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Site-Specific Traffic Load Assessment Recommendations

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Traffic loading on bridges varies considerably between regions and between sites within regions. It has been found that the mean characteristic load effect from three sites in Slovenia are about 20% less that the corresponding values from three sites in the Netherlands. This difference is due to the numbers and weights of trucks at the sites. The variation in particular sites can be far greater.

Traffic load can be assessed at a site in one of two ways:

- Monte Carlo simulation
- Calibrated notional load model

In the Monte Carlo simulation approach, the procedure is quite elaborate. Truck weight data is collected at the site for an extended period (many weeks) representing seasonal fluctuations and periods when heavy loading might be expected. Statistical distributions are fitted to the histograms of weight data. It is common to use Bi-modal or Tri-modal Gaussian distributions for this but it has been shown that this is not always accurate. It is better to simulate directly from the histogram for trucks of up to about 40 tonnes and to fit a Gaussian distribution to the tail above this level.

Monte Carlo simulation is used to "sample" the fitted weight distribution to generate trucks with "typical" weights. In this way, truck crossing and meeting events are simulated on the bridge. It is of course possible to directly simulate the crossing of the recorded data. While this clearly has advantages, it is generally limited by the size of the database available. With simulation, it is possible to

Abstract

Traffic load is identified as one of the greatest sources of uncertainty in the assessment of bridges. In recent years, simulation techniques, using measured traffic data, have been used to predict the characteristic traffic load effects on bridges. However, the techniques are complex, sensitive to the assumptions adopted and require specialist statistical expertise. This work presents a simplified site-specific traffic load model that generates comparable load effects to the corresponding results from a full simulation. While the simplified model is still sensitive to the underlying assumptions, these can be carefully reviewed prior to the method being approved. Further, the simplified method can be employed by practicing engineers for bridge assessment.

KEYWORDS: Bridge, simplified model, assessment, site-specific, weigh-in-motion, Monte Carlo simulation.

1 INTRODUCTION

The traffic load models given in codes of practice are intentionally made conservative in order to be valid for a wide range of bridge types and loading conditions and because the marginal cost of providing additional capacity is low. Load models for bridge assessment tend to be less conservative. However, in most countries the same bridge assessment principles are applied equally to bridges carrying dense traffic with heavily loaded trucks and those carrying sparse traffic with lighter trucks. In some cases bridges are judged to be structurally deficient according to these conservative load models. An approach which considers the traffic weight and volume statistics for a specific bridge site provides a more accurate representation of the actual loading conditions on the bridge considered and can save the costs associated with unnecessary bridge rehabilitation and replacement.

Weigh-In-Motion (WIM) systems are widely available today to provide unbiased vehicle data such as axle weight, axle spacing, gross vehicle weight, number of axles and velocity without interrupting the traffic flow. In recent years, increasingly sophisticated probabilistic analyses have been performed using WIM data resulting in a more accurate knowledge of the actual traffic loading on bridges. Considerable attention has been given to the process of extrapolating the maximum traffic load effects, simulated using WIM data, which is valid provided that there is no change in the underlying traffic weight or density profile. In the context of bridge assessment, ongoing monitoring of WIM data can provide reassurance that no such change has occurred. The prediction of these maximum load effects can be performed utilizing a wide range of simulation and extrapolation techniques.

Many authors (Gazis 1974, Haight 1963, Tung 1969, Larrabee 1978, Desrosiers & Grillo 1973, Goble et al. 1976, Harman & Davenport 1979) have considered the issue of truck arrivals on a bridge and the probability of multiple-truck presences. Eymard & Jacob (1989) describe software to simulate arrivals and calculate load effects. Nowak and Hong (1991), Nowak (1993a) and Ghosn and Moses (1985) have considered two-truck meeting events in short- to medium-span bridges. Methods for the prediction of characteristic traffic load effects using WIM data have been reported by Larrabee & Cornell (1979), Harman & Davenport (1979), Jacob (1991), O'Connor et al. (1997), O'Connor et al. (1998), Cremona (2001), O'Connor et al. (2001), and Getachew (2003). Kim et al. (1997) have highlighted the site dependence of characteristic traffic load effects, even within a geographical region. This is counter to the principle that is applied in many regions today where the same bridge assessment rules are used for bridges carrying dense traffic with heavily loaded trucks and those carrying sparse traffic with lighter trucks. Many authors (e.g., Nowak (1993), Agarwal & Cheung (1986), Cooper (1997)) have proposed adjustments to notional code models as a simplified method of allowing for site-specific variations. In particular, Moses (2001) proposes an adjustment of the HS20 model for bridge evaluation in the United States and a factored HL93 model is specified in the AASHTO (2003) specification.

In this work, the site traffic dependence of extrapolated load effects is investigated. A simplified model is developed which aims to reproduce similar critical loading events from knowledge of the site-specific traffic characteristics without having to perform a full Monte Carlo simulation. It should be emphasized that the simplified model is site-specific, that is, the parameters for the model are directly related to traffic data specific to the site considered. The objective was that the simplified model would be accurate, robust and easily applied by practicing engineers. Full Monte Carlo simulations require specialist knowledge of Statistics and are sensitive to the assumptions adopted. The simplified method on the other hand is calibrated against Monte Carlo simulations for which the assumptions have been carefully reviewed.

The investigation has been limited to the case of mid-span moment and end shear in simply supported bridges with spans ranging from 15 to 35 meters. The bridges are assumed to have two traffic lanes, one in each direction. The new method is validated using WIM data from four different sites. From these, load effects corresponding to different return periods are calculated. The results of the Monte Carlo simulation are then compared to the results obtained from the simplified model.

The recorded data used in this work gives the static weights of vehicles. The dynamic contribution of the vehicle load is filtered by the WIM calibration procedure. Therefore, no allowance for the dynamic effect or the impact factors is made in the present work.

2 WIM DATA

The WIM data sets used in the present work were recorded at four different sites. The first three data sets were recorded on three different highways in the Netherlands while the fourth was recorded on a highway in France. The sites are referred to here as Site 1, Site 2, Site 3 and Site 4, respectively. In all cases, the highways are dual carriageway with three to four traffic lanes in each direction. The data was collected on the outermost (slower) lanes in each direction. Data from the slow lanes of multi-lane carriageways will have a significantly greater proportion of trucks than the same traffic on a 2-lane road. It is therefore conservative to use such data for simulations of bridges with only two opposing lanes of traffic. However, where possible, more appropriate WIM data should be used for simulations of 2-lane bridges. Only vehicles weighing at least 3.5 tonnes (i.e., only trucks) were registered. The measurement locations and periods are given in Table 1. The data were recorded continuously for different periods as can be seen in the table.

Figure 1 illustrates the distributions of trucks by number of axles in each site and direction. While the dominant recorded truck type, in all cases, has six or less axles, there are a small but important number of trucks having more than that. The vast majority of the five-axle trucks from all sites are articulated trucks. Most of the vehicles recorded with more than five axles seem to be trucks with a tractor unit pulling a trailer. Figure 2 provides a comparison of the Gross Vehicle Weight (GVW) distributions determined using the WIM data measured at the different sites. Clearly, the histograms have two main peaks representing two different truck populations. It is generally assumed that the first part of such histograms represents small trucks and unloaded large trucks while the second part represents fully loaded large trucks. As can be seen in the figure the measured GVW histograms for Site 1–Site 3 (from the Netherlands in 2003) have heavier right tails than that for Site 4 (from France in 1996).

2.1 SIMULATIONS

Generally, the Monte Carlo simulation technique is utilized in order to determine the characteristic values of different traffic load effects such as bending moment and shear force using weigh-in-motion data. Histograms for traffic characteristics such as gross vehicle weight (GVW) are usually fitted with appropriate probability density functions which are then used for the simulations. The motivation for using the fitted distributions for the simulations is to reproduce the general trend in the data, taking into account other possible vehicle data, which are not obtained from the traffic records in the period of data collection. There are usually very few data points in the right hand tails of the GVW histograms. Parametric probability density functions which are obtained by fitting to the entire histograms of GVW, can give a poor description of the histogram tails. The right-hand tail of the histogram is particularly important as it represents the heaviest vehicles and describes their probabilities of occurrence. Getachew and O'Brien (2005) have shown that the calculated characteristic load effects are very sensitive to the model used to represent the tail for the GVW distributions. They propose a 'semi-parametric' model to fit the distribution of the GVW. This model effectively generalizes the trend in the tail region of the GVW distribution while reverting to a direct use of the histogram when there is sufficient data for a clear trend to be evident. As the simulated data sets are based on a fit to the data in the tail region, they are more representative of the trend underlying the recorded data sets than applying the measured data directly. The semi-parametric distribution is used to represent the GVW histograms for the simulations in the present work.

Earlier studies have shown that, for short and medium span bridges, free-flowing traffic with two trucks present simultaneously on the bridge, gives the critical loading events, see, e.g., Nowak (1993). Ongoing research at University Collage Dublin (OBrien and Caprani, 2005) is investigating the effect of the presence of more than two trucks on the bridge simultaneously on the traditional design load effect extrapolation techniques. However, for this study, two trucks meeting on the bridge is assumed to represent the critical loading scenarios. Of course, the case where two heavily loaded trucks are driving beside each other on adjacent lanes of the bridge can be critical, especially for end shear. However, the probability of a very heavily loaded truck overtaking another very heavily loaded truck, in a lane of opposing traffic, is believed to be very low.

In order to determine the number of truck meeting events, artificial traffic streams, which represent four weeks of traffic flow, are first simulated. The meeting events are defined as events involving the presence of at least one axle of a truck in each direction on the bridge simultaneously. The number of truck meeting events for each site and bridge length is found from the arrival and departure times in the 4-week simulation. Inter-truck distances are sampled directly from the measured histogram. Once the number of meeting events per day is known, meeting events are simulated that number of times.

The mid-span moment and end shear for simply supported bridges of different lengths, are calculated by using the influence line to determine the effects of each axle of each truck and superposing to find the total effect. For each meeting event, the relative location of the two trucks on the bridge is found by generating a number from a Uniform distribution within the possible range. This is based on the principle that, given that two trucks are known to be involved, then all possible relative locations are equally probable. Starting with the first truck to arrive, each truck is moved in increments of 0.1 m across the bridge. The load effects due to the two trucks are combined and the maximum load effects are noted.

3 LOAD EFFECT EXTRAPOLATION

As mentioned previously, the investigated load effects in this work are the mid-span moment and the end shear in simply supported bridges. Using the simulated data sets and the information on the number of truck meeting events for each site, the maximum-per-day load effects are calculated for bridge spans of 15, 20, 25, 30 and 35 meters. The calculated maximum-per-day load effect data sets are fitted to a Generalized Extreme Value (GEV) distribution: see Castillo (1988); Coles (2001). As an example, Figure 3 illustrates the density functions of the GEV model fitted to the calculated load effects for a bridge span of 20 meters and for Site 2. As can be seen in the figure, the histograms of the load effects are well described by the GEV model. Good agreements are also observed between the histograms of the load effects and the GEV models for the other studied bridge spans and sites.

Quantile-quantile plotting (see, for example, Embrechts et al. 1997), a process whereby data is plotted by rank against the rank corresponding to a trial statistical distribution, is a useful means of testing data for compliance with an assumed distribution. An investigation performed using these plots, has also confirmed that the GEV model describes the distribution for the daily maximum load effects reasonably well for all sites and for all studied bridge spans. The characteristic extreme load effect values for different return periods are calculated using the GEV model for each of the four sites and for each of the bridge spans considered. As an example, these values calculated for different return periods and for a bridge span of 20 meters, are illustrated in Figure 4. As seen from the figure, the extrapolated values for both load effects, are in descending order from Site 3 to Site 2, Site 1 and Site 4.

The parameters describing the GEV distribution can, according to Leadbetter et al. (1997) be shown to be dependent and Normally distributed. This and the covariance matrix (describing the dependency of the parameters) obtained from the parameter estimations of the fitted GEV model, allows the calculation of confidence intervals for the extrapolated characteristic load effects. Hence, the 5% and 95% confidence limits are calculated for all extrapolated characteristic load effects. These values are shown in a later section of this paper.

The characteristics of the trucks that are involved in the critical loading cases which give the daily maximum load effects are investigated. Five-axle trucks were found to dominate these loading scenarios. An investigation of the WIM data reveals that most vehicles with more than five axles are trucks with a tractor unit pulling a trailer while, as mentioned previously, the five-axle trucks are mostly articulated lorries. The result is that, generally, the weight per unit length is greater for trucks with five axles than for those with more than five axles. Thus, the dominance of five-axle trucks in the present study is not so surprising considering the lengths and the weights as well as the proportion of this truck type. Table 2 shows the extrapolated 1000 year load effects determined when the entire measured data and only data for five-axle trucks are used as an input for the simulations, for Site 1 and Site 4. The very low relative differences indicate that there is little loss of accuracy in most cases when only five-axle trucks are considered. The differences for Site 1 are generally somewhat higher than for Site 4. This appears to be because the five-axle trucks at Site 1 are not as dominant as at Site 4, as can be seen in Figure 1. For Site 4, it is observed that in some cases the extrapolated shear values from the simulations done when only five-axle trucks are considered are greater than the corresponding values obtained from the simulation performed when all trucks are considered. These cases can only be explained as a consequence of the fitted GEV models which considered the entire data set (i.e. the daily maximum shears).

4 SIMPLIFIED MODEL

Applying the simulation technique described in the previous section requires not only a good knowledge of Extreme Value theory but is also time consuming and complex. A simplified model is described here that generates traffic load effects that can be used for bridge assessment without having to perform full simulations. As discussed in the previous section, the analysis of the daily maximum load effects obtained from the simulations reveals that five-axle trucks, because of their lengths and weights, are dominant in the critical loading scenarios. The simplified model is therefore formulated with pairs of heavy five-axle trucks placed at critical locations on the bridge. The load effects induced by these trucks are assumed to give a good estimate of the characteristic load effect values obtained from a full simulation. The simplified model is site-specific, i.e., the parameters for the model are directly related to Gross Vehicle Weight data measured at or near the site considered. The model is also expected to be accurate, robust and easily applied by practicing engineers. The idea is similar to that of Turkstra's Rule (Nowak 1993), which is based on predicting the weights of trucks for different return periods and locating them at critical locations on the bridge. According to Turkstra's Rule, the resulting load effects correspond to the characteristic values obtained from a full simulation.

Figure 5 shows the characteristic truck GVWs as a function of return period for both traffic directions and all sites. The 1000 year truck is that which is likely to occur only once in 1000 years. According to Turkstra's Rule, the 1000 year loading event can be assumed to involve the 1000 year truck meeting a more common truck — the one month or one week truck. While this is simplistic, it has the advantage of ease of application. It also implicitly allows for variations in volume between sites as a site with higher volume will tend to have a heavier 1000-year truck. With Turkstra's Rule and other simplified approaches, the trucks are assumed to meet at the critical point of the influence line. This is just one example of an extreme loading event. The population of extreme loading events will consist of very heavy trucks meeting near to but generally not exactly at this critical point. Hence a model in which one of the trucks is not exactly at the critical point is intuitive.

In this study, many simplified models were considered. Many models, including Turkstra's Rule, gave inconsistent results for different sites, spans and load effects. While Turkstra's Rule is accurate in particular cases, it gave significant inaccuracies in others. The simplified model developed here was found to be the most effective and consistent. In this model, the second truck is assumed to be in a different location to the first, not quite at the most critical point.

The situation is different for the two load effects. For bending moment, the 3rd axle of the 1000 year truck is placed at the center while the 3rd axle of the 1 week truck is placed $\alpha_M L$ from the end as illustrated in Figure 6. For shear, the most critical location for the 1000 year truck is when the 5th axle has just entered the bridge. At this moment in time, the third axle of the 1-week truck is placed $\alpha_S L$ from the end. Values for α_M and α_S were chosen which gave a best fit between the simplified method and the full simulations, i.e., which minimized the sum of squares of differences for all spans, both load effects and all sites. They were found by trial and error and are therefore not fully optimal.

Figure 7 illustrates the measured distribution of the axle spacing of the five-axle trucks from Site 1. The mean values and the standard deviations of the spacings, denoted as AS12 for the distance between the first and the second axle etc., are also shown in the figure. An investigation of the WIM data sets shows that, for five-axle trucks, there is insignificant correlation between axle spacing and GVW. As the standard deviations of axle spacing are low, it is reasonable to assume mean values for axle spacing of the five-axle truck in the simplified model. It should be mentioned that the difference between the mean values from different sites is insignificant.

5 RESULT COMPARISONS

In this section the results obtained from the full simulations and the simplified model are compared. According to the Eurocode, CEN (2002), the characteristic value for traffic load effects has been defined for a return period of 1000 years, i.e., the value with a probability of exceedance of 10% in 100 years. The 1000 year load effects are determined from the distributions of the daily maximum load effects for each bridge length obtained from the full simulations. For the simplified model, single optimal values for α_M and α_S were sought that produced equivalent characteristic load effect values to the full simulations. According to this investigation, the optimal values for α_M and α_S are 0.63 and 0.42, respectively. Finally, the 5% and 95% confidence limits for the extrapolated values obtained from the full simulations are calculated (see section 3). The 1000 year load effects obtained from the full simulations together with their 5% and 95% confidence limits and the corresponding values calculated from the simplified model are shown in Table 3 (for mid-span moment) and in Table 4 (for end shear). The relative differences between the results from the two approaches are also given in the tables. As can be seen, the absolute differences observed are between 0.9% and 10.9% for the mid-span moment and between 0.3% and 13.6% for end shear. These differences are small relative to the differences between sites evident in the table. The simplified model gives reasonably good estimates of the characteristic values in all cases. It is clearly possible to get a low value of α_M and α_S for a particular site. However, it is highly significant to find values which are consistent across different sites with completely different traffic and a wide range of spans.

It should also be mentioned that when $\alpha_M = 0.63$, not all axles are on the bridge for spans of 25 meters and less. For $\alpha_S = 0.42$, all axles of the lighter truck are involved in the critical loading cases for all spans with the exception of the 15 meter span bridge where only the last four axles are involved.

6 CONCLUSIONS

This work presents a site-specific simplified traffic load model that generates characteristic load effects which can otherwise only be determined utilizing a complex simulation technique. The results show that it is mostly five-axle trucks, considering their weights and lengths, which are involved in the critical loading scenarios. For data at each of four sites, pairs of heavy trucks with weights derived from the measured data are placed at specified locations on the bridge. The same locations of the trucks are valid for all sites considered. The simplified model gives reasonably comparable characteristic load effects to those obtained from full simulation.

The authors believe that the results can be employed by practicing engineers for bridge assessment without having to perform full simulations.

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Table 1: Measurement locations and periods.

Denotation	Highway	Site location	Measurement period
Site 1	R04	Amsterdam	Oct. 6–19, 2003
Site 2	R12	Utrecht	Oct. 6–19, 2003
Site 3	R16	Dordrecht	Oct. 6–19, 2003
Site 4	A1	near Ressons	Sep. 9–14, 1996

Table 2: Comparison of the 1000 year return period load effects obtained when data for all trucks and data for only five-axle trucks are used as an input for the full simulations.

Site	L [m]	Moment [kNm]			Shear [kN]		
		All trucks	5-axle trucks	Diff. [%]	All trucks	5-axle trucks	Diff. [%]
1	15	3573	3249	10.0	1124	1091	3.1
	20	5242	4769	9.9	1253	1208	3.7
	25	7021	6588	6.6	1299	1285	1.1
	30	9347	8559	9.2	1342	1315	2.0
	35	10592	9975	6.2	1390	1378	0.9
4	15	2162	2026	6.7	652	645	1.1
	20	3598	3551	1.3	758	774	-2.1
	25	5194	4752	9.3	824	820	0.5
	30	6311	6235	1.2	883	897	-1.6
	35	8330	7718	7.9	926	929	-0.2

Table 3: Comparison of the 1000 year mid-span moment (M) in kNm obtained from the full simulations (FS) and the corresponding values obtained from the simplified model (SM) with α_M=0.63. The 5 % ($M_{0.05}$) and 95 %($M_{0.95}$) confidence limits of the extrapolated values are also given in the table.

Site	L [m]	FS			SM	Diff. [%]
		$M_{0.05}$	M	$M_{0.95}$	M	
1	15	3554	3573	3591	3787	-5.7
	20	5217	5242	5266	5601	-6.4
	25	6992	7021	7051	7578	-7.3
	30	9302	9347	9388	9592	-2.5
	35	10549	10592	10633	11649	-9.1
2	15	3852	3874	3895	3959	-2.1
	20	5685	5714	5741	5796	-1.4
	25	7647	7681	7717	7875	-2.5
	30	9829	9873	9916	10035	-1.6
	35	12457	12523	12583	12163	3.0
3	15	4187	4214	4242	3947	6.8
	20	6052	6085	6118	5715	6.5
	25	8529	8578	8624	7762	10.5
	30	10258	10305	10353	9845	4.7
	35	12573	12635	12696	11974	5.5
4	15	2154	2162	2169	2420	-10.7
	20	3581	3598	3616	3567	0.9
	25	5167	5194	5222	4871	6.6
	30	6289	6311	6333	6177	2.2
	35	8281	8330	8382	7511	10.9
Max						10.9
Min						0.9

Table 4: Comparison of the 1000 year end shear (S) in kN obtained from the full simulations (FS) and the corresponding values obtained from the simplified model (SM) with α_S=0.42. The 5 % ($S_{0.05}$) and 95 % ($S_{0.95}$) confidence limits of the extrapolated values are also given in the table.

Site	L [m]	FS			SM	Diff. [%]
		$S_{0.05}$	S	$S_{0.95}$	S	
1	15	1117	1124	1131	1137	-1.1
	20	1245	1253	1259	1192	5.1
	25	1293	1299	1306	1222	6.3
	30	1336	1342	1348	1402	-4.3
	35	1382	1390	1397	1416	-1.8
2	15	1247	1255	1263	1191	5.4
	20	1326	1333	1339	1247	6.9
	25	1392	1400	1407	1269	10.3
	30	1432	1439	1446	1473	-2.3
	35	1496	1504	1511	1479	1.6
3	15	1226	1233	1240	1172	5.2
	20	1389	1397	1405	1234	13.3
	25	1411	1417	1423	1248	13.6
	30	1485	1491	1498	1447	3.1
	35	1496	1505	1513	1453	3.5
4	15	650	652	654	707	-7.8
	20	756	758	760	738	2.8
	25	821	824	826	755	9.1
	30	880	883	885	917	-3.7
	35	924	926	929	923	0.3
Max						13.6
Min						0.3

Figure Captions

Fig. 1. Comparison of measured distributions of truck types recorded in each direction.

Fig. 2. Comparison of measured distributions of GVW of five-axle trucks, Direction 1.

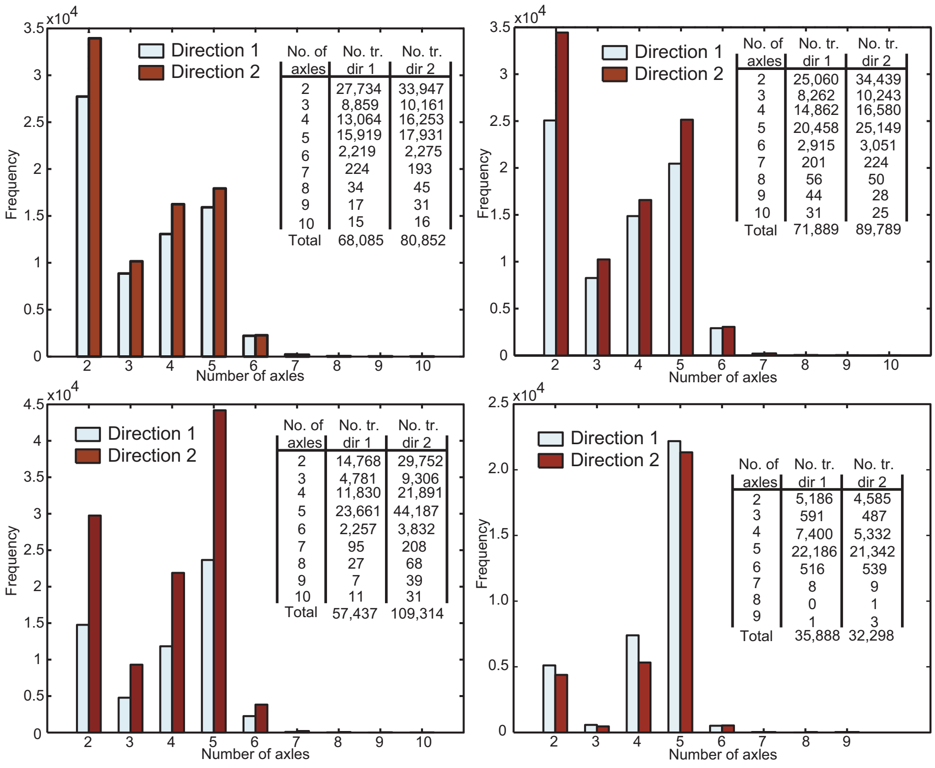
Fig. 3. GEV density functions fitted to the daily maximum load effect histograms obtained from the full simulation, span = 20m. The inserted figures show magnified sections of the tails.

Fig. 4. Comparison of estimated return loads versus return periods obtained for different sites, span = 20m.

Fig. 5. GVW of five-axle trucks versus return period.

Fig. 6. Description of the simplified model.

Fig. 7. Measured distributions of axle spacing for 5-axle trucks obtained from Site 1. AS_{ij} indicate the axle spacing between the i^{th} and j^{th} axles.



Direction 1
Direction 2
Frequency
Number of axles
x10^4
No. of axles | No. tr. dir 1 | No. tr. dir 2
2 | 27,734 | 33,947
3 | 8,859 | 10,161
4 | 13,064 | 16,253
5 | 15,919 | 17,931
6 | 2,219 | 2,275
7 | 224 | 193
8 | 34 | 45
9 | 17 | 31
10 | 15 | 16
Total | 68,085 | 80,852
No. of axles | No. tr. dir 1 | No. tr. dir 2
2 | 25,060 | 34,439
3 | 8,262 | 10,243
4 | 14,862 | 16,580
5 | 20,458 | 25,149
6 | 2,915 | 3,051
7 | 201 | 224
8 | 56 | 50
9 | 44 | 28
10 | 31 | 25
Total | 71,889 | 89,789
No. of axles | No. tr. dir 1 | No. tr. dir 2
2 | 14,768 | 29,752
3 | 4,781 | 9,306
4 | 11,830 | 21,891
5 | 23,661 | 44,187
6 | 2,257 | 3,832
7 | 95 | 208
8 | 27 | 68
9 | 7 | 39
10 | 11 | 31
Total | 57,437 | 109,314
No. of axles | No. tr. dir 1 | No. tr. dir 2
2 | 5,186 | 4,585
3 | 591 | 487
4 | 7,400 | 5,332
5 | 22,186 | 21,342
6 | 516 | 539
7 | 8 | 9
8 | 0 | 1
9 | 1 | 3
Total | 35,888 | 32,298

Figure 1

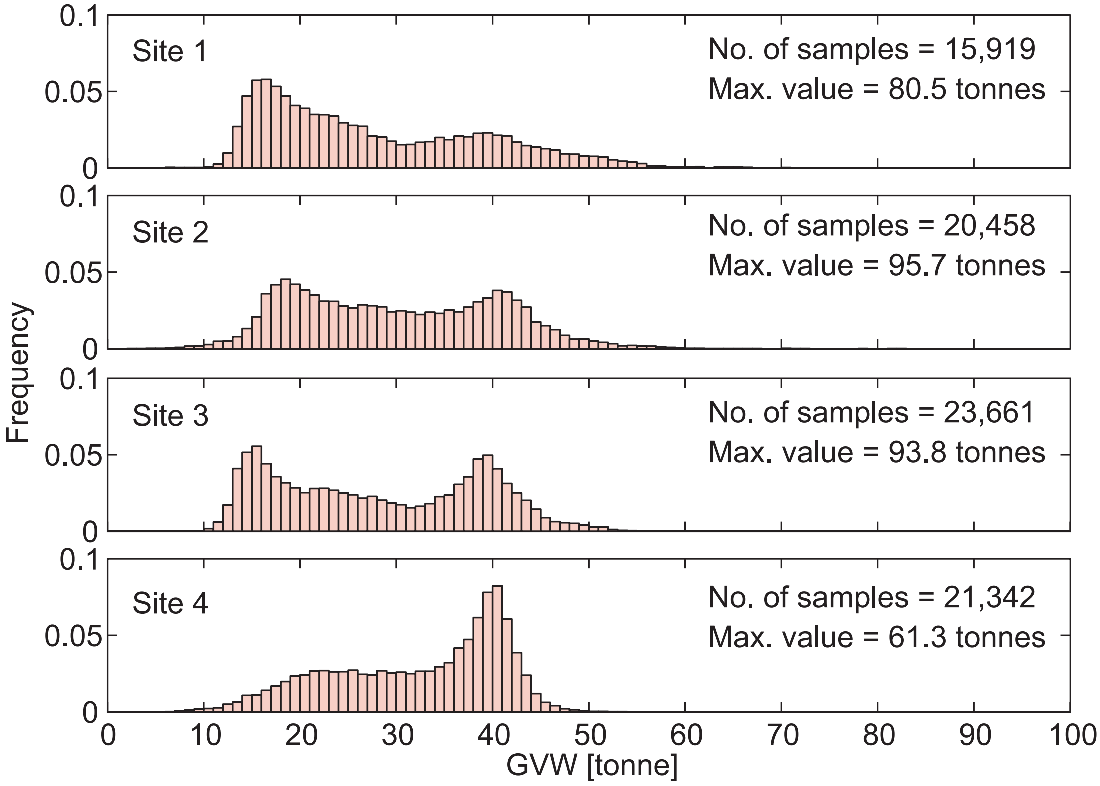
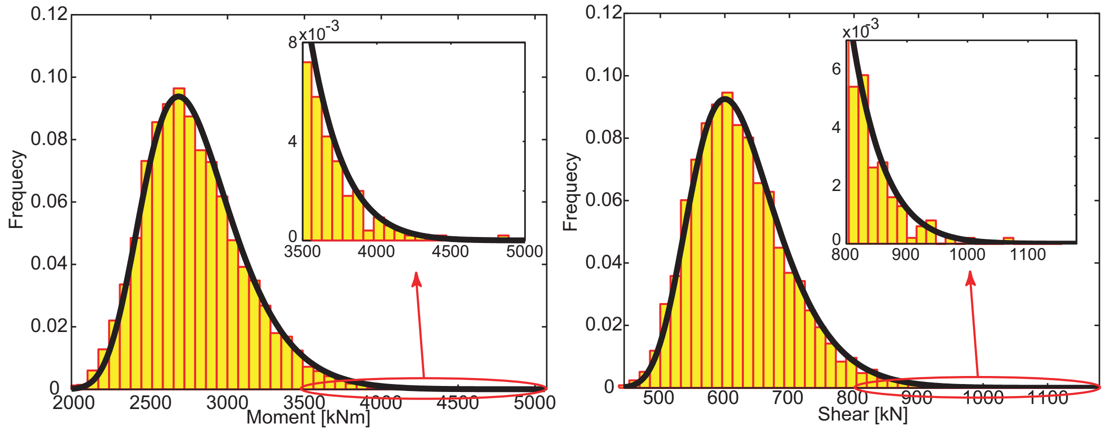

Site 1
No. of samples = 15,919
Max. value = 80.5 tonnes
Site 2
No. of samples = 20,458
Max. value = 95.7 tonnes
Site 3
No. of samples = 23,661
Max. value = 93.8 tonnes
Site 4
No. of samples = 21,342
Max. value = 61.3 tonnes
Frequency
0.1
0.05
0
0
10
20
30
40
50
60
70
80
90
100
GVW [tonne]

Figure 2



0.12
0.10
0.08
0.06
0.04
0.02
0
Frequecy
2000
2500
3000
3500
4000
4500
5000
Moment [kNm]
x10-3
8
4
0
3500
4000
4500
5000
0.12
0.10
0.08
0.06
0.04
0.02
0
Frequecy
500
600
700
800
900
1000
1100
Shear [kN]
x10-3
6
4
2
0
800
900
1000
1100

Figure 3

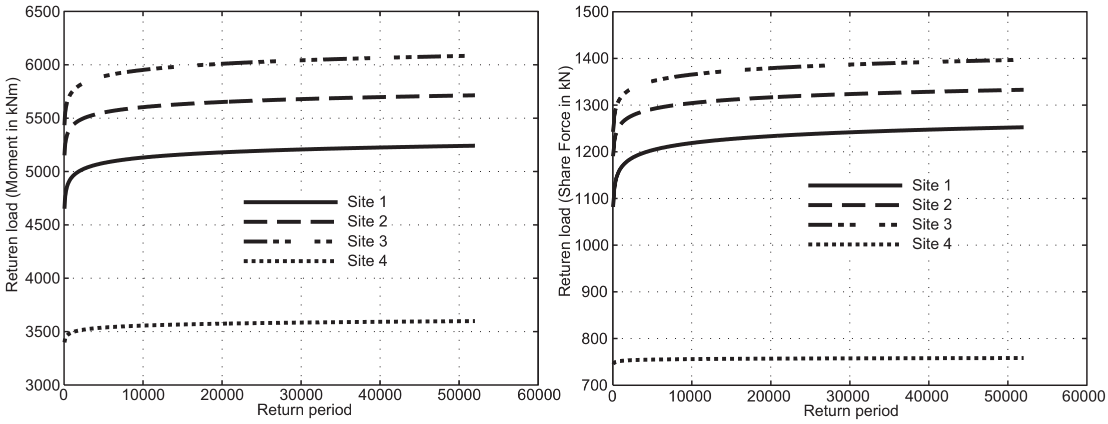
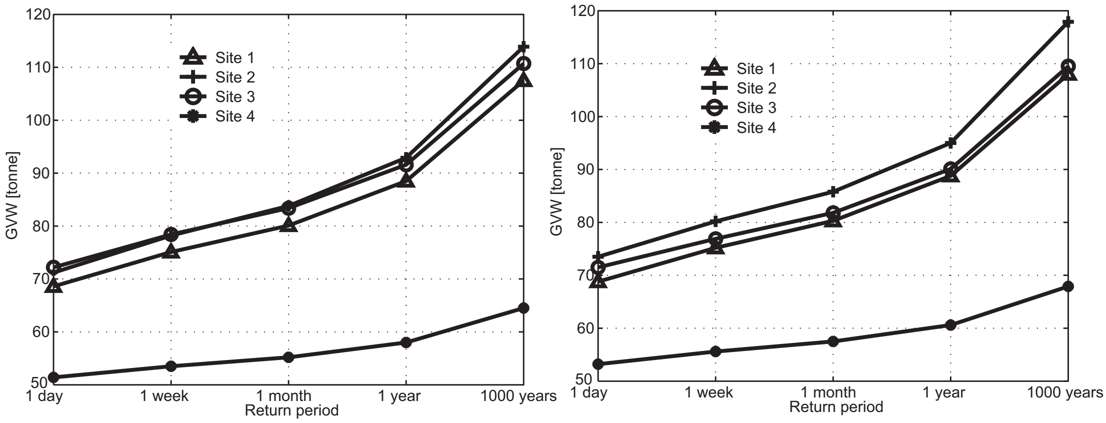

Returen load (Moment in kNm)
Return period
Site 1
Site 2
Site 3
Site 4
Returen load (Share Force in kN)
Return period
Site 1
Site 2
Site 3
Site 4

Figure 4



Site 1
Site 2
Site 3
Site 4
GVW [tonne]
Return period
1 day
1 week
1 month
1 year
1000 years
50
60
70
80
90
100
110
120

Figure 5

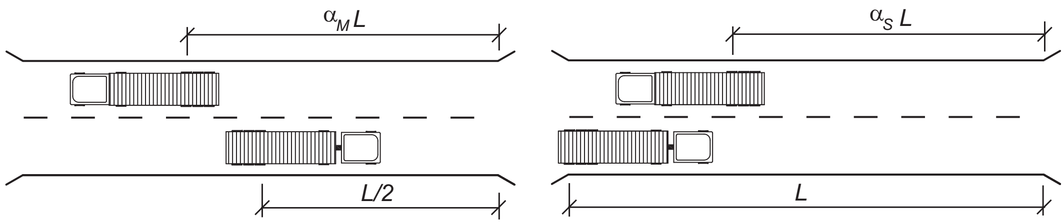


Figure 6

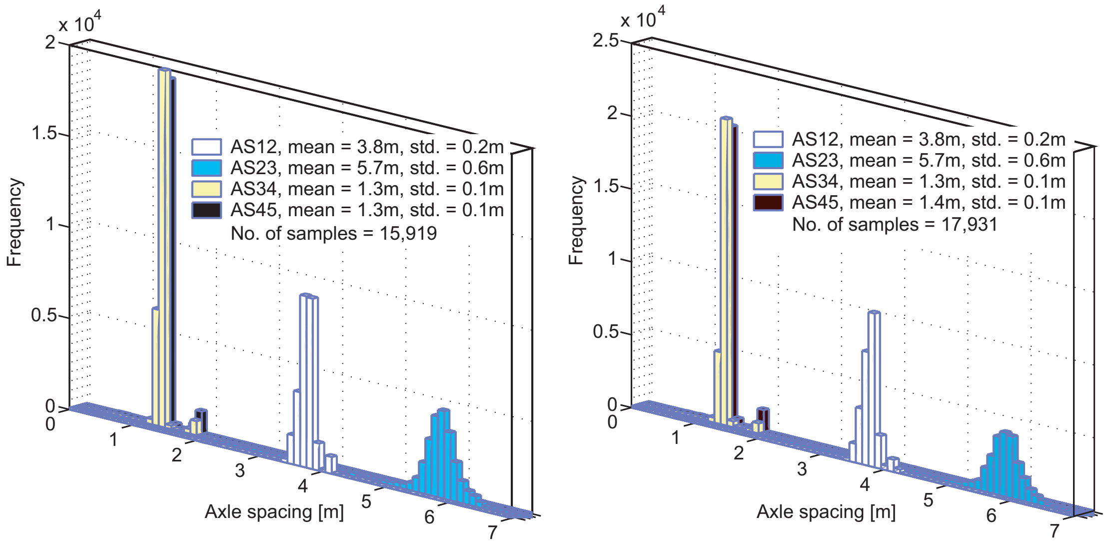

x 10^4
Frequency
Axle spacing [m]
AS12, mean = 3.8m, std. = 0.2m
AS23, mean = 5.7m, std. = 0.6m
AS34, mean = 1.3m, std. = 0.1m
AS45, mean = 1.3m, std. = 0.1m
No. of samples = 15,919
AS12, mean = 3.8m, std. = 0.2m
AS23, mean = 5.7m, std. = 0.6m
AS34, mean = 1.3m, std. = 0.1m
AS45, mean = 1.4m, std. = 0.1m
No. of samples = 17,931

Figure 7