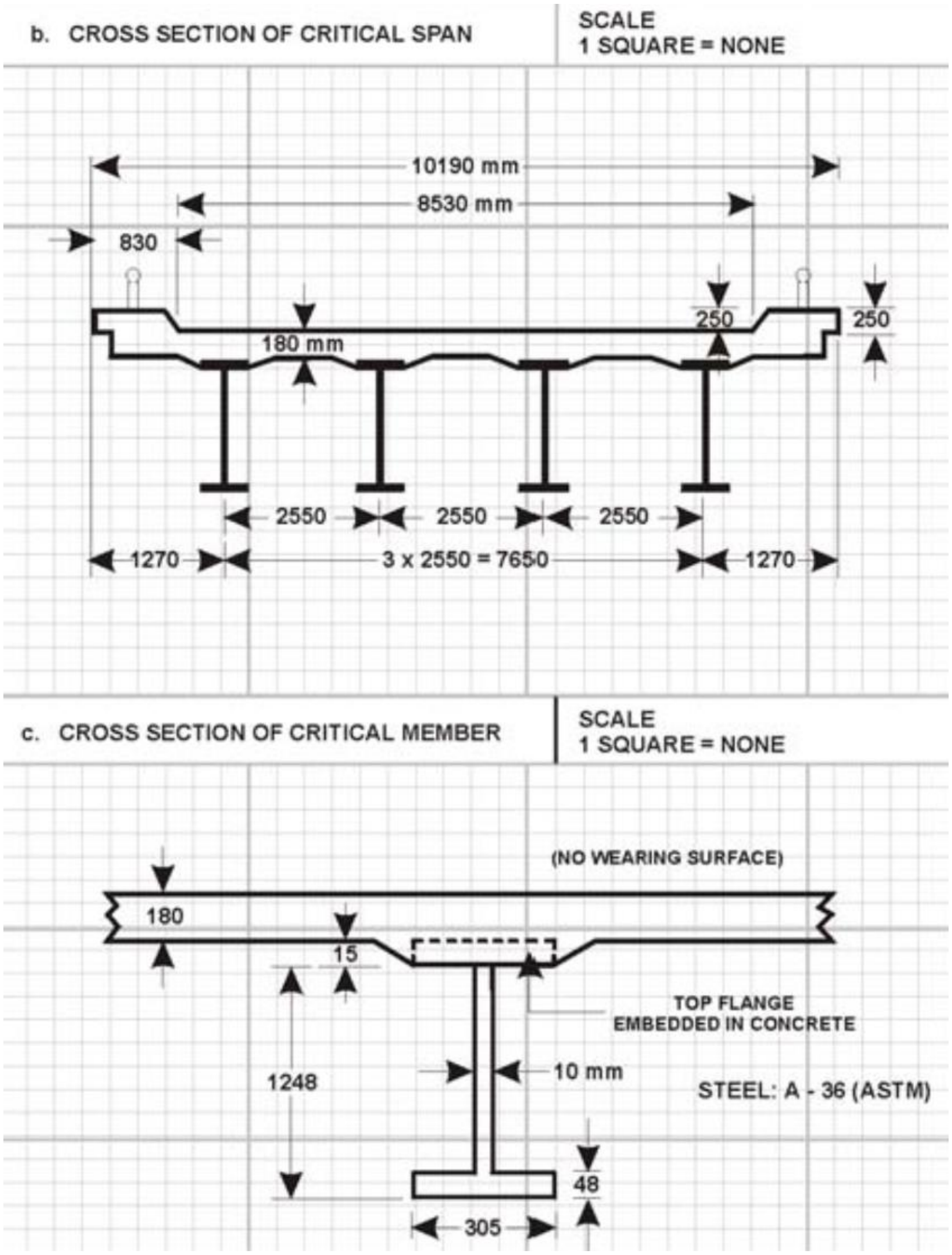


Figure H.4 - Cross section of bridge (DND, 2007a), 24.38 m steel-composite (x4)

H.4.2 – Section Parameters

Span Length, $L = 24.38$ m

Number of Girder, 4

Girder Spacing, $S = 2{,}550$ mm

Effective Width, $b = 2{,}550$ mm

Concrete Strength, $f_c{}' = 30$ MPa

Steel Yield Stress, $F_y = 250$ MPa

Area of Steel, $A_s = 31{,}215\ \text{mm}^2$

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

Centroid of Steel, $d_s = 999\text{mm}$

Class of Steel Section:

4. Top Flange – Class 2
5. Web – Class 3
6. Bottom Flange – Class 1

H.4.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = A_s \cdot \gamma_s + (A_{curb} \cdot \gamma_c)/4 = 0.0312\ \text{m}^2 \cdot 77\,\text{kN/m}^3 + (0.415\ \ \text{m}^2 \cdot 24\,\text{kN/m}^3)/4$$

$$= 4.893\ \ \text{kN/m}$$

$$D_2 = \frac{[A_{slab} \cdot \gamma_c + (\text{Rails and Bracing})]}{4} = \frac{[1.510\text{m}^2 \cdot 24\,\text{kN/m}^3 + 1.5\,\text{kN/m}]}{4}$$

$$= 11.38\ \ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(4.893\ \ \text{kN/m}) \cdot (24.38\text{m})^2}{8} = 363.5\,\text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(11.38\ \text{kN/m}) \cdot (24.38\text{m})^2}{8} = 845.5\ \text{kN} \cdot \text{m}$$

H.4.4 – Vehicle Live Load

Table H.4 - Vehicle live load moment at mid-span of interior girder

<table>
<tr><th colspan="6">L_1 (kNm)
CSA (2006a): $F_m = 2.35$
Pinero (2001): $F_m = 1.94$</th></tr>
<tr><td colspan="2">AHSVS-PLS</td><td colspan="2">LAV III-ISC</td><td colspan="2">Leopard 2A4M</td></tr>
<tr><td rowspan="2">No Trailer</td><td>Trailer</td><td rowspan="2">Case (1) / (2)</td><td rowspan="2">Case (3)</td><td colspan="2">Lateral Load Dist.</td></tr>
<tr><td>Uncorrelated / Correlated</td><td>Pinero (2001)</td><td>CSA (2006a)</td></tr>
<tr><td>1,097</td><td>1,393</td><td>630</td><td>752</td><td>1,596</td><td>1,933</td></tr>
</table>

H.4.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Note: a is taken from surface of concrete. Assume full plastic moment can be achieved.

Calculate a for factored material resistance, a_f, by assuming a_f is in the deck:

$$a_f = \frac{\phi_s A_s F_y}{0.85\phi_c f_c{}' b} = \frac{(0.95)(31{,}215\ \text{mm}^2)(250\ \text{MPa})}{0.85(0.75)(30\ \text{MPa})(2550\ \text{mm})} = 152\ \text{mm}$$

With a_f still within the deck, the factored plastic moment resistance, M_{r_f} of the section can be calculated:

$$M_{r_f} = \phi_s A_s F_y \left(d_s - \frac{a_f}{2}\right)$$

$$= (0.95)(31{,}215\ \text{mm}^2)(250\ \text{MPa})\left((999\ \text{mm}) - \frac{(152\ \text{mm})}{2}\right) = 6{,}842.7\ \text{kN} \cdot \text{m}$$

Calculate a for specified material resistance, a_s, by assuming a_s is in the deck:

$$a_s = \frac{A_s F_y}{0.85 f_c{}' b} = \frac{(31{,}215\ \text{mm}^2)(250\ \text{MPa})}{0.85(30\ \text{MPa})(2550\ \text{mm})} = 120\ \text{mm}$$

With a_s still within the deck, the nominal plastic moment resistance, M_{r_s} of the section can be calculated:

$$M_{r_s} = A_s F_y \left(d_s - \frac{a_f}{2}\right)$$

$$= (31{,}215\ \mathrm{mm}^2)(250\ \mathrm{MPa})\left((999\ \mathrm{mm}) - \frac{(120\ \mathrm{mm})}{2}\right) = 7{,}327.7\ \mathrm{kN\cdot m}$$

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{6{,}831.7\ \mathrm{kN\cdot m}}{7{,}322.7\ \mathrm{kN\cdot m}} = 0.934$$

H.5 - DND (2007a), Example from Section F2.7, 15.25 m Concrete T-Beam (x4), Bridge

H.5.1 – Cross Section of Bridge (excerpts from Figure F-163 of DND (2007a))

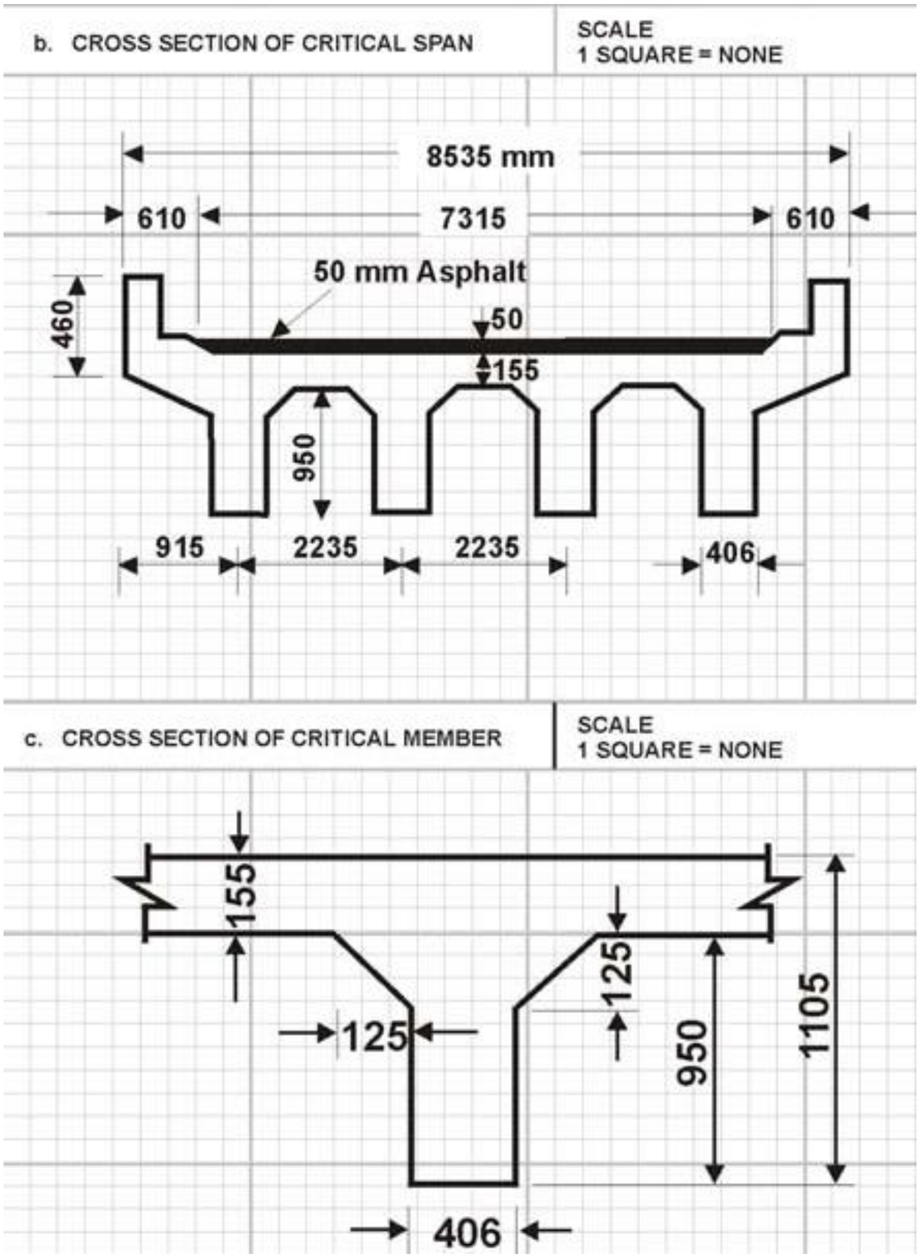


Figure H.5 - Cross section of bridge (DND, 2007a), 15.25 m concrete T-beam (x4)

H.5.2 – Section Parameters

Span Length, $L = 15.25$ m

Number of Girder, 4

Girder Spacing, $S = 2{,}235$ mm

Effective Flange Width, $b_f = 2{,}235$ mm

Concrete Strength $f_c{}' = 25$ MPa

$\alpha_1 = 0.813, \beta_1 = 0.908$

Steel Yield Stress, $F_y = 275$ MPa

Area of Steel, $A_s = 10{,}000\ \text{mm}^2$

Depth of Steel, $d_s = 1{,}020$ mm

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

Density of Asphalt, $\gamma_a = 23.5\ \text{kN/m}^3$

Area of Deck, $A_{slab} = 1{,}605{,}300\ \text{mm}^2$

Area of Beam, $A_{beam} = 4 \times 401{,}325\ \text{mm}^2$

Area of Asphalt, $A_{wear} = 365{,}750\ \text{mm}^2$

H.5.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = A_{beam} \cdot \gamma_c = (0.401{,}325\ \text{m}^2)(24\ \text{kN/m}^3) = 9.625\ \text{kN/m}$$

$$D_2 = \frac{(A_{slab} \cdot \gamma_c + A_{wear} \cdot \gamma_a)}{4}$$

$$= \big((1.6053\ \text{m}^2)(24\ \text{kN/m}^3) + (0.36575\ \text{m}^2)(23.5\ \text{kN/m}^3)\big)/4 = 12.275\ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(9.625\ \text{kN/m}) \cdot (15.25\text{m})^2}{8} = 279.8\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(12.275\ \text{kN/m}) \cdot (15.25\text{m})^2}{8} = 356.8\ \text{kN} \cdot \text{m}$$

H.5.4 – Vehicle Live Load

Table H.5 - Vehicle live load moment at mid-span of interior girder

L_1 (kNm) CSA (2006a): $F_m = 2.14$ Pinero (2001): $F_m = 2.27$					
AHSVS-PLS		LAV III-ISC		Leopard 2A4M	
No Trailer	Trailer	Case (1) / (2)	Case (3)	Lateral Load Dist.	
	Uncorrelated / Correlated			Pinero (2001)	CSA (2006a)
537	598	335	400	1,093	1,030

H.5.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Note: a is taken from surface of concrete.

Calculate a for factored material resistance, a_f, by assuming a_f is in the flange of the T-beam:

$$a_f = \frac{\phi_s A_s F_y}{\phi_c \alpha_1 f_c{}' b} = \frac{(0.90)(10{,}000\ \text{mm}^2)(275\ \text{MPa})}{(0.75)(0.8125)(25\ \text{MPa})(2{,}235\ \text{mm})} = 72.7\ \text{mm}$$

Calculate factored moment arm, d_f, between centroid of compression and tension:

$$d_f = d_s - \frac{a}{2} = 1{,}020\ \text{mm} - \frac{72.7\ \text{mm}}{2} = 984\ \text{mm}$$

Calculate the factored plastic moment resistance, M_{r_f} of the section:

$$M_{r_f} = \phi_s A_s F_y d_f = (0.9)(10{,}000\ \text{mm}^2)(275\ \text{MPa})(984\ \text{mm}) = 2{,}435\ \text{kN} \cdot \text{m}$$

Calculate a for specified material resistance, a_s, by assuming a_s is in the flange of the T-beam:

$$a_s = \frac{A_s F_y}{\alpha_1 f_c{}' b} = \frac{(10{,}000\ \text{mm}^2)(275\ \text{MPa})}{(0.8125)(25\ \text{MPa})(2{,}235\ \text{mm})} = 60.6\ \text{mm}$$

Calculate specified moment arm, d_f, between centroid of compression and tension:

$$d_f = d_s - \frac{a}{2} = 1{,}020 \text{ mm} - \frac{60.6 \text{ mm}}{2} = 990 \text{ mm}$$

Calculate the specified plastic moment resistance, M_{r_s} of the section:

$$M_{r_s} = A_s F_y d_f = (10{,}000 \text{ mm}^2)(275 \text{ MPa})(990 \text{ mm}) = 2{,}722.5 \text{ kN} \cdot \text{m}$$

With the specified and factored moment resistance, ϕ_{oe} can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{2{,}435 \text{ kN} \cdot \text{m}}{2{,}722.5 \text{ kN} \cdot \text{m}} = 0.894$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, the reinforcement ratio, ρ, and balance ratio, ρ_b, must be calculated:

$$\rho = \frac{A_s}{A_c} = \frac{10{,}000 \text{ mm}^2}{747{,}750 \text{ mm}^2} = 0.013$$

$$\rho_b = \frac{0.85\beta_1 f_c{}'}{F_y}\left(\frac{700}{700 + F_y}\right) = \frac{0.85(0.9075)(25 \text{ MPa})}{(275 \text{ MPa})}\left(\frac{700}{700 + (275 \text{ MPa})}\right) = 0.05$$

$$0.4\rho_b = 0.4(0.05) = 0.02 > \rho = 0.013 \rightarrow \delta_R = 1.04, V_R = 0.08$$

H.6 – DND (2007a), Example from Section F2.9, 22.9 m CPCI Girder (x5), Bridge

H.6.1 – Cross Section of Bridge (except from Figure F-20 of DND (2007a))

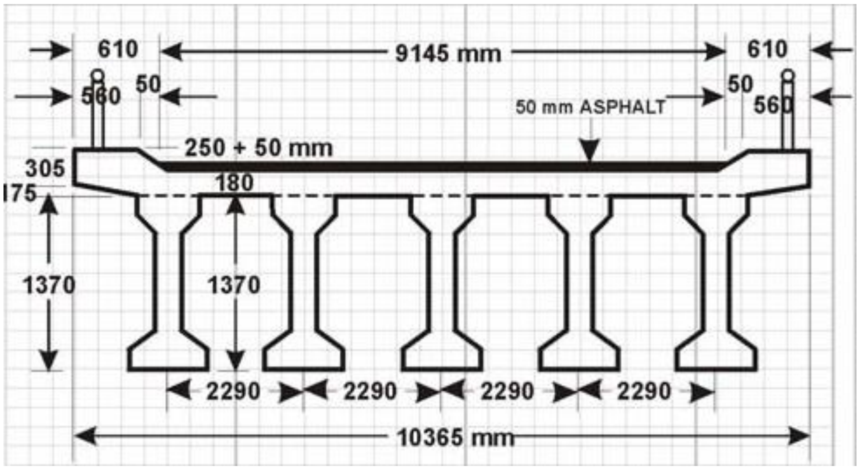


Figure H.6 – Cross section of bridge (DND, 2007a), 22.9 m CPCI girder (x5)

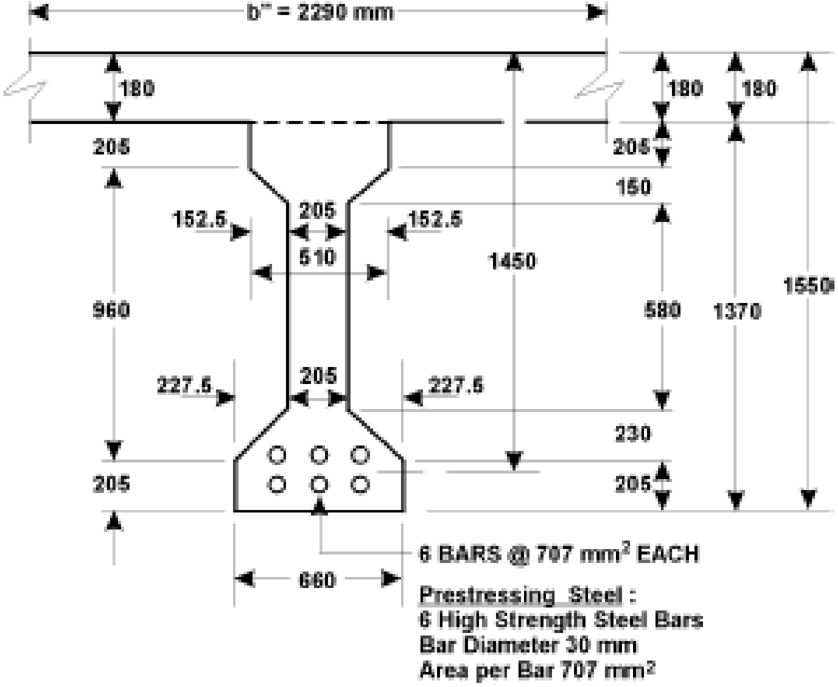


Figure H.7 - Cross section of interior girder at mid-span (DND, 2007a)

H.6.2 – Section Parameters

Span Length, $L = 22.9$ m

Number of Girder, 5

Girder Spacing, $S = 2{,}290$ mm

Effective Flange Width, $b_f = 2{,}290$ mm

Concrete Strength of Deck, $f_c{}' = 35$ MPa

High Strength Steel bars, $K_p = 0.5$

Strands Ultimate Stress, $f_{pu} = 1{,}655$ MPa

Area of Pre-Stressing, $A_{ps} = 4{,}242\ \text{mm}^2$

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

$\alpha_1 = 0.80, \beta_1 = 0.883$ (for deck)

H.6.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = (\text{Girder}) + \frac{\text{Barriers}}{5} = \left[(0.513\ \text{m}^2) + \frac{2}{5}(0.56\ \text{m})(0.3\ \text{m})\right](24\ \text{kN/m}^3)$$

$$= 13.9\ \text{kN/m}$$

$$D_2 = (\text{Deck Slab } + \text{Rails} + \text{Ashpalt })/5$$

$$= [(10.365\ \text{m})(0.18\ \text{m})(24\ \text{kN/m}^3) + 2(1\,\text{kN/m}) + (9.145\ \text{m})(0.05\ \text{m})(23.5\ \text{kN/m}^3)]/5$$

$$= 11.5\ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(13.9\ \text{kN/m}) \cdot (22.9\text{m})^2}{8} = 911.2\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(11.5\ \text{kN/m}) \cdot (22.9\text{m})^2}{8} = 753.8\ \text{kN} \cdot \text{m}$$

$$M_{D_3} = 0$$

H.6.4 – Vehicle Live Load

Table H.6 - Vehicle live load moment at mid-span of interior girder

<table>
<tr><th colspan="6">L_1 (kNm)
CSA (2006a): $F_m = 2.65$
Pinero (2001): $F_m = 2.32$</th></tr>
<tr><th colspan="2">AHSVS-PLS</th><th colspan="2">LAV III-ISC</th><th colspan="2">Leopard 2A4M</th></tr>
<tr><th rowspan="2">No Trailer</th><th>Trailer</th><th rowspan="2">Case (1) / (2)</th><th rowspan="2">Case (3)</th><th colspan="2">Lateral Load Dist.</th></tr>
<tr><th>Uncorrelated / Correlated</th><th>Pinero (2001)</th><th>CSA (2006a)</th></tr>
<tr><td>1,166</td><td>1,529</td><td>659</td><td>787</td><td>1,817</td><td>2,023</td></tr>
</table>

H.6.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate factored value of c/d_p, where c is the distance from the extreme compression fiber to the neutral axis and d_p is the depth of centroid of pre-stress from extreme compression fiber.

$$c/d_p = \frac{\phi_p A_{ps} f_{pu}}{\alpha_1 \phi_c \beta_1 f_c{}' b_f d_p + \phi_p k_p A_{ps} f_{pu}}$$

$$= \frac{(0.9)(4{,}242)(1{,}655)}{(0.8)(0.75)(0.8825)(35)(2{,}290)(1{,}450) + (0.9)(0.5)(4{,}242)(1{,}655)}$$

$$= 0.098$$

Check if compression is in slab:

$$c = 0.098 d_p = (0.098)(1{,}450\ \text{mm}) = 142\ \text{mm} < 180\ \text{mm}, \quad \therefore\ \text{OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.8825)(142\ \text{mm}) = 125\ \text{mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p\frac{c}{d_p}\right) = (1{,}655\ \text{MPa})\big(1 - (0.5)(0.098)\big) = 1{,}574\ \text{MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_f} = \phi_p A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (0.9)(4{,}242\ \text{mm}^2)(1{,}574\ \text{MPa})\left((1{,}450\ \text{mm}) - \frac{(125\ \text{mm})}{2}\right)$$

$$= 8{,}337.8\ \text{kN} \cdot \text{m}$$

Calculate specified value of c/d_p:

$$c/d_p = \frac{A_{ps}f_{pu}}{\alpha_1\beta_1 f_c{}' b_f d_p + k_p A_{ps} f_{pu}}$$

$$= \frac{(4{,}242)(1{,}655)}{(0.8)(0.8825)(35)(2{,}290)(1{,}450) + (0.5)(4{,}242)(1{,}655)}$$

$$= 0.082$$

Check if compression is in slab:

$$c = 0.082 d_p = (0.082)(1{,}450\ \text{mm}) = 119\ \text{mm} < 180\ \text{mm}, \quad \therefore\ \text{OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.8825)(119\ \text{mm}) = 105\ \text{mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p\frac{c}{d_p}\right) = (1{,}655\ \mathrm{MPa})\big(1 - (0.5)(0.082)\big) = 1{,}587\ \mathrm{MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_s} = A_{ps}f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (4{,}242\ \mathrm{mm}^2)(1{,}587\ \mathrm{MPa})\left((1{,}450\ \mathrm{mm}) - \frac{(105\ \mathrm{mm})}{2}\right)$$

$$= 9{,}408\ \mathrm{kN\cdot m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{8{,}337.8\ \mathrm{kN\cdot m}}{9{,}408\ \mathrm{kN\cdot m}} = 0.886$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, ω_p must be calculated:

$$\omega_p \approx 0.85\frac{a}{d_p} = 0.85\frac{(105\ \mathrm{mm\ to\ }125\ \mathrm{mm})}{1{,}450\ \mathrm{mm}} = 0.062\ \mathrm{to}\ 0.073$$

$$\therefore\ \omega_p < 0.15 \rightarrow \delta_R = 1.06, V_R = 0.05$$

H.7 – Bartlett (1980), 20 m CPCI Girder (x6), Bridge

H.7.1 – Cross Section of Interior Girder at Mid-span

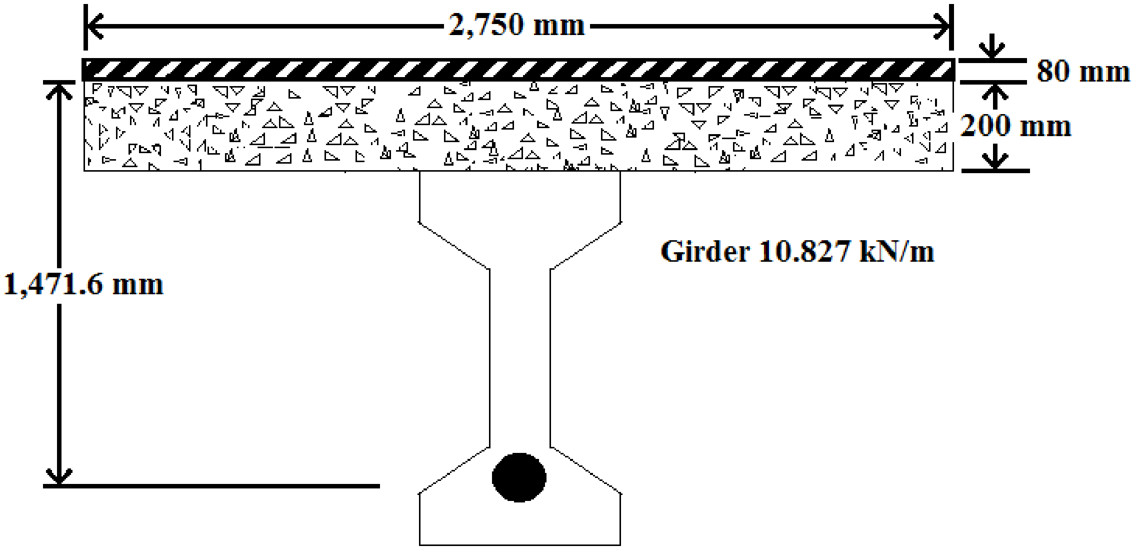


Figure H.8 – Cross section of interior girder at mid-span, 20 m CPCI Girder (x6)

H.7.2 – Section Parameters

Span Length, $L = 20$ m

Number of Girder, 6

Girder Spacing, $S = 2{,}750$ mm

Effective Flange Width, $b_f = 2{,}750$ mm

CPCI Concrete Strength, $f_c{}' = 40$ MPa

Concrete Strength of Deck, $f_c{}' = 30$ MPa

Strands Ultimate Stress, $f_{pu} = 1{,}860$ MPa

Area of Pre-Stressing, $A_{ps} = 1{,}980\ \text{mm}^2$

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

Density of Asphalt, $\gamma_a = 23.5\ \text{kN/m}^3$

$\alpha_1 = 0.805$, $\beta_1 = 0.895$ (for deck)

Depth of Pre-stressing, $d_p = 1{,}471.6$ mm

Low-Relax Strands, $K_p = 0.3$

H.7.3 – Dead Load

Dead loads, per interior girder:

$D_1 = (\text{Girder}) + (\text{Haunch}) = (10.827\ \text{kN/m}) + (1.006\ \text{kN/m})$

$= 11.83\ \text{kN/m}$

$D_2 = (\text{Deck Slab})\ + ((\text{Asphalt}) + (\text{Barrier and Rails}))/6$

$= (13.2\ \text{kN/m}) + [(29.67\,\text{kN/m}) + (10.08\,\text{kN/m})]/6$

$= 19.66\ \text{kN/m}$

$D_3 = 0$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(11.83\ \text{kN/m}) \cdot (20\ \text{m})^2}{8} = 591.7\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(19.66\ \text{kN/m}) \cdot (20\ \text{m})^2}{8} = 983\ \text{kN} \cdot \text{m}$$

$M_{D_3} = 0$

H.7.4 – Vehicle Live Load

Table H.7 - Vehicle live load moment at mid-span of interior girder

<table>
<tr><td colspan="6">L_1 (kNm)
CSA (2006a): $F_m = 3.85$
Pinero (2001): $F_m = 3.39$</td></tr>
<tr><td colspan="2">AHSVS-PLS</td><td colspan="2">LAV III-ISC</td><td colspan="2">Leopard 2A4M</td></tr>
<tr><td rowspan="2">No Trailer</td><td>Trailer</td><td rowspan="2">Case (1) / (2)</td><td rowspan="2">Case (3)</td><td colspan="2">Lateral Load Dist.</td></tr>
<tr><td>Uncorrelated / Correlated</td><td>Pinero (2001)</td><td>CSA (2006a)</td></tr>
<tr><td>929.6</td><td>1,106</td><td>550</td><td>656</td><td>1,486</td><td>1,688</td></tr>
</table>

H.7.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate factored value of c/d_p, where c is the distance from the extreme compression fiber to the neutral axis and d_p is the depth of centroid of pre-stress from extreme compression fiber.

$$c/d_p = \frac{\phi_p A_{ps} f_{pu}}{\alpha_1 \phi_c \beta_1 f_c{}' b_f d_p + \phi_p k_p A_{ps} f_{pu}}$$

$$= \frac{(0.95)(1{,}980)(1{,}860)}{(0.805)(0.75)(0.895)(30)(2{,}750)(1{,}471.6) + (0.95)(0.3)(1{,}980)(1{,}860)}$$

$$= 0.052$$

Check if compression is in slab:

$$c = 0.052 d_p = (0.052)(1{,}471.6\text{ mm}) = 77\text{ mm} < 200\text{ mm}, \quad \therefore \text{ OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(77\text{ mm}) = 69\text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860\text{ MPa})\big(1 - (0.3)(0.052)\big) = 1{,}831\text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_f} = \phi_p A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (0.95)(1{,}980\text{ mm}^2)(1{,}831\text{ MPa})\left((1{,}471.6\text{ mm}) - \frac{(77\text{ mm})}{2}\right)$$

$$= 4{,}935.8\text{ kN}\cdot\text{m}$$

Calculate specified value of c/d_p:

$$c/d_p = \frac{A_{ps}f_{pu}}{\alpha_1\beta_1 f_c{}' b_f d_p + k_p A_{ps} f_{pu}}$$

$$= \frac{(1{,}980)(1{,}860)}{(0.805)(0.895)(30)(2{,}750)(1{,}471.6) + (0.3)(1{,}980)(1{,}860)}$$

$$= 0.042$$

Check if compression is in slab:

$$c = 0.042 d_p = (0.042)(1{,}471.6\text{ mm}) = 61\text{ mm} < 200\text{ mm}, \quad \therefore\ \text{OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(61\text{ mm}) = 55\text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860\text{ MPa})\big(1 - (0.3)(0.042)\big) = 1{,}837\text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_s} = A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (1{,}980\text{ mm}^2)(1{,}837\text{ MPa})\left((1{,}471.6\text{ mm}) - \frac{(55\text{ mm})}{2}\right)$$

$$= 5{,}252.6\text{ kN}\cdot\text{m}$$

With the specified and factored moment resistance, ϕ_{oe} can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{4{,}935.8\ \mathrm{kN \cdot m}}{5{,}252.6\ \mathrm{kN \cdot m}} = 0.940$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, ω_p must be calculated:

$$\omega_p \approx 0.85\frac{a}{d_p} = 0.85\frac{(55\ \mathrm{mm\ to\ 69\ mm})}{1{,}471.6\ \mathrm{mm}} = 0.032\ \mathrm{to}\ 0.040$$

$$\therefore\ \omega_p < 0.15 \rightarrow \delta_R = 1.06, V_R = 0.05$$

H.8 – Bartlett (1980), 25 m CPCI Girder (x5), Bridge

H.8.1 – Cross Section of Interior Girder at Mid-span

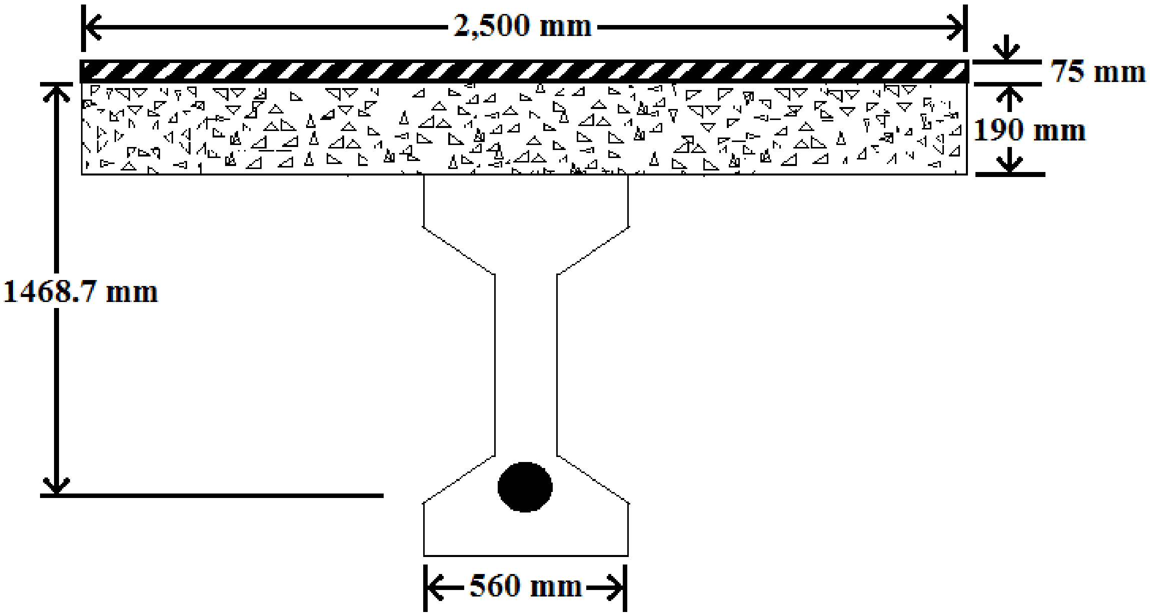


Figure H.9 – Cross section of interior girder at mid-span 25 m CPCI girder (x5)

H.8.2 – Section Parameters

Span Length, $L = 25$ m

Girder Spacing, $S = 2{,}500$ mm

Number of Girder, 5

Effective Flange Width, $b_f = 2{,}500$ mm

Concrete Strength of Deck, $f_c{}' = 30$ MPa

Strands Ultimate Stress, $f_{pu} = 1{,}860$ MPa

Area of Pre-Stressing, $A_{ps} = 2{,}772\ \text{mm}^2$

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

Density of Asphalt, $\gamma_a = 23.5\ \text{kN/m}^3$

$\alpha_1 = 0.805$, $\beta_1 = 0.895$ (for deck)

Depth of Pre-stressing, $d_p = 1{,}468.7$ mm

Low-Relax Strands, $K_p = 0.3$

H.8.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = (\text{Girder}) + \frac{\text{Barriers}}{5} = \left[(10.8\ \text{kN/m}) + \frac{(9.989\,\text{kN/m})}{5}\right]$$

$$= 12.82\ \text{kN/m}$$

$$D_2 = (\text{Deck Slab } + \text{Asphalt} + \text{Other})/5$$

$$= [(56.316\ \text{kN/m}) + (20.269\,\text{kN/m}) + (0.09\,\text{kN/m})]/5$$

$$= 15.335\ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(12.82\ \text{kN/m}) \cdot (25\ \text{m})^2}{8} = 1{,}001.6\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(15.335\ \text{kN/m}) \cdot (25\ \text{m})^2}{8} = 1{,}199.6\ \text{kN} \cdot \text{m}$$

$$M_{D_3} = 0$$

H.8.4 – Vehicle Live Load

Table H.8 - Vehicle live load moment at mid-span of interior girder

L_1 (kNm) CSA (2006a): $F_m = 2.87$ Pinero (2001): $F_m = 2.40$					
AHSVS-PLS		LAV III-ISC		Leopard 2A4M	
No Trailer	Trailer Uncorrelated / Correlated	Case (1) / (2)	Case (3)	Lateral Load Dist. Pinero (2001)	 CSA (2006a)
1,104	1,411	632	755	1,623	1,941

H.8.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate factored value of c/d_p, where c is the distance from the extreme compression fiber to the neutral axis and d_p is the depth of centroid of pre-stress from extreme compression fiber.

$$c/d_p = \frac{\phi_p A_{ps} f_{pu}}{\alpha_1 \phi_c \beta_1 f_c{}' b_f d_p + \phi_p k_p A_{ps} f_{pu}}$$

$$= \frac{(0.95)(2{,}772)(1{,}860)}{(0.805)(0.75)(0.895)(30)(2{,}500)(1{,}468.7) + (0.95)(0.3)(2{,}772)(1{,}860)}$$

$$= 0.080$$

Check if compression is in slab:

$$c = 0.080 d_p = (0.080)(1{,}468.7 \text{ mm}) = 117 \text{ mm} < 190 \text{ mm}, \quad \therefore \text{ OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(117 \text{ mm}) = 105 \text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860 \text{ MPa})\big(1 - (0.3)(0.080)\big) = 1{,}815 \text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_f} = \phi_p A_{ps} f_{ps} \left(d_p - \frac{a}{2}\right)$$

$$= (0.95)(2{,}772\text{ mm}^2)(1{,}815\text{ MPa})\left((1{,}468.7\text{ mm}) - \frac{(105\text{ mm})}{2}\right)$$

$$= 6{,}768.9\text{ kN}\cdot\text{m}$$

Calculate specified value of c/d_p:

$$c/d_p = \frac{A_{ps} f_{pu}}{\alpha_1 \beta_1 f_c{}' b_f d_p + k_p A_{ps} f_{pu}}$$

$$= \frac{(2{,}772)(1{,}860)}{(0.805)(0.895)(30)(2{,}500)(1{,}468.7) + (0.3)(2{,}772)(1{,}860)}$$

$$= 0.064$$

Check if compression is in slab:

$$c = 0.064 d_p = (0.062)(1{,}468.7\text{ mm}) = 93.6\text{ mm} < 190\text{ mm}, \quad \therefore\ \text{OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.895)(93.6\text{ mm}) = 84\text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860\text{ MPa})\big(1 - (0.3)(0.064)\big) = 1{,}824\text{ MPa}$$

Calculate specified moment resistance, M_{r_s}:

$$M_{r_s} = A_{ps} f_{ps} \left(d_p - \frac{a}{2}\right)$$

$$= (2{,}772\ \mathrm{mm}^2)(1{,}824\ \mathrm{MPa})\left((1{,}468.7\ \mathrm{mm}) - \frac{(84\ \mathrm{mm})}{2}\right)$$

$$= 7{,}213.5\ \mathrm{kN \cdot m}$$

With the specified and factored moment resistance, ϕ_{oe} can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{6{,}768.9\ \mathrm{kN \cdot m}}{7{,}213.5\ \mathrm{kN \cdot m}} = 0.938$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, ω_p must be calculated:

$$\omega_p \approx 0.85\frac{a}{d_p} = 0.85\frac{(84\ \mathrm{mm\ to\ 105\ mm})}{1{,}468.7\ \mathrm{mm}} = 0.049\ \mathrm{to}\ 0.061$$

$$\therefore\ \omega_p < 0.15 \rightarrow \delta_R = 1.06, V_R = 0.05$$

H.9 – Bartlett (1980), 35 m Steel-Composite (x4), Bridge

H.9.1 – Interior Girder Cross Section

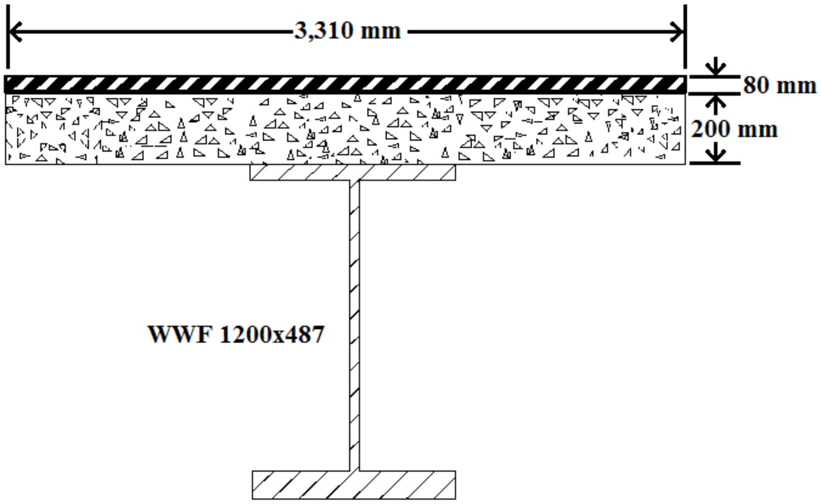


Figure H.10 – Cross section of interior girder, 35 m steel-composite (x4)

H.9.2 – Section Parameters

Span Length, $L = 35$ m

Number of Girder, 4

Girder Spacing, $S = 3{,}310$ mm

Effective Width, $b = 3{,}310$ mm

Concrete Strength, $f_c' = 30$ MPa

Steel Yield Stress, $F_y = 350$ MPa

Beam Dead Load, $= 4.78\ \text{kN/m}$

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24\ \text{kN/m}^3$

Area of Steel, $A_s = 62{,}100\ \text{mm}^2$

Class of Steel Section:

7. Flange – Class 1
8. Web – Class 2

H.9.3 – Dead Load

Dead loads, per interior girder:

$$D_1 = \frac{[(\text{Beam with 5\% for bracing}) + (\text{Barriers})]}{4}$$

$$= [(20.065\ \text{kN/m}) + (9.989\ \text{kN/m})]/4$$

$$= 7.51\ \text{kN/m}$$

$$D_2 = \frac{[(\text{Slab}) + (\text{Asphalt}) + (\text{Rails})]}{4}$$

$$= \frac{[(59.22\ \text{kN/m}) + (21.62\ \text{kN/m}) + (0.09\ \text{kN/m})]}{4}$$

$$= 20.23\ \text{kN/m}$$

$$D_3 = 0$$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(7.51\ \text{kN/m}) \cdot (35\ \text{m})^2}{8} = 1{,}150\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(20.23\ \text{kN/m}) \cdot (35\ \text{m})^2}{8} = 3{,}098\ \text{kN} \cdot \text{m}$$

H.9.4 – Vehicle Live Load

Table H.9 - Vehicle live load moment at mid-span of interior girder

L_1 (kNm) CSA (2006a): $F_m = 2.99$ Pinero (2001): $F_m = 3.00$					
AHSVS-PLS		LAV III-ISC		Leopard 2A4M	
No Trailer	Trailer	Case (1) / (2)	Case (3)	Lateral Load Dist.	
	Uncorrelated / Correlated			Pinero (2001)	CSA (2006a)
2,151	2,948	1,190	1,420	3,661	3,649

H.9.5 – Calculation of Factored, Unfactored Resistance, and ϕ

Calculate neutral axis, $\bar{y}$, for factored material resistance, by assuming $\bar{y}$ is in the top flange of the steel section:

$$\bar{y} = \frac{\phi_s A_s F_y - 0.85\phi_c f_c{}' h_{slab} b}{2b_2\phi_s F_y}$$

$$= \frac{(0.95)(62{,}100\ \text{mm}^2)(350\ \text{MPa}) - 0.85(0.75)(30\ \text{MPa})(200\ \text{mm})(3{,}310\ \text{mm})}{2(550\ \text{mm})(0.95)(350\ \text{MPa})}$$

$= 21.8\ \text{mm} < 40\ \text{mm}$ ∴ Assumption is correct

where, h_{slab} is the depth of the concrete slab, and b_2 is the width of the top flange of the steel girder. The factored moment resistance, M_{r_f}, is calculated by taking moments from the centroid of the concrete. Centroid of Steel in tension, $\bar{y}_T$, is 719.7 mm below the neutral axis.

$$M_{r_f} = \phi_s F_y (A_s - b_2\bar{y})\left(\frac{h_{slab}}{2} + \bar{y} + \bar{y}_T\right) - \phi_s F_y b_2 \bar{y}\left(\frac{h_{slab} + \bar{y}}{2}\right)$$

$$= (0.95)(350\ )[(62{,}100) - (550)(21.8)]\left[\frac{(200)}{2} + (21.8) + (719.7)\right]$$

$$- (0.95)(350)(550)(21.8)\left[\frac{(200) + (21.8)}{2}\right]$$

$$= 13{,}578.6\ \mathrm{kN \cdot m}$$

Calculate neutral axis, $\bar{y}$, for specified material resistance, by assuming $\bar{y}$ is in the top flange of the steel section:

$$\bar{y} = \frac{A_s F_y - 0.85 f_c{}' h_{slab} b}{2 b_2 F_y}$$

$$= \frac{(62{,}100\ \mathrm{mm}^2)(350\ \mathrm{MPa}) - 0.85(30\ \mathrm{MPa})(200\ \mathrm{mm})(3{,}310\ \mathrm{mm})}{2(550\ \mathrm{mm})(350\ \mathrm{MPa})}$$

$= 12.6\ \mathrm{mm} < 40\ \mathrm{mm}$ ∴ Assumption is correct

The specified moment resistance, M_{r_s}, is calculated by taking moments from the centroid of the concrete. Centroid of Steel in tension, $\bar{y}_T$, is 662.2 mm below the neutral axis.

$$M_{r_s} = F_y(A_s - b_2\bar{y})\left(\frac{h_{slab}}{2} + \bar{y} + \bar{y}_T\right) - F_y b_2 \bar{y}\left(\frac{h_{slab} + \bar{y}}{2}\right)$$

$$= (350\ )[(62{,}100) - (550)(12.6)]\left[\frac{(200)}{2} + (12.6) + (662.2)\right]$$

$$- (350)(550)(12.6)\left[\frac{(200) + (12.6)}{2}\right]$$

$$= 14{,}703\ \mathrm{kN \cdot m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{13{,}579\ \mathrm{kN \cdot m}}{14{,}703\ \mathrm{kN \cdot m}} = 0.924$$

H.10 – Genivar (2012), 30.8 m Pre-Stressed Box-Girder (x8), Bridge

H.10.1 – Cross Section of Interior Girder at Mid-span

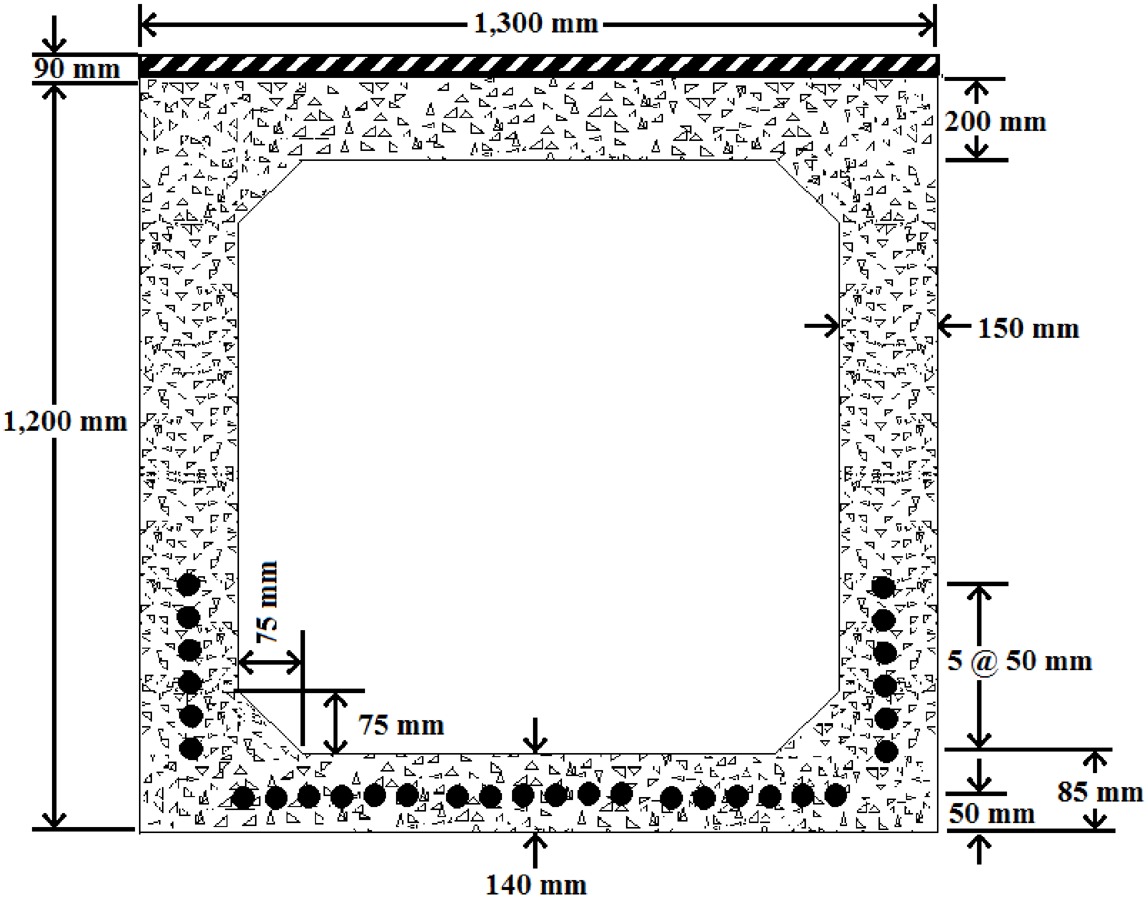


Figure H.11 – Cross section of interior girder at mid-span, 30.8 m pre-stressed box-girder (x 8)

H.10.2 – Section Parameters

Span Length, $L = 30.8$ m

Roadway Width, $W = 9.5$ m

Number of Girder, 8

Concrete Strength, $f_c' = 60$ MPa

Strands Ultimate Stress, $f_{pu} = 1{,}860$ MPa

Density of Steel, $\gamma_s = 77\ \text{kN/m}^3$

Density of Concrete, $\gamma_c = 24.5\ \text{kN/m}^3$

Density of Asphalt, $\gamma_a = 23.5\ \text{kN/m}^3$

$\alpha_1 = 0.76$, $\beta_1 = 0.82$

Area of Concrete, $A_c = 711{,}250\ \text{mm}^2$

Area of Pre-Stressing, $A_{ps} = 2{,}970\ \text{mm}^2$

Depth Pre-stressing Centroid, $d_p = 1{,}086\ \text{mm}$

Low-Relax Strands, $K_p = 0.3$

H.10.3 – Dead Load

Dead loads, per interior girder:

$D_1 = (\text{Girder}) = A_c\gamma_c = (711{,}250\ \text{mm}^2)(24.5\ \text{kN/m}^3)$

$= 17.43\,\text{kN/m}$

$D_2 = [(\text{Asphalt}) + (\text{Curb and Rail})]/8$

$= [(0.09\ \text{m})(9.5\ \text{m})(23.5\ \text{kN/m}^3) + (1\ \text{kN/m})]/8$

$= 2.64\ \text{kN/m}$

$D_3 = 0$

Dead load moment per interior girder at mid-span:

$$M_{D_1} = \frac{D_1 \cdot L^2}{8} = \frac{(17.43\ \text{kN/m}) \cdot (30.8\ \text{m})^2}{8} = 2{,}066\ \text{kN} \cdot \text{m}$$

$$M_{D_2} = \frac{D_2 \cdot L^2}{8} = \frac{(2.64\ \text{kN/m}) \cdot (30.8\ \text{m})^2}{8} = 312.8\ \text{kN} \cdot \text{m}$$

$M_{D_3} = 0$

H.10.4 – Vehicle Live Load

Following CSA (2006a) to calculate lateral load distribution using simplified methods, values for F and C_f are not specified for single lane traffic for box-girder type bridges. For this case, since C_f remains unchanged for 2, 3, and 4 lanes at ultimate limit states, it will be assumed that this also applies for single lane traffic with a $C_f = 13.3\%$. The difference for F between 4 lanes and 3 lanes, as well as between 3 lanes to 2 lanes is 2.734. Given this, it will be assumed this difference is the same between 2 lanes and a single lane, with a $F = 5.37$. Using these values $F_m = 1.72$.

Table H.10 - Vehicle live load moment at mid-span of interior girder

L_1 (kNm) CSA (2006a): $F_m = 1.72$				
AHSVS-PLS		LAV III-ISC		Leopard 2A4M
No Trailer	Trailer	Case (1) / (2)	Case (3)	
	Uncorrelated / Correlated			
353	472	198	236	606

H.8.5 – Calculation of Factored, Unfactored Resistance, and $\boldsymbol{\phi}$

Calculate factored value of c/d_p, where c is the distance from the extreme compression fiber to the neutral axis and d_p is the depth of centroid of pre-stress from extreme compression fiber.

$$c/d_p = \frac{\phi_p A_{ps} f_{pu}}{\alpha_1 \phi_c \beta_1 f_c{}' b_f d_p + \phi_p k_p A_{ps} f_{pu}}$$

$$= \frac{(0.95)(2{,}970)(1{,}860)}{(0.76)(0.75)(0.82)(60)(1{,}300)(1{,}086) + (0.95)(0.3)(2{,}970)(1{,}860)}$$

$$= 0.127$$

Check if compression is in slab:

$$c = 0.127 d_p = (0.127)(1{,}086\text{ mm}) = 138\text{ mm} < 200\text{ mm}, \quad \therefore \text{ OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.82)(138\text{ mm}) = 113.5\text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860 \text{ MPa})\big(1 - (0.3)(0.127)\big) = 1{,}789 \text{ MPa}$$

Calculate factored moment resistance, M_{r_f}:

$$M_{r_f} = \phi_p A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right)$$

$$= (0.95)(2{,}970 \text{ mm}^2)(1{,}789 \text{ MPa})\left((1{,}086 \text{ mm}) - \frac{(113.5 \text{ mm})}{2}\right)$$

$$= 5{,}195 \text{ kN} \cdot \text{m}$$

Calculate specified value of c/d_p:

$$c/d_p = \frac{A_{ps} f_{pu}}{\alpha_1 \beta_1 f_c{}' b_f d_p + k_p A_{ps} f_{pu}}$$

$$= \frac{(2{,}970)(1{,}860)}{(0.76)(0.82)(60)(1{,}300)(1{,}086) + (0.3)(2{,}970)(1{,}860)}$$

$$= 0.101$$

Check if compression is in slab:

$$c = 0.101 d_p = (0.101)(1{,}086 \text{ mm}) = 110 \text{ mm} < 200 \text{ mm}, \quad \therefore \text{ OK}$$

Depth of equivalent stress block:

$$a = \beta_1 c = (0.82)(110 \text{ mm}) = 90 \text{ mm}$$

With c/d_p, calculate the tendon stress at ultimate limit state, f_{ps}:

$$f_{ps} = f_{pu}\left(1 - k_p \frac{c}{d_p}\right) = (1{,}860 \text{ MPa})\big(1 - (0.3)(0.101)\big) = 1{,}804 \text{ MPa}$$

Calculate specified moment resistance, M_{r_s}:

$$M_{r_s} = A_{ps} f_{ps} \left(d_p - \frac{a}{2}\right)$$

$$= (2{,}970\ \text{mm}^2)(1{,}804\ \text{MPa})\left((1{,}086\ \text{mm}) - \frac{(90\ \text{mm})}{2}\right)$$

$$= 5{,}573\ \text{kN} \cdot \text{m}$$

With the specified and factored moment resistance, ϕ can be calculated:

$$\phi = \frac{M_{r_f}}{M_{r_s}} = \frac{5{,}195\ \text{kN} \cdot \text{m}}{5{,}573\ \text{kN} \cdot \text{m}} = 0.932$$

To use the appropriate statistical parameters given in CSA (2006b) for resistance bias coefficient and CoV, ω_p must be calculated:

$$\omega_p \approx 0.85 \frac{a}{d_p} = 0.85 \frac{(110\ \text{mm to } 138\ \text{mm})}{1{,}086\ \text{mm}} = 0.086\ \text{to}\ 0.108$$

$$\therefore\ \omega_p < 0.15 \rightarrow \delta_R = 1.06, V_R = 0.05$$

Appendix I

Bridge Specific Load Factors, Interior Girder Moments for Single Lane Traffic

Table I.1 – Live load factors, AHSVS-PLS, other spans (1)

Live Load Factors α_L									
Vehicle =	AHSVS-PLS								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Other								
Span Type =	(Morrison Hershfield Ltd., 2012) 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.82	0.85	0.88	0.91	0.94	0.97	1.01	1.05	1.09
100	1.10	1.13	1.17	1.21	1.25	1.29	1.34	1.39	1.44
1000	1.24	1.28	1.32	1.36	1.41	1.46	1.51	1.56	1.62
10000	1.39	1.44	1.49	1.54	1.59	1.64	1.70	1.76	1.82
100000	1.55	1.60	1.65	1.70	1.76	1.82	1.89	1.95	2.02
Span Type =	(DND 2007a) – Section F.2.2 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.89	0.94	1.00	1.06	1.12	1.18	1.25	1.32	1.39
100	1.19	1.26	1.33	1.40	1.48	1.56	1.64	1.73	1.82
1000	1.34	1.42	1.50	1.58	1.66	1.75	1.84	1.94	2.04
10000	1.51	1.59	1.68	1.77	1.86	1.96	2.07	2.18	2.29
100000	1.67	1.76	1.86	1.96	2.06	2.17	2.28	2.40	2.53
Span Type =	(DND 2007a) – Section F.2.3 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.97	1.02	1.08	1.14	1.20	1.27	1.33	1.40
100	1.22	1.28	1.35	1.43	1.50	1.58	1.67	1.75	1.84
1000	1.37	1.45	1.52	1.60	1.69	1.78	1.87	1.97	2.07
10000	1.54	1.62	1.71	1.80	1.90	2.00	2.10	2.21	2.32
100000	1.70	1.80	1.89	1.99	2.10	2.21	2.32	2.44	2.57
Span Type =	(DND 2007a) – Section F.2.9 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.75	0.79	0.82	0.86	0.90	0.93	0.98	1.02	1.06
100	1.04	1.08	1.13	1.18	1.23	1.28	1.34	1.40	1.45
1000	1.18	1.23	1.29	1.34	1.40	1.46	1.53	1.59	1.66
10000	1.34	1.40	1.46	1.53	1.59	1.66	1.73	1.81	1.88
100000	1.50	1.56	1.63	1.70	1.78	1.85	1.93	2.02	2.10

Table I.2 - Live load factors, AHSVS-PLS, other spans (2)

Live Load Factors α_L									
Vehicle =	AHSVS-PLS								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.87	0.91	0.94	0.98	1.02	1.06	1.11	1.15	1.20
100	1.17	1.22	1.26	1.32	1.37	1.42	1.48	1.54	1.60
1000	1.32	1.37	1.43	1.49	1.55	1.61	1.67	1.74	1.81
10000	1.49	1.55	1.61	1.68	1.75	1.82	1.89	1.97	2.05
100000	1.65	1.72	1.79	1.86	1.94	2.02	2.10	2.18	2.27
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.86	0.89	0.93	0.97	1.01	1.05	1.09	1.13	1.18
100	1.15	1.20	1.25	1.30	1.35	1.40	1.46	1.52	1.58
1000	1.30	1.35	1.41	1.47	1.52	1.59	1.65	1.71	1.78
10000	1.47	1.53	1.59	1.65	1.72	1.79	1.86	1.93	2.01
100000	1.63	1.69	1.76	1.84	1.91	1.99	2.07	2.15	2.23
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.97	1.03	1.09	1.16	1.23	1.30	1.38	1.46
100	1.20	1.27	1.34	1.42	1.50	1.58	1.67	1.76	1.86
1000	1.35	1.42	1.50	1.59	1.68	1.77	1.86	1.96	2.07
10000	1.51	1.59	1.68	1.77	1.87	1.97	2.08	2.19	2.30
100000	1.66	1.76	1.85	1.95	2.06	2.17	2.28	2.40	2.53
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.89	0.94	1.00	1.07	1.13	1.20	1.27	1.34	1.41
100	1.15	1.22	1.29	1.36	1.43	1.50	1.58	1.66	1.74
1000	1.29	1.36	1.43	1.51	1.59	1.67	1.75	1.83	1.92
10000	1.44	1.52	1.60	1.68	1.76	1.84	1.93	2.02	2.12
100000	1.59	1.67	1.75	1.84	1.93	2.02	2.11	2.21	2.31

Table I.3 - Live load factors, AHSVS-PLS, short spans

Live Load Factors α_L									
Vehicle =	AHSVS-PLS								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.94	0.99	1.04	1.10	1.15	1.21	1.27	1.33	1.40
100	1.25	1.32	1.39	1.47	1.54	1.62	1.71	1.79	1.89
1000	1.52	1.60	1.68	1.77	1.86	1.96	2.06	2.16	2.27
10000	1.81	1.91	2.01	2.11	2.22	2.34	2.46	2.58	2.71
100000	2.11	2.22	2.33	2.45	2.58	2.71	2.85	2.99	3.14
Span Type =	(DND 2007a) – Section F.2.7 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.94	0.99	1.04	1.09	1.15	1.21	1.27	1.33	1.39
100	1.25	1.31	1.38	1.46	1.53	1.61	1.69	1.78	1.87
1000	1.51	1.59	1.67	1.76	1.85	1.94	2.04	2.14	2.25
10000	1.81	1.90	2.00	2.10	2.21	2.32	2.43	2.56	2.68
100000	2.10	2.21	2.32	2.44	2.56	2.69	2.82	2.96	3.11

Table I.4 - Live load factors, AHSVS-PLS and trailer uncorrelated, other spans (1)

Live Load Factors α_L									
Vehicle =					AHSVS-PLS with Trailer (uncorrelated)				
Lateral Load Distribution =					CSA (2006a, 2006b)				
DLA =					Trimble, Cousins and Seda-Sanabria (2003) - both				
Span Type =					Other				
Span Type =	(Morrison Hershfield Ltd., 2012) 37 m CPCI Girder (5)								
$\beta =$	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.75	0.77	0.80	0.83	0.85	0.89	0.92	0.95	0.99
100	0.99	1.02	1.05	1.09	1.13	1.16	1.21	1.25	1.29
1000	1.10	1.13	1.17	1.21	1.25	1.30	1.34	1.39	1.44
10000	1.21	1.25	1.29	1.34	1.38	1.43	1.48	1.53	1.59
100000	1.32	1.37	1.41	1.46	1.51	1.57	1.62	1.68	1.74
Span Type =	(DND 2007a) – Section F.2.2 21.95 m Steel Stringer (5)								
$\beta =$	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.81	0.86	0.91	0.96	1.01	1.07	1.13	1.19	1.26
100	1.06	1.12	1.18	1.25	1.31	1.38	1.46	1.53	1.61
1000	1.18	1.24	1.31	1.38	1.46	1.53	1.61	1.70	1.79
10000	1.29	1.36	1.44	1.52	1.60	1.68	1.77	1.86	1.96
100000	1.41	1.49	1.57	1.65	1.74	1.83	1.93	2.03	2.13
Span Type =	(DND 2007a) – Section F.2.3 24.38 m Steel Composite Girder (4)								
$\beta =$	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.83	0.88	0.93	0.98	1.03	1.09	1.15	1.21	1.27
100	1.08	1.14	1.20	1.27	1.34	1.41	1.48	1.56	1.64
1000	1.20	1.27	1.34	1.41	1.48	1.56	1.64	1.72	1.81
10000	1.32	1.39	1.46	1.54	1.62	1.71	1.80	1.89	1.99
100000	1.44	1.52	1.60	1.68	1.77	1.86	1.96	2.06	2.16
Span Type =	(DND 2007a) – Section F.2.9 22.9 m CPCI (5)								
$\beta =$	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.70	0.73	0.76	0.80	0.83	0.87	0.91	0.95	0.99
100	0.94	0.98	1.02	1.07	1.11	1.16	1.21	1.26	1.32
1000	1.05	1.10	1.15	1.20	1.25	1.30	1.36	1.41	1.47
10000	1.16	1.21	1.27	1.32	1.38	1.44	1.50	1.56	1.63
100000	1.27	1.33	1.39	1.45	1.51	1.58	1.65	1.72	1.79

Table I.5 - Live load factors, AHSVS-PLS and trailer uncorrelated, other spans (2)

Live Load Factors α_L									
Vehicle =	AHSVS-PLS with Trailer (uncorrelated)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.79	0.82	0.86	0.89	0.93	0.97	1.01	1.05	1.09
100	1.04	1.08	1.13	1.17	1.22	1.27	1.32	1.37	1.42
1000	1.16	1.21	1.25	1.30	1.36	1.41	1.47	1.53	1.59
10000	1.27	1.33	1.38	1.44	1.49	1.55	1.62	1.68	1.75
100000	1.39	1.45	1.51	1.57	1.63	1.70	1.77	1.84	1.91
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.78	0.81	0.85	0.88	0.92	0.96	1.00	1.04	1.08
100	1.03	1.07	1.11	1.16	1.21	1.25	1.30	1.36	1.41
1000	1.15	1.19	1.24	1.29	1.34	1.40	1.45	1.51	1.57
10000	1.26	1.31	1.37	1.42	1.48	1.54	1.60	1.66	1.73
100000	1.38	1.43	1.49	1.55	1.62	1.68	1.75	1.82	1.89
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.82	0.87	0.92	0.97	1.03	1.09	1.15	1.22	1.28
100	1.06	1.12	1.19	1.25	1.32	1.39	1.47	1.55	1.63
1000	1.18	1.24	1.31	1.38	1.46	1.54	1.62	1.70	1.79
10000	1.29	1.36	1.43	1.51	1.59	1.68	1.77	1.86	1.96
100000	1.41	1.48	1.56	1.64	1.73	1.82	1.92	2.02	2.12
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.79	0.84	0.89	0.94	0.99	1.04	1.10	1.16	1.22
100	1.02	1.07	1.13	1.19	1.25	1.31	1.37	1.44	1.50
1000	1.13	1.19	1.24	1.31	1.37	1.43	1.50	1.57	1.64
10000	1.23	1.30	1.36	1.42	1.49	1.56	1.63	1.71	1.78
100000	1.34	1.41	1.47	1.54	1.62	1.69	1.77	1.84	1.93

Table I.6 - Live load factors, AHSVS-PLS and trailer uncorrelated, short spans

Live Load Factors α_L									
Vehicle =	AHSVS-PLS with Trailer (uncorrelated)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.96	1.01	1.06	1.12	1.17	1.23	1.29	1.35
100	1.26	1.33	1.40	1.48	1.56	1.64	1.73	1.82	1.91
1000	1.52	1.60	1.68	1.77	1.86	1.96	2.06	2.16	2.27
10000	1.80	1.89	1.99	2.09	2.20	2.31	2.43	2.55	2.68
100000	2.07	2.18	2.29	2.41	2.53	2.66	2.80	2.94	3.08
Span Type =	(DND 2007a) – Section F.2.7 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.96	1.01	1.06	1.12	1.17	1.23	1.29	1.35
100	1.26	1.33	1.40	1.47	1.55	1.63	1.72	1.81	1.90
1000	1.52	1.59	1.68	1.76	1.85	1.95	2.05	2.15	2.26
10000	1.79	1.89	1.98	2.08	2.19	2.30	2.42	2.54	2.66
100000	2.07	2.17	2.29	2.40	2.52	2.65	2.78	2.92	3.06

Table I.7 - Live load factors, AHSVS-PLS and trailer correlated, other spans (1)

Live Load Factors α_L									
Vehicle =	AHSVS-PLS with Trailer (correlated)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Other								
Span Type =	(Morrison Hershfield Ltd., 2012) 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.76	0.79	0.82	0.85	0.88	0.92	0.95	0.99	1.03
100	1.14	1.18	1.22	1.27	1.32	1.36	1.41	1.47	1.52
1000	1.32	1.37	1.42	1.47	1.52	1.58	1.64	1.70	1.76
10000	1.54	1.60	1.66	1.72	1.78	1.85	1.92	1.99	2.07
100000	1.75	1.81	1.88	1.95	2.03	2.10	2.18	2.26	2.35
Span Type =	(DND 2007a) – Section F.2.2 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.83	0.88	0.93	0.99	1.05	1.11	1.17	1.24	1.31
100	1.22	1.29	1.37	1.44	1.52	1.61	1.70	1.79	1.88
1000	1.41	1.49	1.57	1.66	1.75	1.84	1.94	2.05	2.15
10000	1.64	1.73	1.83	1.93	2.03	2.14	2.25	2.37	2.50
100000	1.85	1.95	2.06	2.17	2.29	2.41	2.54	2.67	2.81
Span Type =	(DND 2007a) – Section F.2.3 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.85	0.90	0.95	1.01	1.07	1.13	1.19	1.26	1.33
100	1.25	1.32	1.40	1.47	1.55	1.64	1.73	1.82	1.91
1000	1.44	1.52	1.60	1.69	1.78	1.88	1.98	2.08	2.19
10000	1.67	1.76	1.86	1.96	2.07	2.18	2.29	2.41	2.54
100000	1.89	1.99	2.10	2.21	2.33	2.45	2.58	2.72	2.86
Span Type =	(DND 2007a) – Section F.2.9 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.72	0.76	0.79	0.83	0.87	0.91	0.96	1.00	1.05
100	1.10	1.15	1.20	1.26	1.32	1.38	1.44	1.51	1.57
1000	1.28	1.34	1.40	1.46	1.53	1.60	1.67	1.74	1.82
10000	1.50	1.57	1.64	1.71	1.79	1.87	1.96	2.05	2.14
100000	1.70	1.78	1.86	1.95	2.04	2.13	2.22	2.32	2.43

Table I.8 - Live load factors, AHSVS-PLS and trailer correlated, other spans (2)

Live Load Factors α_L									
Vehicle =	AHSVS-PLS with Trailer (correlated)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.81	0.85	0.89	0.93	0.97	1.01	1.05	1.10	1.14
100	1.21	1.26	1.31	1.37	1.43	1.49	1.55	1.62	1.68
1000	1.40	1.45	1.52	1.58	1.65	1.72	1.79	1.86	1.94
10000	1.62	1.70	1.77	1.84	1.92	2.00	2.09	2.18	2.27
100000	1.84	1.92	2.00	2.09	2.18	2.27	2.36	2.47	2.57
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.80	0.84	0.88	0.91	0.95	0.99	1.04	1.08	1.13
100	1.20	1.25	1.30	1.35	1.41	1.47	1.53	1.60	1.66
1000	1.38	1.44	1.50	1.56	1.63	1.70	1.77	1.84	1.92
10000	1.61	1.68	1.75	1.83	1.90	1.98	2.07	2.15	2.24
100000	1.82	1.90	1.98	2.07	2.16	2.25	2.34	2.44	2.54
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.83	0.89	0.94	1.00	1.06	1.12	1.19	1.26	1.33
100	1.22	1.29	1.36	1.44	1.52	1.60	1.69	1.78	1.88
1000	1.40	1.48	1.56	1.65	1.74	1.83	1.93	2.03	2.14
10000	1.63	1.72	1.81	1.91	2.01	2.12	2.23	2.35	2.47
100000	1.84	1.94	2.04	2.15	2.27	2.39	2.51	2.64	2.78
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.80	0.85	0.90	0.96	1.01	1.07	1.13	1.19	1.25
100	1.17	1.23	1.29	1.36	1.42	1.49	1.56	1.64	1.71
1000	1.34	1.41	1.48	1.55	1.62	1.70	1.77	1.86	1.94
10000	1.56	1.63	1.71	1.79	1.87	1.95	2.04	2.13	2.23
100000	1.76	1.84	1.92	2.01	2.10	2.20	2.29	2.39	2.49

Table I.9 - Live load factors, AHSVS-PLS and trailer correlated, short spans

Live Load Factors α_L									
Vehicle =	AHSVS-PLS with Trailer (correlated)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	Trimble, Cousins and Seda-Sanabria (2003) - both								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.93	0.98	1.03	1.09	1.15	1.21	1.27	1.34	1.41
100	1.25	1.32	1.39	1.46	1.54	1.62	1.70	1.79	1.88
1000	1.52	1.60	1.69	1.77	1.87	1.96	2.06	2.17	2.28
10000	1.80	1.89	1.99	2.09	2.20	2.31	2.43	2.55	2.68
100000	2.07	2.17	2.28	2.40	2.52	2.65	2.79	2.93	3.07
Span Type =	(DND 2007a) – Section F.2.7 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.93	0.98	1.03	1.09	1.15	1.21	1.27	1.33	1.40
100	1.25	1.32	1.39	1.46	1.53	1.61	1.70	1.78	1.87
1000	1.52	1.60	1.68	1.77	1.86	1.95	2.05	2.16	2.27
10000	1.79	1.89	1.98	2.08	2.19	2.30	2.41	2.53	2.66
100000	2.06	2.17	2.28	2.39	2.52	2.64	2.77	2.91	3.05

Table I.10 – Live load factors, LAV III-ISC Case (1), other spans (1)

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 1)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	(Morrison Hershfield Ltd., 2012) - 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.09	1.13	1.17	1.21	1.25	1.29	1.34	1.39
100	1.14	1.17	1.20	1.24	1.28	1.33	1.37	1.42	1.48
1000	1.16	1.19	1.22	1.26	1.30	1.35	1.40	1.45	1.50
10000	1.17	1.21	1.24	1.28	1.32	1.37	1.42	1.47	1.52
100000	1.19	1.23	1.26	1.30	1.34	1.39	1.44	1.49	1.54
Span Type =	(DND 2007a) – Section F.2.2- 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.12	1.18	1.25	1.32	1.40	1.47	1.55	1.64	1.72
100	1.20	1.27	1.34	1.41	1.49	1.57	1.65	1.74	1.83
1000	1.22	1.29	1.36	1.44	1.51	1.60	1.68	1.77	1.86
10000	1.24	1.31	1.38	1.46	1.54	1.62	1.71	1.79	1.89
100000	1.26	1.33	1.40	1.48	1.56	1.64	1.73	1.82	1.91
Span Type =	(DND 2007a) – Section F.2.3 - 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.15	1.21	1.28	1.35	1.42	1.49	1.57	1.65	1.73
100	1.23	1.30	1.36	1.43	1.51	1.59	1.67	1.75	1.84
1000	1.25	1.32	1.39	1.46	1.54	1.61	1.70	1.78	1.87
10000	1.27	1.34	1.41	1.48	1.56	1.64	1.72	1.81	1.90
100000	1.29	1.36	1.43	1.50	1.58	1.66	1.75	1.83	1.92
Span Type =	(DND 2007a) – Section F.2.7 - 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.09	1.14	1.19	1.25	1.30	1.36	1.42	1.49	1.55
100	1.17	1.22	1.28	1.34	1.40	1.46	1.52	1.59	1.66
1000	1.19	1.25	1.30	1.36	1.42	1.48	1.55	1.62	1.69
10000	1.21	1.27	1.32	1.38	1.44	1.51	1.57	1.64	1.71
100000	1.23	1.29	1.35	1.41	1.47	1.53	1.60	1.67	1.74
Span Type =	(DND 2007a) – Section F.2.9 - 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.88	0.91	0.95	0.99	1.02	1.06	1.10	1.14	1.19
100	0.95	0.99	1.03	1.07	1.11	1.15	1.19	1.23	1.28
1000	0.98	1.01	1.05	1.09	1.13	1.17	1.21	1.26	1.31
10000	0.99	1.03	1.07	1.11	1.15	1.19	1.24	1.28	1.33
100000	1.01	1.05	1.09	1.13	1.17	1.21	1.26	1.31	1.35

Table I.11 - Live load factors, LAV III-ISC Case (1), other spans (2)

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 1)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.08	1.12	1.15	1.19	1.24	1.28	1.32	1.37	1.42
100	1.16	1.19	1.24	1.28	1.32	1.37	1.41	1.46	1.52
1000	1.18	1.22	1.26	1.30	1.35	1.39	1.44	1.49	1.54
10000	1.20	1.24	1.28	1.32	1.37	1.42	1.46	1.51	1.57
100000	1.22	1.26	1.30	1.34	1.39	1.44	1.49	1.54	1.59
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.07	1.11	1.15	1.19	1.23	1.28	1.32	1.37	1.42
100	1.14	1.18	1.23	1.27	1.32	1.36	1.41	1.46	1.52
1000	1.17	1.21	1.25	1.29	1.34	1.39	1.44	1.49	1.54
10000	1.18	1.23	1.27	1.31	1.36	1.41	1.46	1.51	1.57
100000	1.20	1.25	1.29	1.33	1.38	1.43	1.48	1.54	1.59
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.19	1.27	1.36	1.44	1.54	1.63	1.74	1.84	1.95
100	1.27	1.35	1.44	1.53	1.62	1.72	1.83	1.94	2.05
1000	1.29	1.37	1.46	1.55	1.65	1.75	1.86	1.97	2.08
10000	1.31	1.39	1.48	1.57	1.67	1.77	1.88	1.99	2.11
100000	1.33	1.41	1.50	1.59	1.69	1.79	1.90	2.01	2.13
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.19	1.28	1.37	1.47	1.57	1.67	1.78	1.89	2.00
100	1.26	1.35	1.45	1.54	1.64	1.75	1.86	1.97	2.08
1000	1.28	1.37	1.47	1.56	1.67	1.77	1.88	1.99	2.11
10000	1.30	1.39	1.49	1.58	1.68	1.79	1.90	2.01	2.13
100000	1.32	1.41	1.50	1.60	1.70	1.81	1.92	2.03	2.15

Table I.12 - Live load factors, LAV III-ISC Case (1), short spans

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 1)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.23	1.29	1.35	1.40	1.47	1.53	1.60	1.66	1.74
100	1.38	1.44	1.50	1.56	1.63	1.70	1.77	1.85	1.92
1000	1.42	1.48	1.55	1.61	1.68	1.75	1.83	1.90	1.98
10000	1.46	1.52	1.58	1.65	1.72	1.79	1.87	1.95	2.03
100000	1.49	1.56	1.62	1.69	1.76	1.84	1.92	2.00	2.08

Table I.13 - Live load factors, LAV III-ISC Case (2), other spans (1)

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 2)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	(Morrison Hershfield Ltd., 2012) - 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.07	1.10	1.13	1.17	1.21	1.26	1.30	1.35	1.41
100	1.25	1.28	1.32	1.36	1.41	1.45	1.50	1.56	1.61
1000	1.31	1.35	1.39	1.43	1.47	1.52	1.57	1.63	1.69
10000	1.37	1.40	1.45	1.49	1.53	1.58	1.64	1.69	1.75
100000	1.43	1.46	1.51	1.55	1.60	1.65	1.70	1.76	1.82
Span Type =	(DND 2007a) – Section F.2.2- 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.13	1.19	1.26	1.34	1.41	1.49	1.57	1.66	1.75
100	1.33	1.40	1.48	1.56	1.64	1.73	1.82	1.91	2.01
1000	1.39	1.47	1.55	1.63	1.72	1.81	1.90	2.00	2.10
10000	1.46	1.53	1.62	1.70	1.79	1.88	1.98	2.08	2.18
100000	1.52	1.60	1.69	1.77	1.87	1.96	2.06	2.16	2.27
Span Type =	(DND 2007a) – Section F.2.3 - 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.16	1.22	1.29	1.36	1.43	1.51	1.59	1.67	1.76
100	1.36	1.43	1.50	1.58	1.66	1.75	1.83	1.92	2.02
1000	1.43	1.50	1.58	1.66	1.74	1.83	1.92	2.01	2.11
10000	1.49	1.57	1.65	1.73	1.82	1.91	2.00	2.10	2.20
100000	1.56	1.63	1.72	1.80	1.89	1.98	2.08	2.18	2.29
Span Type =	(DND 2007a) – Section F.2.7 - 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.10	1.15	1.21	1.26	1.32	1.38	1.45	1.51	1.58
100	1.30	1.36	1.42	1.48	1.55	1.62	1.69	1.76	1.83
1000	1.37	1.43	1.49	1.56	1.63	1.70	1.77	1.85	1.92
10000	1.43	1.49	1.56	1.63	1.70	1.77	1.85	1.93	2.01
100000	1.49	1.56	1.63	1.70	1.77	1.85	1.93	2.01	2.10
Span Type =	(DND 2007a) – Section F.2.9 - 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.89	0.93	0.96	1.00	1.04	1.08	1.13	1.17	1.22
100	1.08	1.12	1.16	1.20	1.24	1.29	1.34	1.39	1.44
1000	1.14	1.18	1.22	1.27	1.32	1.36	1.41	1.47	1.52
10000	1.20	1.24	1.29	1.33	1.38	1.43	1.49	1.54	1.60
100000	1.26	1.30	1.35	1.40	1.45	1.50	1.56	1.62	1.67

Table I.14 - Live load factors, LAV III-ISC Case (2), other spans (2)

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 2)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.09	1.13	1.17	1.21	1.25	1.30	1.35	1.40	1.45
100	1.28	1.32	1.37	1.42	1.47	1.52	1.57	1.62	1.68
1000	1.35	1.39	1.44	1.49	1.54	1.59	1.65	1.70	1.76
10000	1.41	1.46	1.51	1.56	1.61	1.66	1.72	1.78	1.84
100000	1.47	1.52	1.57	1.62	1.68	1.74	1.80	1.86	1.92
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.08	1.12	1.16	1.20	1.25	1.29	1.34	1.39	1.45
100	1.27	1.31	1.36	1.41	1.46	1.51	1.56	1.62	1.67
1000	1.33	1.38	1.43	1.48	1.53	1.58	1.64	1.70	1.75
10000	1.39	1.44	1.49	1.54	1.60	1.65	1.71	1.77	1.83
100000	1.45	1.50	1.56	1.61	1.67	1.72	1.78	1.85	1.91
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.19	1.28	1.36	1.45	1.55	1.65	1.75	1.86	1.97
100	1.39	1.48	1.57	1.66	1.76	1.87	1.98	2.10	2.22
1000	1.45	1.54	1.64	1.74	1.84	1.95	2.06	2.18	2.30
10000	1.51	1.60	1.70	1.80	1.91	2.02	2.13	2.25	2.38
100000	1.57	1.67	1.77	1.87	1.98	2.09	2.21	2.33	2.46
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.19	1.28	1.38	1.47	1.57	1.68	1.79	1.90	2.01
100	1.37	1.47	1.56	1.66	1.77	1.87	1.98	2.10	2.22
1000	1.43	1.53	1.63	1.73	1.83	1.94	2.05	2.17	2.29
10000	1.49	1.58	1.68	1.79	1.89	2.00	2.11	2.23	2.35
100000	1.55	1.64	1.74	1.85	1.95	2.06	2.18	2.30	2.42

Table I.15 - Live load factors, LAV III-ISC Case (2), short spans

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 2)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.24	1.30	1.36	1.42	1.48	1.55	1.62	1.69	1.76
100	1.46	1.52	1.59	1.66	1.73	1.80	1.88	1.96	2.04
1000	1.53	1.60	1.67	1.74	1.82	1.89	1.97	2.06	2.14
10000	1.61	1.68	1.75	1.83	1.91	1.99	2.07	2.16	2.25
100000	1.69	1.76	1.84	1.92	2.00	2.08	2.17	2.26	2.36

Table I.16 - Live load factors, LAV III-ISC Case (3), other spans (1)

Live Load Factors α_L									
Vehicle =	LAV III-ISC (Case 3)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	(Morrison Hershfield Ltd., 2012) - 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.89	0.92	0.95	0.98	1.02	1.05	1.09	1.13	1.18
100	1.05	1.08	1.11	1.14	1.18	1.22	1.26	1.30	1.35
1000	1.10	1.13	1.16	1.20	1.23	1.27	1.32	1.36	1.41
10000	1.14	1.18	1.21	1.25	1.28	1.33	1.37	1.42	1.47
100000	1.19	1.22	1.26	1.30	1.34	1.38	1.42	1.47	1.52
Span Type =	(DND 2007a) – Section F.2.2- 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.94	1.00	1.06	1.12	1.18	1.25	1.32	1.39	1.46
100	1.11	1.17	1.24	1.30	1.37	1.45	1.52	1.60	1.68
1000	1.17	1.23	1.30	1.37	1.44	1.51	1.59	1.67	1.76
10000	1.22	1.28	1.35	1.42	1.50	1.58	1.66	1.74	1.83
100000	1.27	1.34	1.41	1.48	1.56	1.64	1.72	1.81	1.90
Span Type =	(DND 2007a) – Section F.2.3 - 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.97	1.02	1.08	1.14	1.20	1.26	1.33	1.40	1.47
100	1.14	1.20	1.26	1.32	1.39	1.46	1.54	1.61	1.69
1000	1.20	1.26	1.32	1.39	1.46	1.53	1.61	1.69	1.77
10000	1.25	1.31	1.38	1.45	1.52	1.59	1.67	1.75	1.84
100000	1.30	1.37	1.43	1.51	1.58	1.66	1.74	1.82	1.91
Span Type =	(DND 2007a) – Section F.2.7 - 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.92	0.97	1.01	1.06	1.11	1.16	1.21	1.27	1.33
100	1.09	1.14	1.19	1.24	1.30	1.35	1.41	1.47	1.54
1000	1.14	1.20	1.25	1.30	1.36	1.42	1.48	1.54	1.61
10000	1.20	1.25	1.30	1.36	1.42	1.48	1.55	1.61	1.68
100000	1.25	1.30	1.36	1.42	1.48	1.55	1.61	1.68	1.75
Span Type =	(DND 2007a) – Section F.2.9 - 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.75	0.78	0.81	0.84	0.87	0.91	0.94	0.98	1.02
100	0.90	0.93	0.97	1.01	1.04	1.08	1.12	1.16	1.21
1000	0.95	0.99	1.02	1.06	1.10	1.14	1.18	1.23	1.27
10000	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.29	1.33
100000	1.05	1.09	1.13	1.17	1.21	1.26	1.30	1.35	1.40

Table I.17 - Live load factors, LAV III-ISC Case (3), other spans (2)

Live Load Factors αL									
Vehicle =	LAV III-ISC (Case 3)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Other								
Span Type =	Bartlett (1980) 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.91	0.94	0.98	1.01	1.05	1.09	1.13	1.17	1.21
100	1.07	1.11	1.15	1.19	1.23	1.27	1.31	1.36	1.41
1000	1.13	1.17	1.20	1.25	1.29	1.33	1.38	1.43	1.47
10000	1.18	1.22	1.26	1.30	1.35	1.39	1.44	1.49	1.54
100000	1.23	1.27	1.31	1.36	1.40	1.45	1.50	1.55	1.60
Span Type =	Bartlett (1980) 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.90	0.94	0.97	1.01	1.04	1.08	1.13	1.17	1.21
100	1.06	1.10	1.14	1.18	1.22	1.26	1.31	1.35	1.40
1000	1.12	1.15	1.19	1.24	1.28	1.32	1.37	1.42	1.47
10000	1.17	1.21	1.25	1.29	1.33	1.38	1.43	1.48	1.53
100000	1.22	1.26	1.30	1.35	1.39	1.44	1.49	1.54	1.60
Span Type =	Bartlett (1980) 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.07	1.14	1.22	1.30	1.38	1.47	1.56	1.65
100	1.16	1.24	1.31	1.39	1.48	1.57	1.66	1.76	1.86
1000	1.22	1.29	1.37	1.45	1.54	1.63	1.72	1.82	1.93
10000	1.27	1.34	1.42	1.51	1.60	1.69	1.79	1.89	1.99
100000	1.32	1.39	1.48	1.56	1.65	1.75	1.85	1.95	2.06
Span Type =	Genivar (2012) 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.08	1.15	1.24	1.32	1.41	1.50	1.59	1.69
100	1.15	1.23	1.31	1.39	1.48	1.57	1.66	1.76	1.86
1000	1.20	1.28	1.36	1.45	1.53	1.62	1.72	1.81	1.91
10000	1.25	1.33	1.41	1.49	1.58	1.67	1.77	1.87	1.97
100000	1.29	1.37	1.46	1.54	1.63	1.72	1.82	1.92	2.02

Table I.18 - Live load factors, LAV III-ISC Case (3), short spans

Live Load Factors αL									
Vehicle =	LAV III-ISC (Case 3)								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	Short								
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.10	1.15	1.21	1.26	1.32	1.37	1.43	1.50
100	1.24	1.29	1.35	1.41	1.47	1.53	1.59	1.66	1.73
1000	1.30	1.36	1.42	1.48	1.54	1.61	1.68	1.75	1.82
10000	1.36	1.42	1.48	1.54	1.61	1.68	1.75	1.82	1.90
100000	1.42	1.48	1.54	1.61	1.68	1.75	1.82	1.90	1.98

Table I.19 – Live load factors, Leopard 2A4M tank, all spans (1)

Live Load Factors αL									
Vehicle =	Leopard 2A4M								
Lateral Load Distribution =	Pinero (2001): ABRAMS								
DLA =	CSA (2006a, 2006b)								
Span Type =	All								
Span Type =	(Morrison Hershfield Ltd., 2012) - 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.03	1.05	1.08	1.10	1.13	1.16	1.19	1.23
100	1.02	1.05	1.07	1.10	1.12	1.15	1.18	1.22	1.25
1000	1.03	1.05	1.07	1.10	1.13	1.16	1.19	1.22	1.25
10000	1.03	1.05	1.08	1.10	1.13	1.16	1.19	1.22	1.26
100000	1.03	1.05	1.08	1.10	1.13	1.16	1.19	1.22	1.26
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.10	1.14	1.18	1.22	1.27	1.32	1.37	1.42
100	1.08	1.12	1.16	1.20	1.25	1.29	1.34	1.39	1.44
1000	1.08	1.12	1.16	1.21	1.25	1.30	1.34	1.39	1.44
10000	1.08	1.12	1.17	1.21	1.25	1.30	1.35	1.40	1.45
100000	1.09	1.13	1.17	1.21	1.26	1.30	1.35	1.40	1.45
Span Type =	(DND 2007a) – Section F.2.2- 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.07	1.12	1.17	1.22	1.27	1.33	1.39	1.44	1.51
100	1.09	1.14	1.19	1.24	1.30	1.35	1.41	1.47	1.53
1000	1.10	1.14	1.19	1.25	1.30	1.36	1.41	1.47	1.54
10000	1.10	1.15	1.20	1.25	1.30	1.36	1.42	1.48	1.54
100000	1.10	1.15	1.20	1.25	1.31	1.36	1.42	1.48	1.54
Span Type =	(DND 2007a) – Section F.2.3 - 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.09	1.14	1.19	1.24	1.29	1.34	1.40	1.46	1.52
100	1.11	1.16	1.21	1.26	1.31	1.37	1.43	1.48	1.55
1000	1.11	1.16	1.21	1.26	1.32	1.37	1.43	1.49	1.55
10000	1.12	1.17	1.21	1.27	1.32	1.38	1.43	1.49	1.56
100000	1.12	1.17	1.22	1.27	1.32	1.38	1.44	1.50	1.56

Table I.20 - Live load factors, Leopard 2A4M tank, all spans (2)

Live Load Factors αL									
Vehicle =	Leopard 2A4M								
Lateral Load Distribution =	Pinero (2001): ABRAMS								
DLA =	CSA (2006a, 2006b)								
Span Type =	(DND 2007a) – Section F.2.7 - 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.10	1.14	1.19	1.23	1.28	1.32	1.37	1.42
100	1.08	1.12	1.17	1.21	1.25	1.30	1.35	1.40	1.45
1000	1.09	1.13	1.17	1.21	1.26	1.30	1.35	1.40	1.45
10000	1.09	1.13	1.17	1.22	1.26	1.31	1.35	1.40	1.46
100000	1.09	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.46
Span Type =	All								
Span Type =	(DND 2007a) – Section F.2.9 - 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.04	1.08	1.12	1.17	1.22	1.27	1.32	1.37	1.43
100	1.06	1.10	1.14	1.19	1.24	1.29	1.34	1.39	1.45
1000	1.06	1.10	1.15	1.19	1.24	1.29	1.34	1.40	1.45
10000	1.06	1.11	1.15	1.20	1.25	1.30	1.35	1.40	1.46
100000	1.06	1.11	1.15	1.20	1.25	1.30	1.35	1.41	1.46
Span Type =	Bartlett (1980) - 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.04	1.07	1.10	1.14	1.17	1.20	1.24	1.28	1.31
100	1.06	1.09	1.13	1.16	1.19	1.23	1.26	1.30	1.34
1000	1.07	1.10	1.13	1.16	1.19	1.23	1.27	1.30	1.34
10000	1.07	1.10	1.13	1.16	1.20	1.23	1.27	1.31	1.34
100000	1.07	1.10	1.13	1.17	1.20	1.24	1.27	1.31	1.35
Span Type =	Bartlett (1980) - 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.03	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30
100	1.05	1.08	1.11	1.15	1.18	1.21	1.25	1.28	1.32
1000	1.05	1.09	1.12	1.15	1.18	1.22	1.25	1.29	1.33
10000	1.06	1.09	1.12	1.15	1.19	1.22	1.26	1.29	1.33
100000	1.06	1.09	1.12	1.15	1.19	1.22	1.26	1.29	1.33
Span Type =	Bartlett (1980) - 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.08	1.13	1.18	1.23	1.29	1.35	1.41	1.47	1.53
100	1.10	1.15	1.20	1.25	1.31	1.37	1.43	1.49	1.56
1000	1.10	1.15	1.20	1.26	1.31	1.37	1.43	1.50	1.56
10000	1.10	1.15	1.21	1.26	1.32	1.38	1.44	1.50	1.57
100000	1.11	1.16	1.21	1.26	1.32	1.38	1.44	1.50	1.57

Table I.21 - Live load factors, Leopard 2A4M tank, all spans (3)

Live Load Factors αL									
Vehicle =	Leopard 2A4M								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	All								
Span Type =	(Morrison Hershfield Ltd., 2012) - 37 m CPCI Girder (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.97	0.99	1.02	1.05	1.08	1.11	1.15	1.18	1.22
100	0.98	1.01	1.04	1.07	1.10	1.13	1.17	1.20	1.24
1000	0.99	1.01	1.04	1.07	1.10	1.14	1.17	1.21	1.24
10000	0.99	1.02	1.05	1.08	1.11	1.14	1.17	1.21	1.25
100000	0.99	1.02	1.05	1.08	1.11	1.14	1.18	1.21	1.25
Span Type =	(Trimblel, Cousins, & Seda-Sanabria, 2003) – Franklin, 12m T-beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.04	1.08	1.13	1.18	1.23	1.28	1.33	1.39	1.45
100	1.06	1.10	1.15	1.20	1.25	1.30	1.36	1.41	1.47
1000	1.06	1.10	1.15	1.20	1.25	1.31	1.36	1.42	1.48
10000	1.06	1.11	1.16	1.20	1.26	1.31	1.37	1.42	1.48
100000	1.06	1.11	1.16	1.21	1.26	1.31	1.37	1.43	1.49
Span Type =	(DND 2007a) – Section F.2.2- 21.95 m Steel Stringer (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.04	1.09	1.14	1.19	1.25	1.31	1.37	1.44	1.50
100	1.06	1.11	1.16	1.22	1.27	1.33	1.40	1.46	1.53
1000	1.06	1.11	1.16	1.22	1.28	1.34	1.40	1.47	1.53
10000	1.06	1.11	1.17	1.22	1.28	1.34	1.40	1.47	1.54
100000	1.07	1.12	1.17	1.23	1.28	1.34	1.41	1.47	1.54
Span Type =	(DND 2007a) – Section F.2.3 - 24.38 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.06	1.11	1.16	1.21	1.27	1.33	1.39	1.45	1.52
100	1.08	1.13	1.18	1.23	1.29	1.35	1.41	1.48	1.55
1000	1.08	1.13	1.18	1.24	1.30	1.36	1.42	1.48	1.55
10000	1.08	1.13	1.19	1.24	1.30	1.36	1.42	1.49	1.56
100000	1.08	1.14	1.19	1.24	1.30	1.36	1.42	1.49	1.56
Span Type =	(DND 2007a) – Section F.2.7 - 15.25 m T-Beam (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.03	1.08	1.12	1.17	1.22	1.27	1.33	1.38	1.44
100	1.05	1.10	1.14	1.19	1.24	1.30	1.35	1.41	1.47
1000	1.06	1.10	1.15	1.20	1.25	1.30	1.35	1.41	1.47
10000	1.06	1.10	1.15	1.20	1.25	1.30	1.36	1.42	1.47
100000	1.06	1.11	1.15	1.20	1.25	1.31	1.36	1.42	1.48

Table I.22 - Live load factors, Leopard 2A4M tank, all spans (4)

Live Load Factors αL									
Vehicle =	Leopard 2A4M								
Lateral Load Distribution =	CSA (2006a, 2006b)								
DLA =	CSA (2006a, 2006b)								
Span Type =	All								
Span Type =	(DND 2007a) – Section F.2.9 - 22.9 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.05	1.10	1.15	1.20	1.25	1.31	1.37	1.43
100	1.02	1.07	1.12	1.17	1.22	1.28	1.33	1.39	1.46
1000	1.02	1.07	1.12	1.17	1.23	1.28	1.34	1.40	1.46
10000	1.03	1.07	1.12	1.18	1.23	1.28	1.34	1.40	1.46
100000	1.03	1.08	1.13	1.18	1.23	1.29	1.34	1.40	1.47
Span Type =	Bartlett (1980) - 20 m CPCI (6)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.02	1.06	1.09	1.13	1.17	1.21	1.25	1.30	1.34
100	1.04	1.08	1.11	1.15	1.19	1.23	1.28	1.32	1.37
1000	1.04	1.08	1.12	1.15	1.20	1.24	1.28	1.32	1.37
10000	1.05	1.08	1.12	1.16	1.20	1.24	1.28	1.33	1.37
100000	1.05	1.08	1.12	1.16	1.20	1.24	1.29	1.33	1.38
Span Type =	Bartlett (1980) - 25 m CPCI (5)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.01	1.04	1.08	1.12	1.15	1.19	1.24	1.28	1.32
100	1.03	1.06	1.10	1.14	1.18	1.22	1.26	1.30	1.35
1000	1.03	1.07	1.10	1.14	1.18	1.22	1.26	1.31	1.35
10000	1.03	1.07	1.11	1.14	1.18	1.22	1.27	1.31	1.35
100000	1.04	1.07	1.11	1.15	1.19	1.23	1.27	1.31	1.36
Span Type =	Bartlett (1980) - 35 m Steel Composite Girder (4)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.04	1.09	1.14	1.20	1.26	1.32	1.39	1.45	1.52
100	1.06	1.11	1.17	1.22	1.28	1.34	1.41	1.48	1.55
1000	1.06	1.11	1.17	1.23	1.29	1.35	1.41	1.48	1.55
10000	1.06	1.12	1.17	1.23	1.29	1.35	1.42	1.48	1.55
100000	1.07	1.12	1.17	1.23	1.29	1.35	1.42	1.49	1.56
Span Type =	Genivar (2012) - 30.8 m Pre-stressed Box Girder (8)								
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.04	1.09	1.13	1.18	1.23	1.28	1.34	1.39
100	1.01	1.06	1.10	1.15	1.20	1.25	1.30	1.36	1.41
1000	1.02	1.06	1.11	1.15	1.20	1.25	1.31	1.36	1.42
10000	1.02	1.06	1.11	1.16	1.21	1.26	1.31	1.36	1.42
100000	1.02	1.07	1.11	1.16	1.21	1.26	1.31	1.37	1.42

Appendix J

Partial Load Factors

Table J.1 - AHSVS-PLS partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.02	1.06	1.10	1.14	1.19	1.23	1.28	1.33	1.38
100	1.34	1.39	1.45	1.51	1.57	1.63	1.70	1.77	1.84
1000	1.61	1.67	1.74	1.80	1.87	1.95	2.02	2.10	2.19
10000	1.91	1.98	2.06	2.14	2.22	2.30	2.39	2.48	2.58
100000	2.21	2.29	2.38	2.47	2.56	2.66	2.76	2.86	2.97
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.96	0.99	1.03	1.07	1.11	1.15	1.20	1.25	1.29
100	1.27	1.32	1.37	1.42	1.47	1.52	1.58	1.64	1.70
1000	1.43	1.48	1.54	1.59	1.65	1.71	1.77	1.84	1.90
10000	1.60	1.66	1.72	1.78	1.85	1.92	1.98	2.06	2.13
100000	1.77	1.83	1.90	1.97	2.04	2.11	2.19	2.27	2.35

Table J.2 - AHSVS-PLS and trailer, uncorrelated container, partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.99	1.02	1.06	1.11	1.15	1.19	1.24	1.29	1.34
100	1.34	1.40	1.46	1.52	1.58	1.65	1.72	1.79	1.86
1000	1.61	1.67	1.73	1.80	1.87	1.94	2.02	2.10	2.18
10000	1.89	1.96	2.04	2.11	2.19	2.28	2.36	2.45	2.55
100000	2.17	2.25	2.34	2.42	2.51	2.60	2.70	2.80	2.91
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.87	0.90	0.94	0.97	1.01	1.05	1.09	1.13	1.18
100	1.13	1.17	1.21	1.26	1.30	1.35	1.40	1.45	1.50
1000	1.25	1.30	1.34	1.39	1.44	1.49	1.55	1.60	1.66
10000	1.37	1.42	1.47	1.52	1.58	1.64	1.69	1.75	1.82
100000	1.49	1.55	1.60	1.66	1.72	1.78	1.84	1.91	1.97

Table J.3 - AHSVS-PLS and Trailer, correlated container, partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.00	1.05	1.09	1.14	1.19	1.24	1.29	1.34	1.40
100	1.33	1.39	1.44	1.50	1.56	1.63	1.69	1.76	1.83
1000	1.61	1.67	1.74	1.81	1.88	1.95	2.03	2.11	2.19
10000	1.89	1.96	2.04	2.11	2.19	2.27	2.36	2.45	2.54
100000	2.17	2.25	2.33	2.41	2.50	2.60	2.69	2.79	2.90
Other Spans (>20 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.89	0.93	0.97	1.01	1.05	1.10	1.14	1.19	1.24
100	1.30	1.35	1.41	1.46	1.52	1.57	1.63	1.70	1.76
1000	1.50	1.55	1.61	1.67	1.73	1.80	1.86	1.93	2.00
10000	1.73	1.80	1.86	1.93	2.00	2.08	2.15	2.23	2.31
100000	1.95	2.02	2.09	2.17	2.25	2.33	2.41	2.50	2.59

Table J.4 - LAV III-ISC (Case 1) partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.33	1.37	1.41	1.45	1.50	1.54	1.59	1.63	1.68
100	1.48	1.52	1.57	1.61	1.66	1.71	1.76	1.81	1.86
1000	1.53	1.57	1.62	1.66	1.71	1.76	1.81	1.86	1.91
10000	1.56	1.61	1.65	1.70	1.75	1.80	1.85	1.91	1.96
100000	1.60	1.65	1.69	1.74	1.79	1.84	1.90	1.95	2.01
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.17	1.20	1.24	1.27	1.31	1.35	1.39	1.43	1.47
100	1.25	1.29	1.33	1.36	1.40	1.44	1.48	1.53	1.57
1000	1.28	1.31	1.35	1.39	1.43	1.47	1.51	1.56	1.60
10000	1.30	1.34	1.37	1.41	1.45	1.50	1.54	1.58	1.63
100000	1.32	1.36	1.40	1.44	1.48	1.52	1.56	1.61	1.65

Table J.5 - LAV III-ISC (Case 2) partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.34	1.38	1.43	1.47	1.52	1.56	1.61	1.66	1.72
100	1.57	1.61	1.66	1.71	1.76	1.81	1.86	1.92	1.97
1000	1.65	1.69	1.74	1.79	1.85	1.90	1.95	2.01	2.07
10000	1.73	1.78	1.83	1.88	1.94	1.99	2.05	2.11	2.17
100000	1.81	1.86	1.92	1.97	2.03	2.09	2.15	2.21	2.27
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.47	1.52
100	1.39	1.43	1.48	1.52	1.56	1.61	1.66	1.70	1.75
1000	1.47	1.51	1.55	1.60	1.64	1.69	1.74	1.79	1.84
10000	1.53	1.58	1.62	1.67	1.72	1.77	1.82	1.87	1.93
100000	1.60	1.65	1.69	1.74	1.79	1.85	1.90	1.95	2.01

Table J.6 - LAV III-ISC (Case 3) partial load factors, $\alpha^* = 0.7$, bending moment

Short Spans (< 15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	1.14	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.46
100	1.33	1.37	1.41	1.45	1.49	1.54	1.58	1.63	1.67
1000	1.40	1.44	1.48	1.52	1.57	1.61	1.66	1.71	1.76
10000	1.46	1.50	1.54	1.59	1.64	1.68	1.73	1.78	1.83
100000	1.52	1.56	1.61	1.65	1.70	1.75	1.80	1.85	1.91
Other Spans (>15 m)									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
Event	0.99	1.02	1.06	1.09	1.12	1.16	1.19	1.23	1.27
100	1.17	1.20	1.24	1.27	1.31	1.35	1.39	1.43	1.47
1000	1.23	1.26	1.30	1.34	1.37	1.41	1.46	1.50	1.54
10000	1.28	1.32	1.36	1.40	1.44	1.48	1.52	1.56	1.61
100000	1.34	1.38	1.42	1.46	1.50	1.54	1.59	1.63	1.68

Table J.7 - Leopard 2A4M partial load factors, $\alpha^* = 0.7$, bending moment

All Spans									
β =	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4
All Traffic Rates	1.15	1.17	1.20	1.23	1.25	1.28	1.31	1.34	1.37

Appendix K

Expedient Derivation of Partial Load Factor for the Tracked Light Armoured Vehicle (TLAV) – Remote Weapons System (RWS)

Problem Statement – Derive partial load factor for the Tracked Light Armoured Vehicle with Remote Weapons System (TLAV-RW), at an expected traffic rate of 750 vehicles per year, with a reliability index, β, of 3.75 (Negligable Risk) for spans greater than 10 m.

Step 1: Obtain pertinate vehicle information.

Found in the vehicle data summary for the TLAV-RW (Data Summary, Carrier, Personnel, Full Tracked, Armoured, M113A3 with AN/MWG-505, C-30-775-000/MA-001) is the pertinate weight information for the vehicle. The curb "weight" of the TLAV-RWS is 11,253 kg with a combat "weight" of 16,762 kg, which includes 4,210 kg of uparmour (DND, 2011b). Based on this information we can calculate the payload, if we included the uparmour with the curb "weight":

$$\text{Payload} = \text{Combat "weight"} - \text{Curb "weight"} - \text{Uparmour}$$

$$\text{Payload} = 16{,}762\ \text{kg} - 11{,}253\ \text{kg} - 4{,}210\ \text{kg}$$

$$\text{Payload} = 1{,}299\ \text{kg}$$

Step 2: Calculate vehicle "weight" bias coefficient and CoV.

Using Equation [4.16] the γ of the vehicle is calculated:

$$\gamma = \frac{W_p}{W_V} = \frac{1{,}299\ \text{kg}}{16{,}762\ \text{kg}} = 0.077$$

The TLAV-RWS is best categorized as an Armoured Personnel Carrier, so refering to Table 6.16, for $n = 1{,}000$ per year (since 750 vehicles per year should be conservatively rounded up) the following statistical parameters for the payload are given: $\delta_p = 2.209$; and $V_p = 0.037$.

Thus, the vehicle weight bias coefficient, δ_v, is calculated using Equation [4.20]:

$$\delta_v = \gamma(\delta_p - 1) + 1$$

$$\delta_v = 0.077(2.209 - 1) + 1$$

$$\delta_v = 1.093$$

Likewise, the vehicle weight CoV, V_v, is calculated using Equation [4.22]:

$$V_v = \frac{V_p \delta_p \gamma}{\gamma(\delta_p - 1) + 1}$$

$$V_v = \frac{(0.037)(2.209)(0.077)}{(0.077)((2.209) - 1) + 1}$$

$$V_v = 0.006$$

Also note, since the vehicle is tracked, the statistical parameters for the vehicle load (δ_L and V_L) can be taken as the same as the statistical parameters of the vehicle weight (δ_v and V_v). Thus:

$$\delta_L = 1.093 \quad \text{and} \quad V_L = 0.006$$

Step 3: Selection of probabilistic parameters for dynamic and lateral load distribution

To use Table 5.20, evaluation should use a DLA of 0.25 and determine lateral load distributions following CSA (2006a) (with the exception of the Leopard 2A family of vehicles where Pinero (2001) can be used for lateral load distribution and corresponding parameters). Based Table 5.20, the dynamic effects has a bias coefficient, δ_{DLA} = 0.60 and CoV, V_{DLA} = 0.80. The “Simplified Method” for live load lateral load distribution has a bias coefficient, δ_A = 0.93 and a CoV, V_A = 0.12. Based on these values, and those derived in Step 2, the bias coefficient of the load effect, δ_{L_1}, can be calculated using Equation [5.11]:

$$\delta_{L_1} = \delta_L \delta_A \left(\frac{1 + \delta_{\mathrm{DLA}}\mathrm{DLA}}{1 + \mathrm{DLA}}\right)$$

$$\delta_{L_1} = (1.093)(0.93)\left(\frac{1 + (0.60)(0.25)}{1 + (0.25)}\right)$$

$$\delta_{L_1} = 0.935$$

Using Equation [5.12] the CoV of the load effect, V_{L_1}, can be calculated:

$$V_{L_1} = \sqrt{{V_A}^2 + {V_L}^2 + \left(\frac{\delta_{\mathrm{DLA}}\mathrm{DLA}}{1 + \mathrm{DLA}}\right)^2 {V_{\mathrm{DLA}}}^2}$$

$$V_{L_1} = \sqrt{(0.12)^2 + (0.006)^2 + \left(\frac{(0.60)(0.25)}{1 + (0.25)}\right)^2 (0.80)^2}$$

$$V_{L_1} = 0.154$$

Step 4: Calculate partial load factor

With the information from Step 3, for a target reliability, β, is 3.75, the partial load factor can be calculated using Equation [6.8] using a separation factor, α^* = 0.70:

$$\alpha_{L_1} = \delta_{L_1} e^{(\beta\alpha^*\mathrm{V}_{L_1})}$$

$$\alpha_{L_1} = (0.935)e^{[(3.75)(0.70)(0.154)]}$$

$$\alpha_{L_1} = 1.40$$

Appendix L

Partial Load Factors for Fighting and Wheeled Military Vehicles Based on Payload Weight Fraction

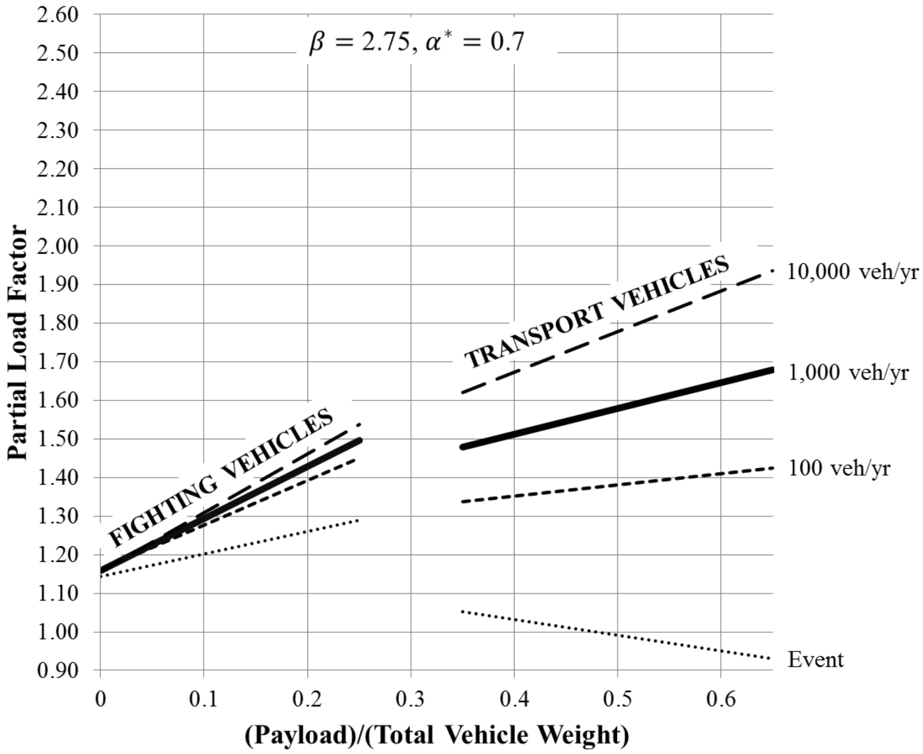


Figure L.1 – Partial load factors, $\beta = 2.75$ with varied traffic rates

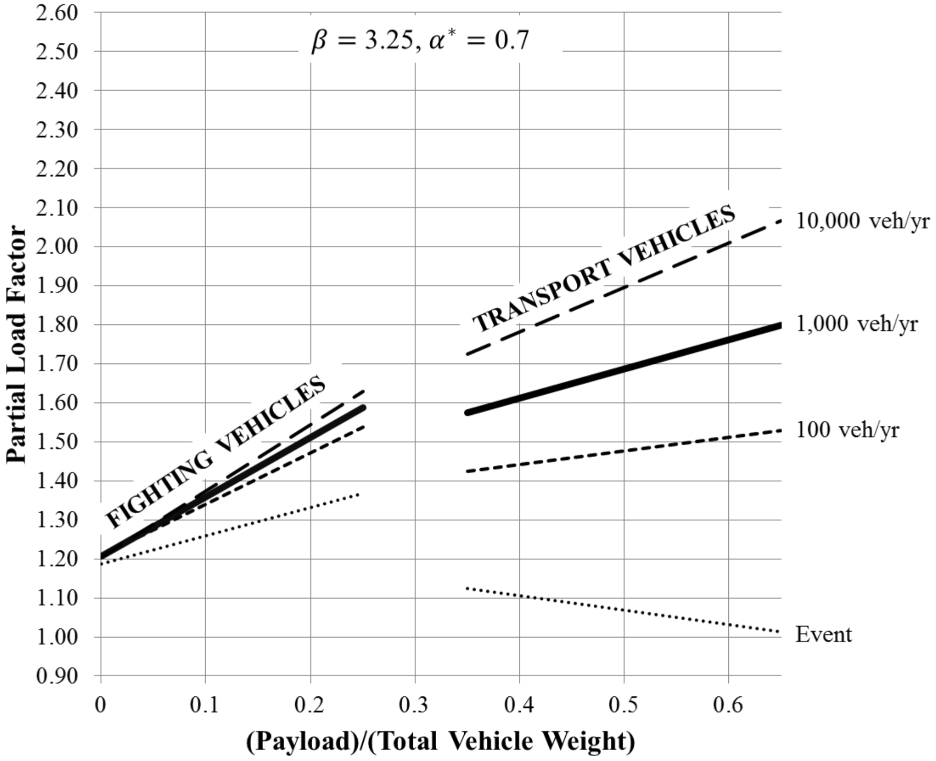


Figure L.2 – Partial load factors, $\beta = 3.25$ with varied traffic rates

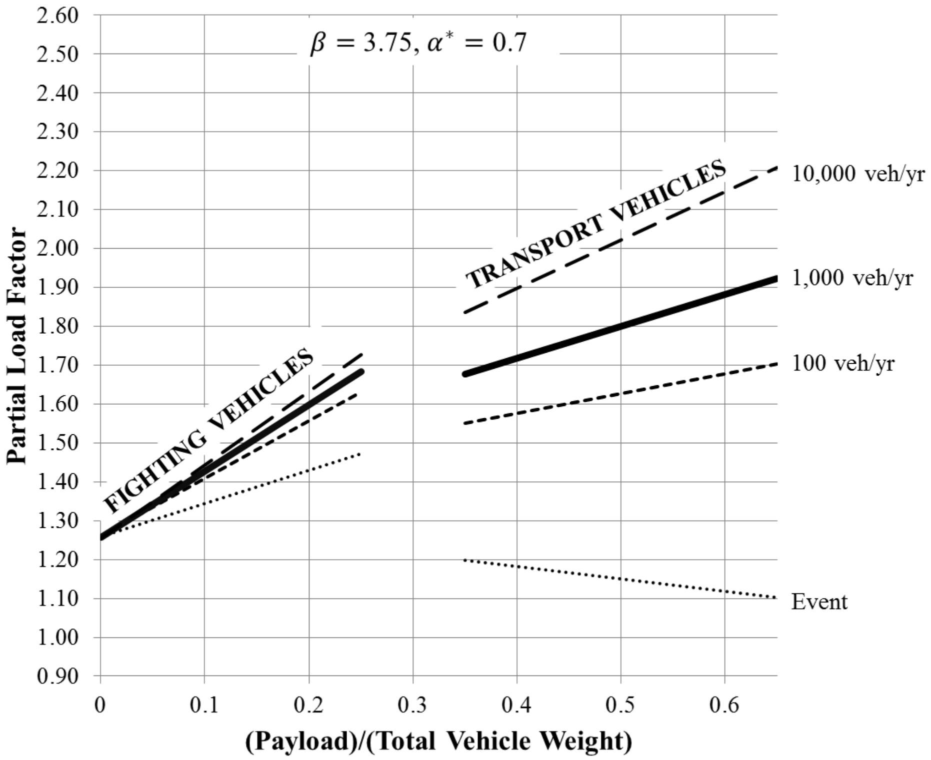


Figure L.3 – Partial load factors, $\beta = 3.75$ with varied traffic rates

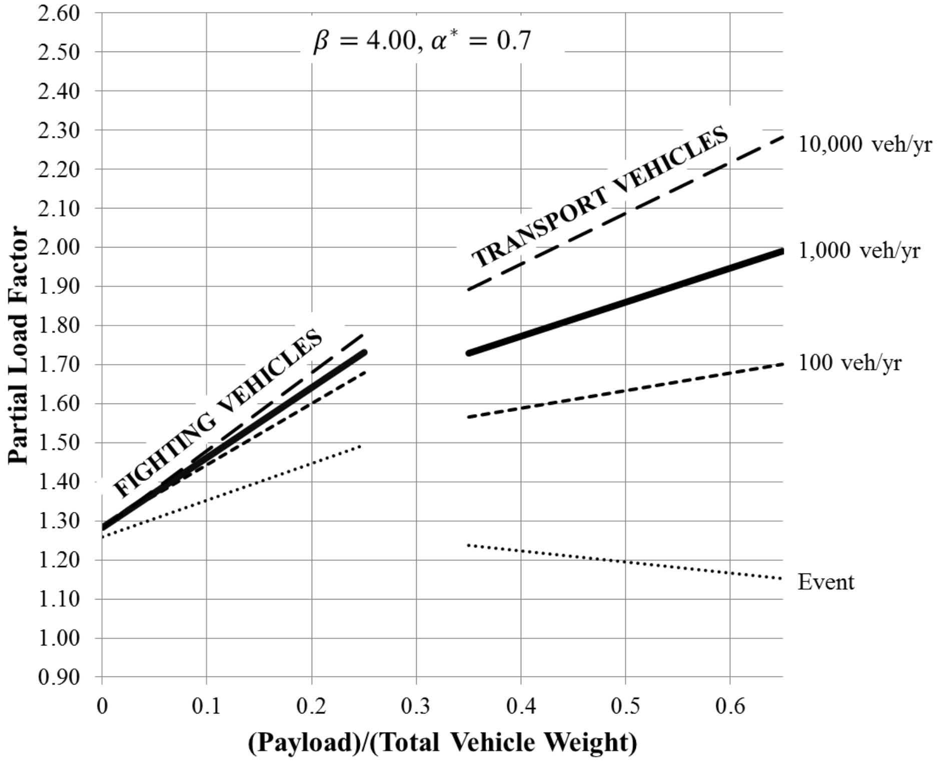


Figure L.4 – Partial load factors, $\beta = 4.00$ with varied traffic rates

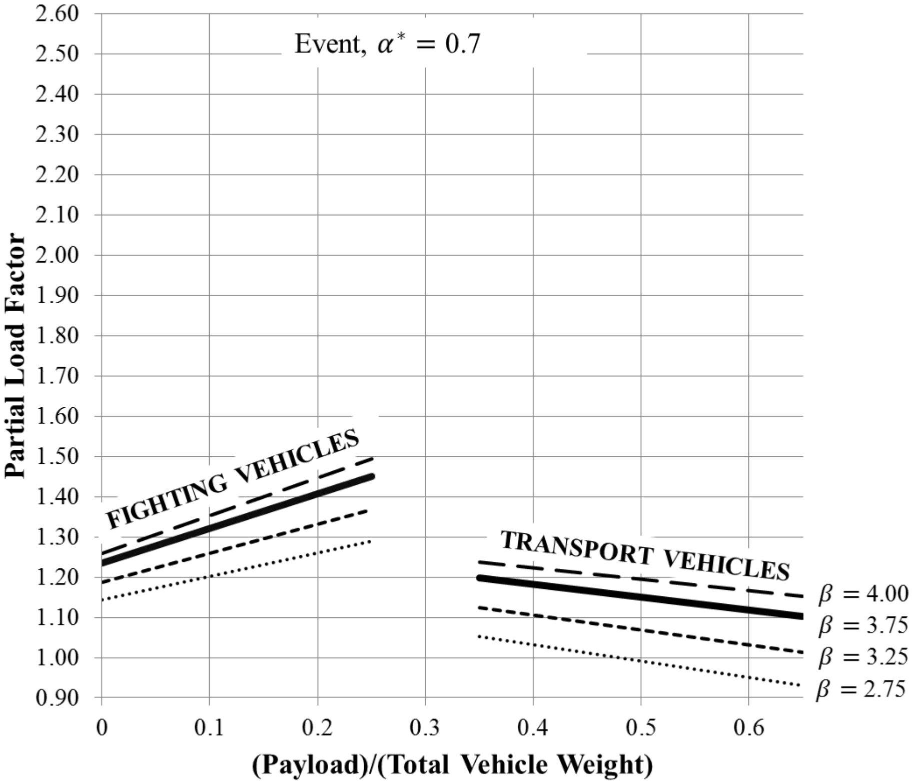


Figure L.5 – Partial load factors for Event vehicle and varied β

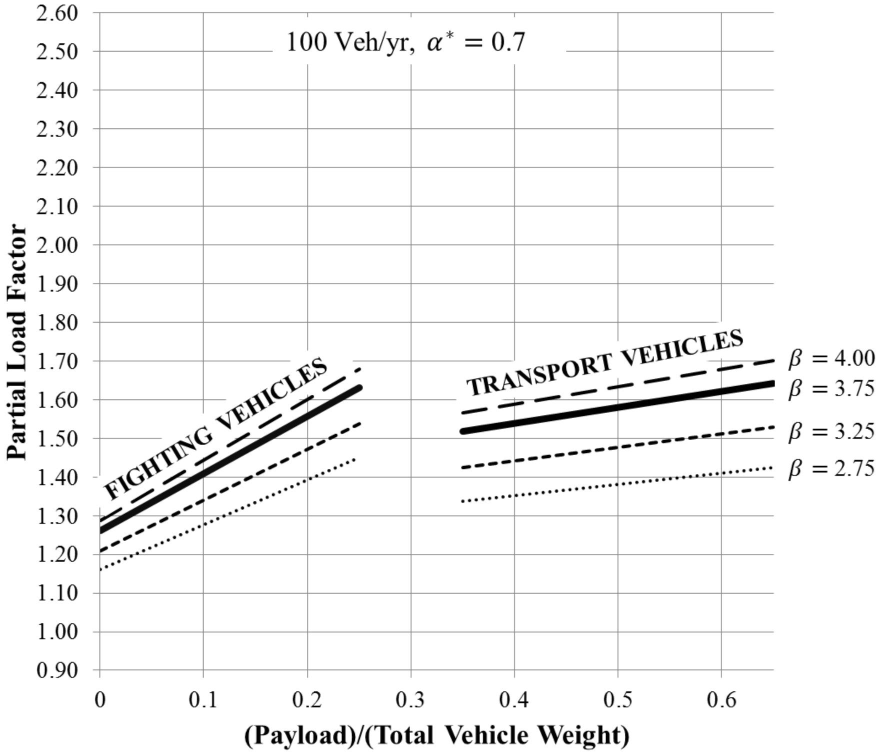


Figure L.6 – Partial load factors for 100 veh/yr traffic and varied β

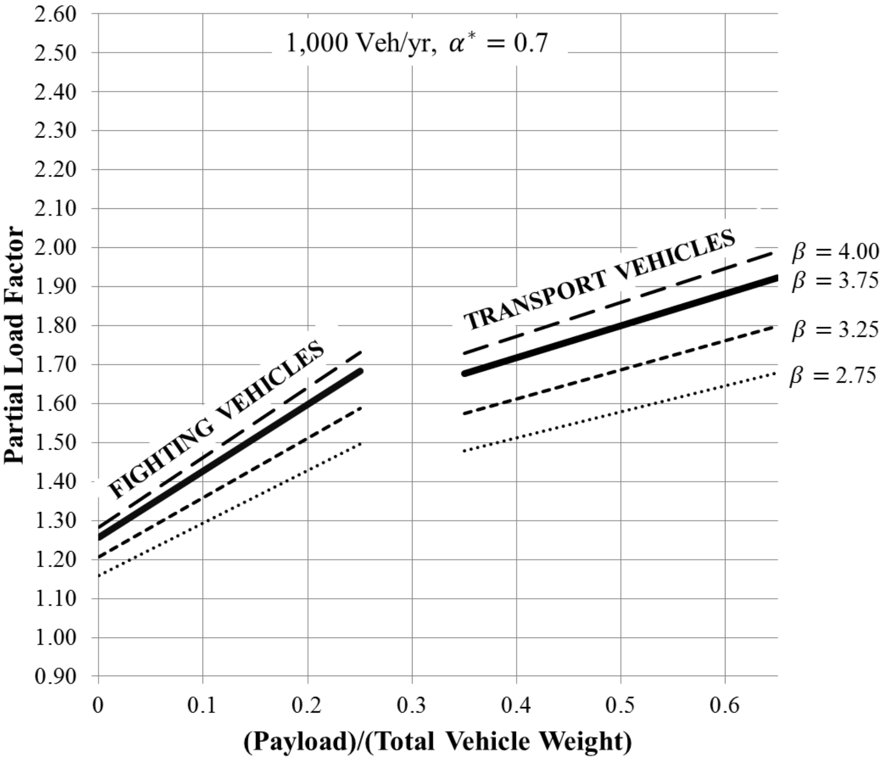


Figure L.7 – Partial load factors for 1,000 veh/yr traffic and varied β

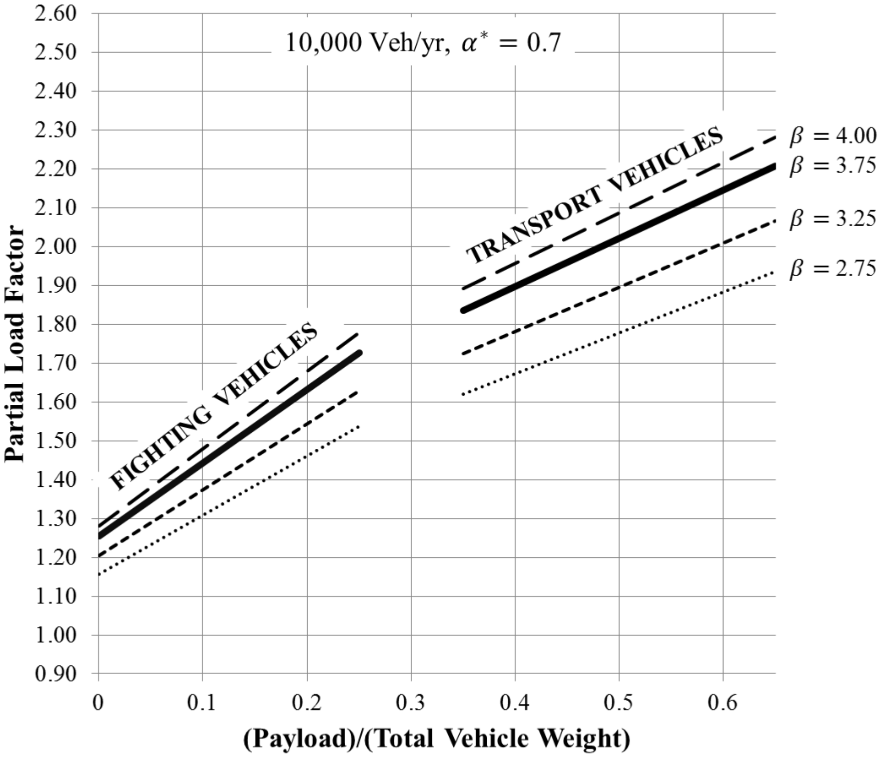


Figure L.8 – Partial load factors for 10,000 veh/yr traffic and varied β

Appendix M

Military Load Classification versus Span for Canadian Forces Vehicles

Table M.1 – Military Load Classification by span of Canadian Forces vehicles

TLAV-RWS					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	19	19	19	19	19
Leopard 2A4M					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	59	65	67	67	67
Leopard 2A6M					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	62	68	69	69	69
HLVW					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	20	20	23	24	25
AHSVS-PLS					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	31	33	41	41	42
AHSVS-PLS with Trailer					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	31	34	47	54	54
AHSVS Tractor with 72 t Trailer					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	56	82	99	113	113
LAV III-ISC - Uparmoured					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	18	20	20	22	22
LAV III-ISC - LORIT					
Span Range (m)	0 - 5	5 - 10	10 - 20	20 - 60	60 - 100
Span Specific MLC	22	24	25	27	27

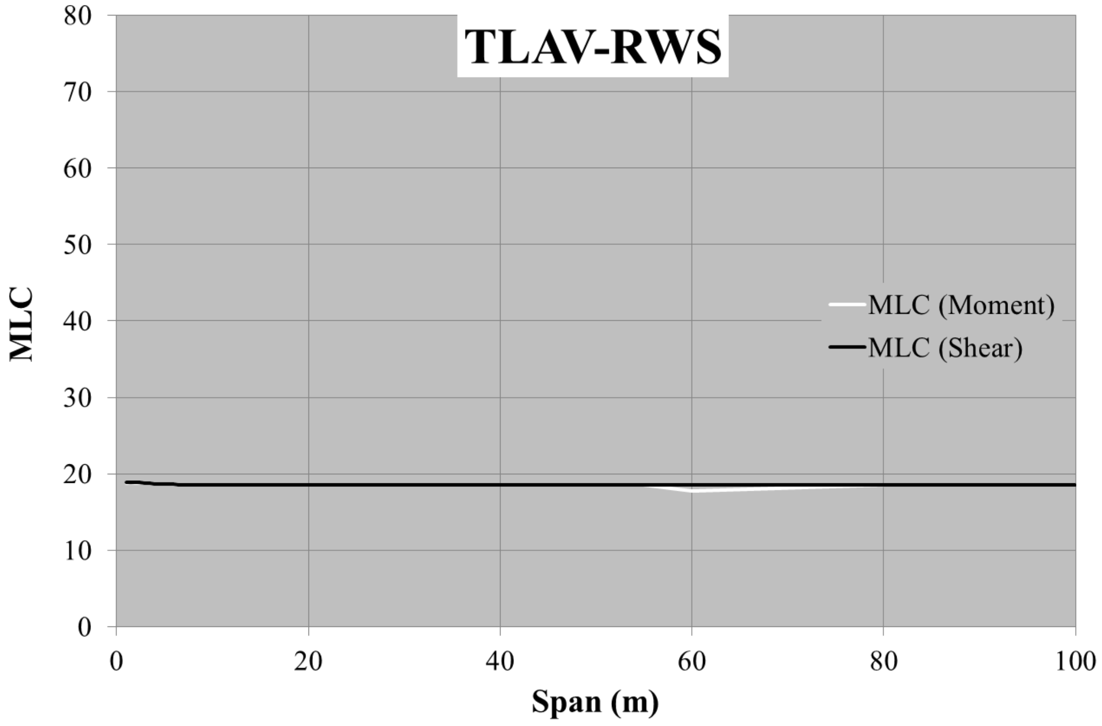


Figure M.1 – Military Load Classification (Tracked) versus span for TLAV-RWS

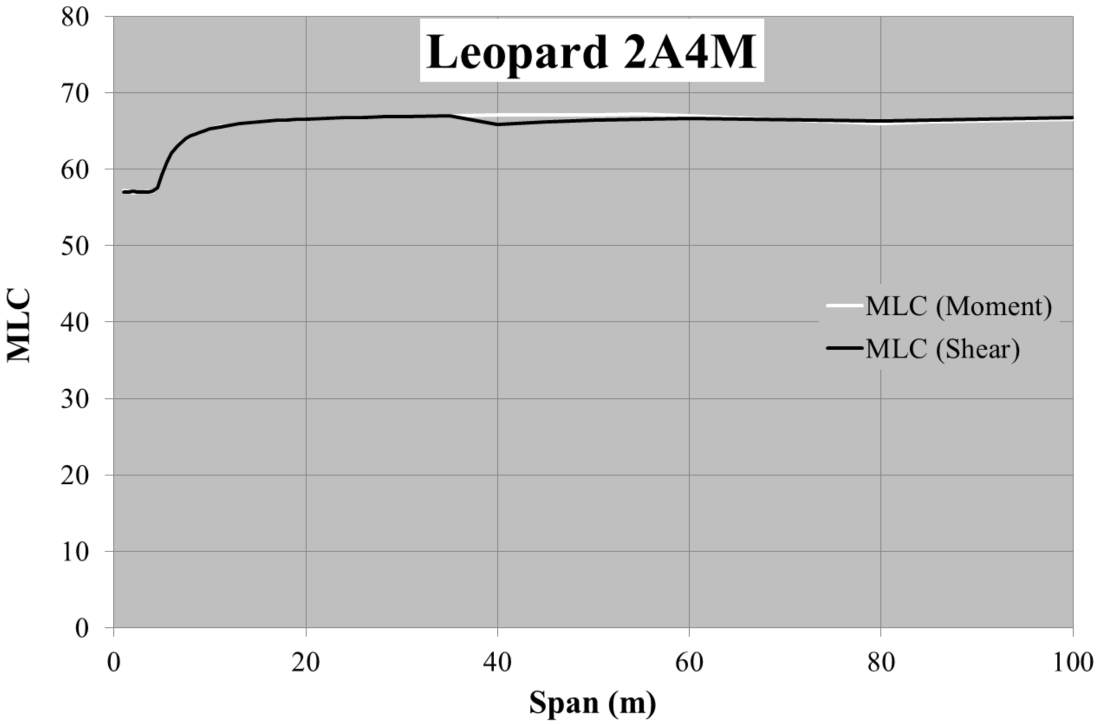


Figure M.2 - Military Load Classification (Tracked) versus span for Leopard 2A4M tank

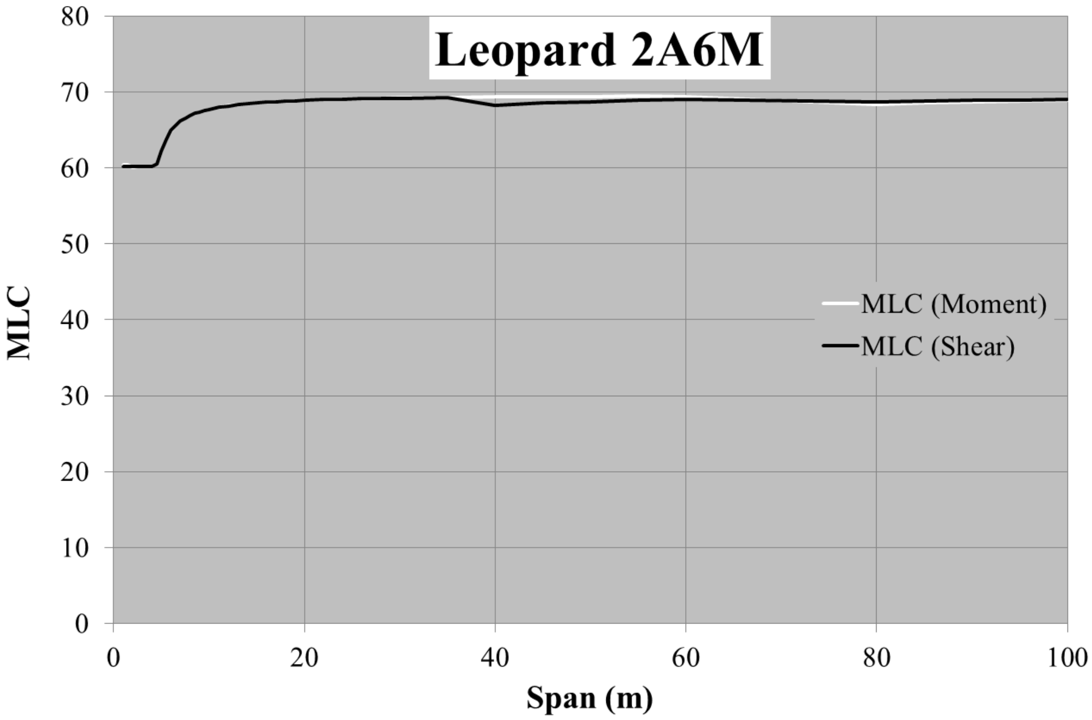


Figure M.3 - Military Load Classification (Tracked) versus span for Leopard 2A6M tank

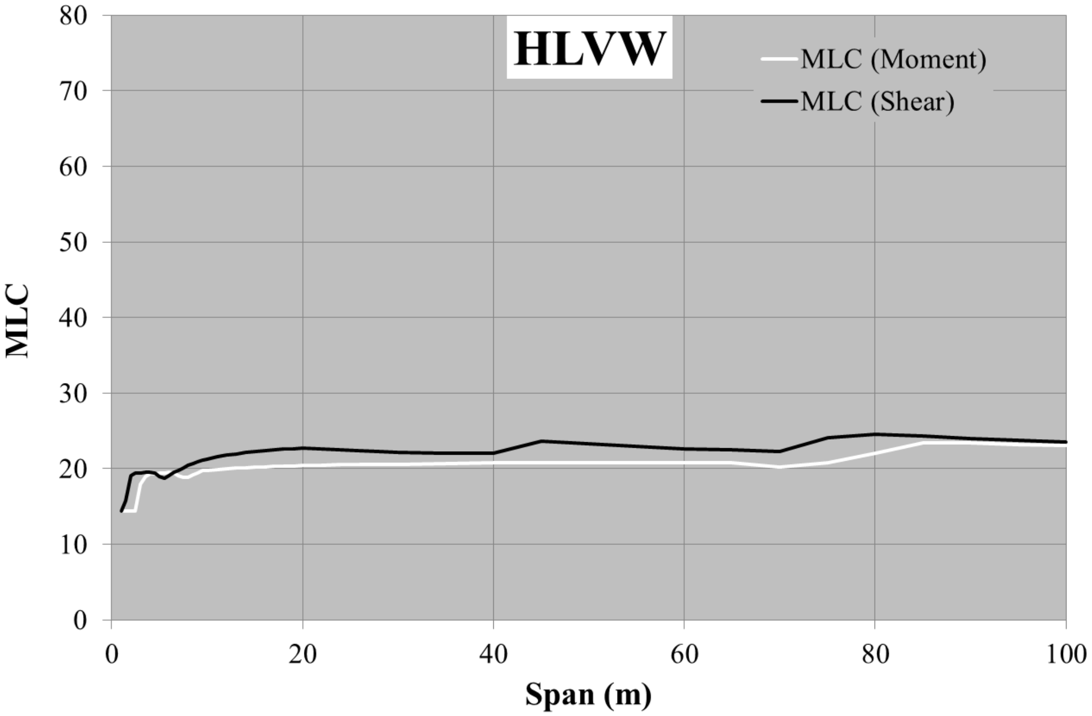


Figure M.4 - Military Load Classification (Wheeled) versus span for HLVW

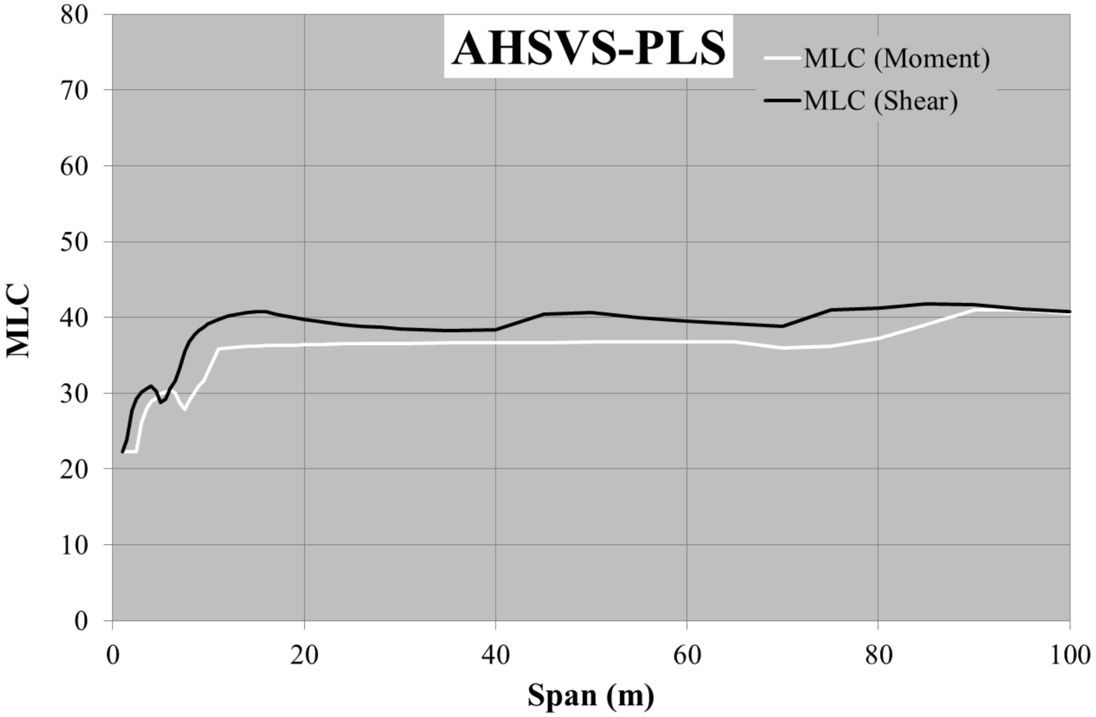


Figure M.5 - Military Load Classification (Wheeled) versus span for AHSVS-PLS

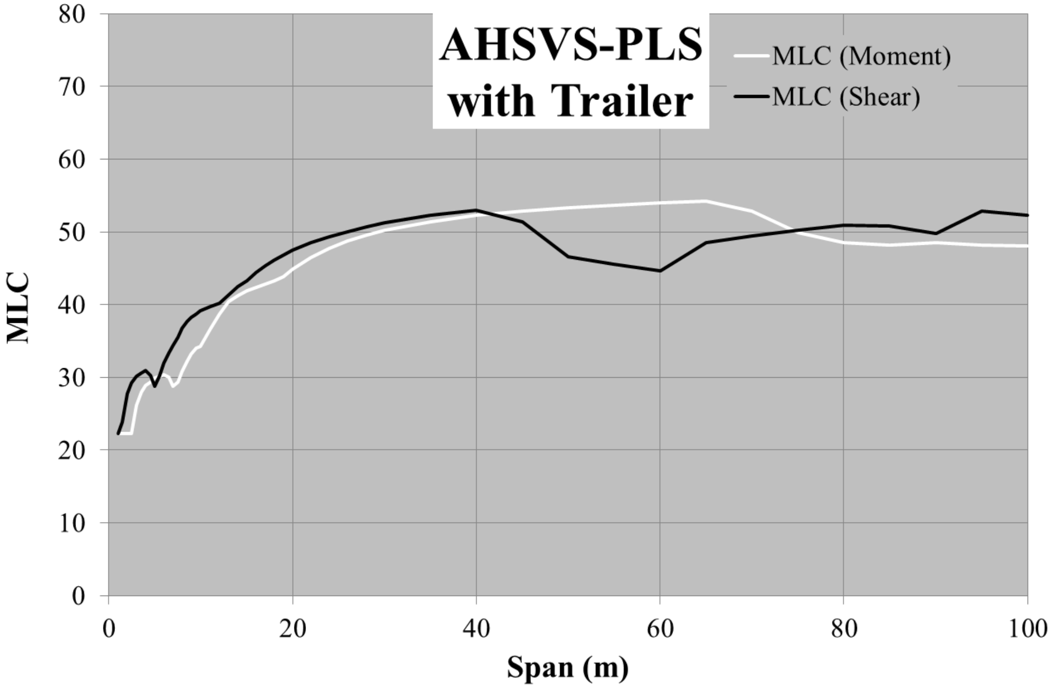


Figure M.6 - Military Load Classification (Wheeled) versus span for AHSVS-PLS with Trailer

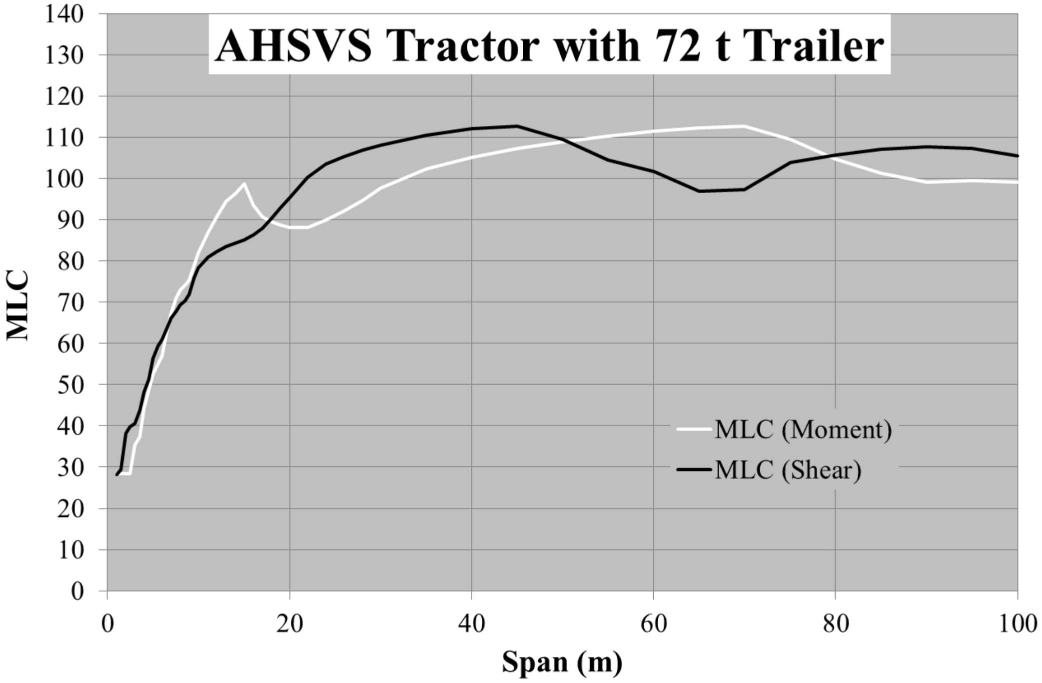


Figure M.7 - Military Load Classification (Wheeled) versus span for AHSVS-PLS with 72 t Trailer

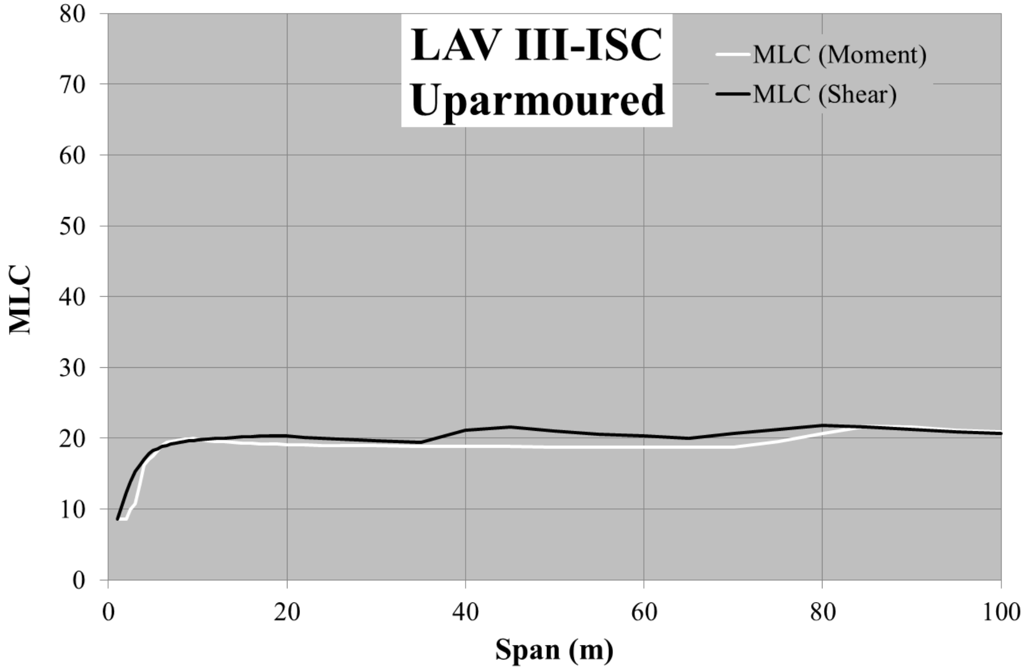


Figure M.8 - Military Load Classification (Wheeled) versus span for LAV III-ISC Uparmoured

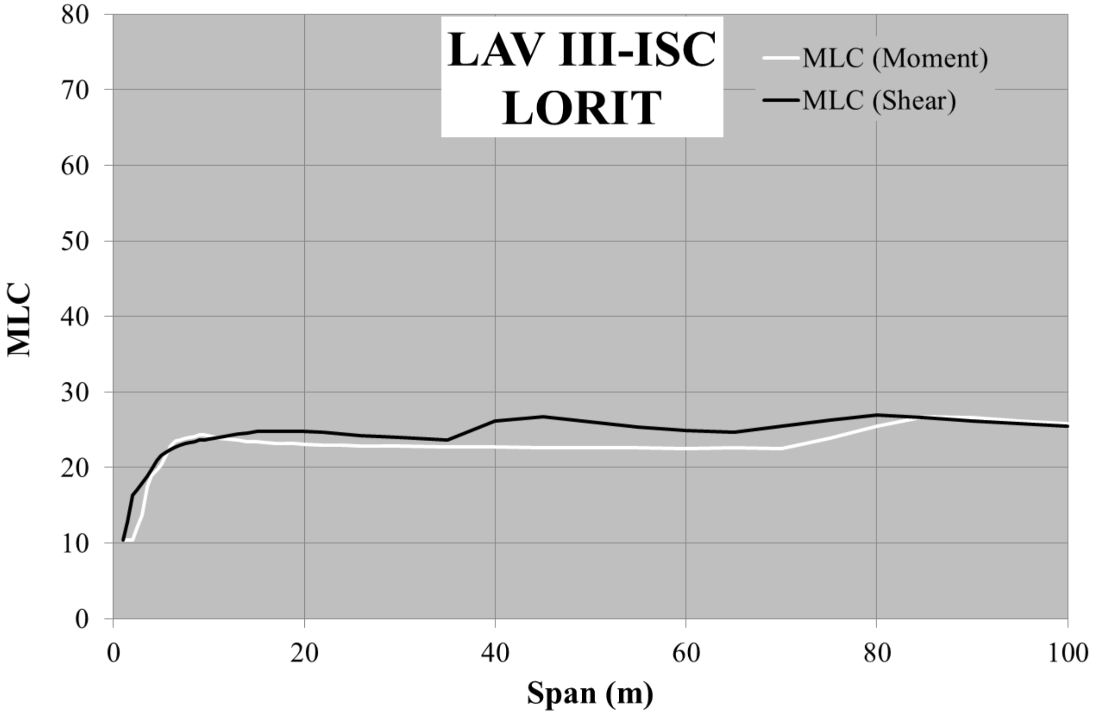


Figure M.9 – Military Load Classification (Wheeled) versus span for LAV III-ISC LORIT

Curriculum Vitae

Name:	Andrew James MacDonald
Post-secondary Education and Degrees:	The University of Western Ontario London, Ontario, Canada 2012-2014 M.E.Sc.
	Royal Military College of Canada Kingston, Ontario, Canada 2002-2006 B.Eng.
Honours and Awards:	-
Related Work Experience	Teaching Assistant The University of Western Ontario 2013-2014
	Construction Engineering Officer Canadian Forces 2002-2013

Publications:

MacDonald, A.J., Bartlett, F.M., Tanovic, R. and Wight, R.G. (2014) "Probabilistic Quantification of Military Vehicle Loading", *Proceedings of the 9th International Conference on Short and Medium Span Bridges*, Calgary, AB