THE STATE OF BRIDGE LOADING IN SOUTH AFRICA

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ABSTRACT

Bridges in South Africa are designed in accordance with TMH7, which was first published in 1981 and revised in 1989. Since the publication of the code, there have been revisions to traffic legislation and the nature of the vehicles that currently occupy our roads has changed over the past forty years with respect to gross vehicle weight, axle weigh, number of axles, axle spacing and dynamic amplification. This paper evaluates the current code provisions by comparing load effects of NA loading to those obtained from modern WIM data for normal traffic. This paper does not address abnormal loading. The shortcomings of TMH7 are presented and an alternative load model is presented that is both up to date and calibrated to international ISO norms. New research in dynamic amplification is presented and a simplified model for multiple lane presence is outlined. A model is presented that is not only modern, but also simpler to apply than the current code, which is seen as cumbersome.

1. INTRODUCTION AND MOTIVATION

Bridges in South Africa are designed in accordance with Technical Methods for Highways 7 (TMH7), which was first published in 1981 and revised in 1989. Since the publication of the code, there have been revisions to traffic legislation and the nature of the vehicles that currently occupy our roads has changed over the past forty years with respect to gross vehicle weight (GVW), axle weigh, number of axles, axle spacing and dynamic amplification.

Since the publication of TMH7 some subsequent studies were performed that point out possible shortcomings of the traffic load models which motivate for investigation. These are:

- Anderson (2006) noted that Liebenberg, in 1978 when deriving the code, stated that a probabilistic study of extreme truck events was not viable due to a lack of statistical information at the time. It is therefore not clear if the loading was treated probabilistically at all. Extreme truck events tend to govern bridge load effects (LEs) on short and medium span bridges and sufficient information is now available to perform a fully probabilistic study.
- Revisions and corrections to the code were issued in 1988, but Oosthuizen et al. (1991) showed there were still shortcomings for normal traffic on narrow and short span bridges. It was found that TMH7 underestimates the bending moments for spans between 4 m and 9 m. The authors also showed that shear forces are underestimated on span lengths below 23 m.

- A committee was formed in 1991 to investigate the simplification of the current traffic loading model by achieving similar results, but with a much simpler application (Oosthuizen et al., 1991). Although the load curve with the aggregate loaded length concept was retained for the distributed NA load, it was proposed that the knife edge load be increased by 25%. This, together with fixing the notional lane widths to 3 m, would address the shortcomings on short and narrow bridges identified by Ullmann in 1988. It was proposed to retain the abnormal load model, but to fix the variable axle spacing to 6 m. None of the recommendations made by this committee were implemented in the code. These deficiencies are confirmed in in this paper where static TMH7 loading is compared to WIM data.

The 1989 axle mass limit, on which the above proposed revisions were based, was 8.2 t according to the Road Traffic Act 29 of 1989. In 1996, after receiving requests from industry, the Department of Transport decided to increase the allowable Gross Combination Mass (GCM) to 56 t and Axle Load to 9 t for vehicles on South African roads. TMH7 was never updated nor checked to allow for this increase.

This paper evaluates the current code provisions by comparing LEs of NA loading to those obtained from modern WIM data for normal traffic. It is reasonable to infer that the traffic load models specified in TMH7 must be investigated and possibly be revised.

2. WEIGH-IN-MOTION DATA

Figure 1 below shows the Weigh-in-Motion (WIM) sensors currently installed in South Africa. Most sensors are located on National Route 3 (N3) between Durban and Johannesburg and on National Route 4 (N4) between Maputo and Pretoria. These are the heaviest freight routes which transport import and export freight between the ports of Richard’s Bay, Durban and Maputo to the Gauteng province and back.

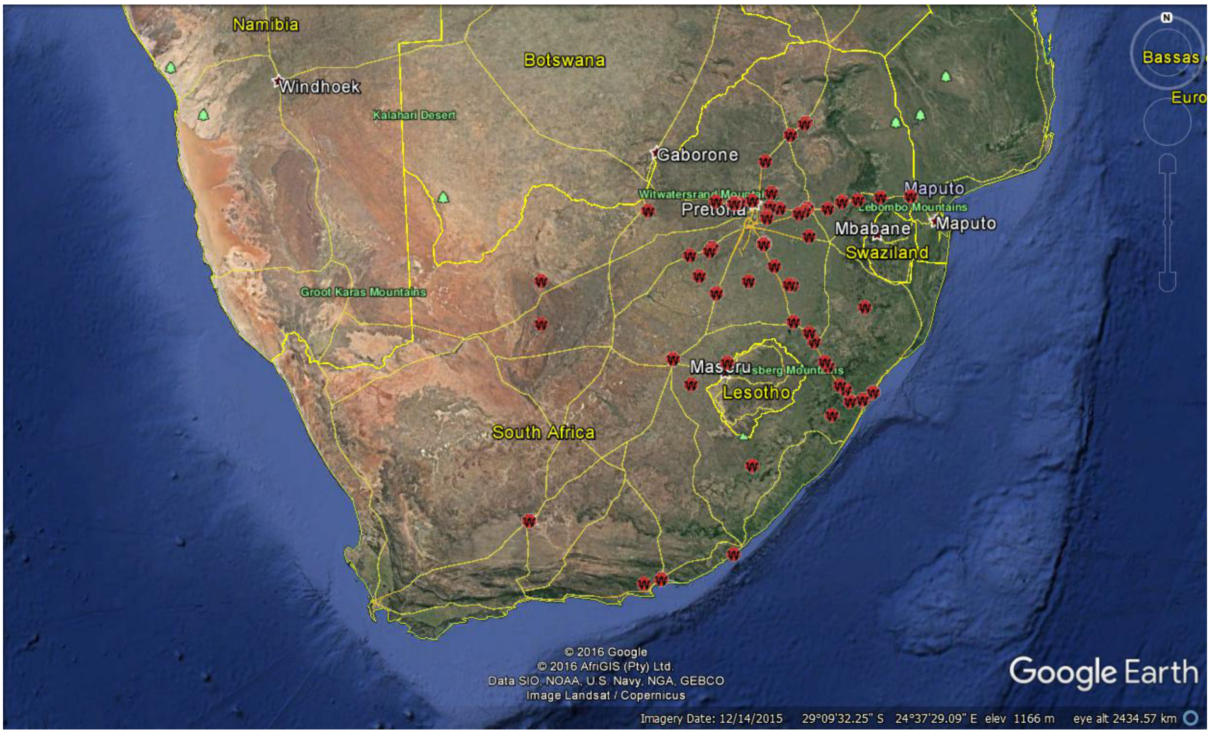

Figure 1: WIM sensors installed across South Africa

In 2007 it was reported that there were 56 permanent WIM stations on national and provincial roads in South Africa (Slavik, 2007). In 2010 it was reported that approximately 100 WIM sensors were installed in South Africa (de Wet, 2010). It is fair to say that enough WIM data is available in South Africa to evaluate the bridge loading critically.

2.1 Identification of a Representative WIM Station

The Roosboom WIM station on the N3 was chosen in previous studies (Lenner, de Wet & Viljoen, 2017) as a representative station in South Africa for describing load effects. At the same time this station is located on the N3 which is considered to be one of the heaviest freight routes in South Africa (Anderson, 2006). It is further considered for the long measurement record of seven years from 2010 to 2016, which was made available for this study, measuring 12.5 million vehicles.

To confirm that Roosboom carries some of the heaviest traffic a comparison was made with two other stations. The LEs for the Roosboom station were compared to the Komatipoort station on the N4 and the Kilner Park station on National Route 1 (N1). The N1 and N4 are the other routes in South Africa that carry large volumes of heavy vehicles and are thereby selected as benchmarking stations. Results showed that there is no reason to believe that the Roosboom station is not representative of the heaviest traffic in South Africa.

2.2 Traffic Composition at the Roosboom WIM Station

The number of recorded vehicles at Roosboom in the seven years of data is 12 511 698. Figure 2 shows the Gross Vehicle Wass (GVW) distribution of vehicle types indicating that seven axle vehicles comprise the GVW tail.

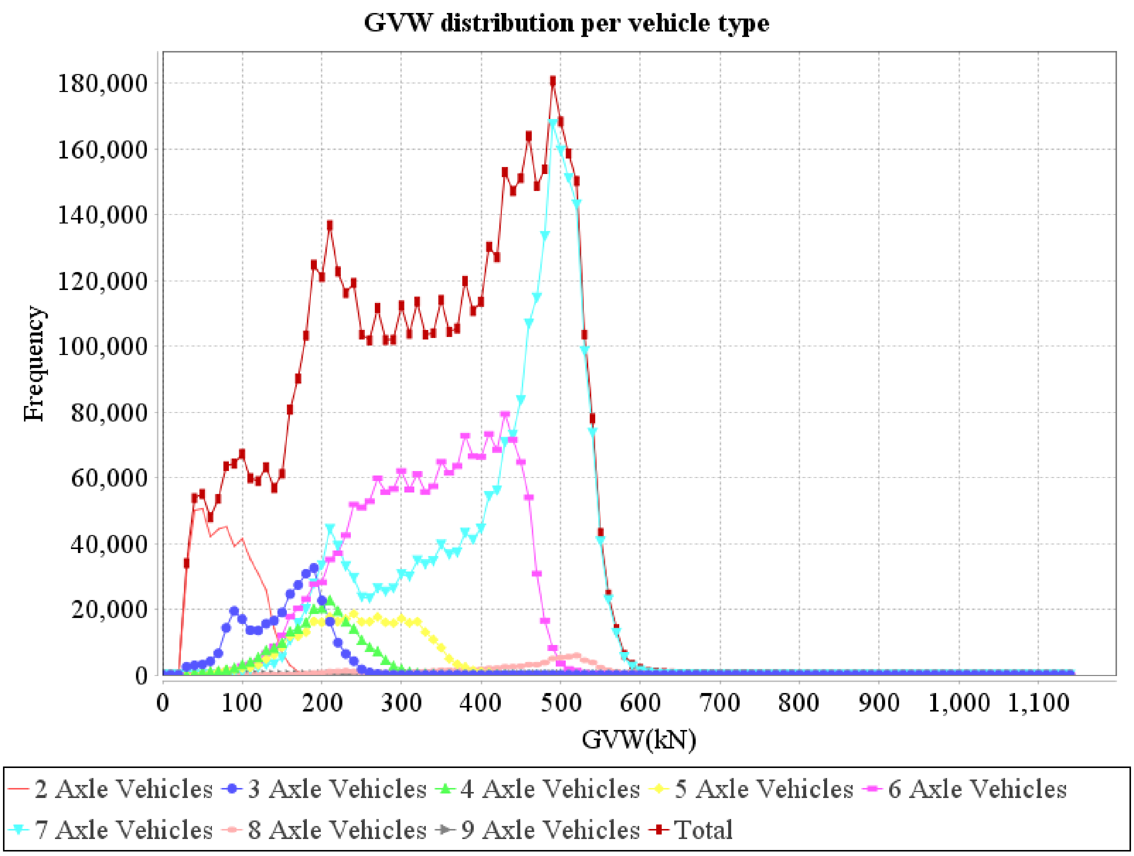

Figure 2: Vehicle type distribution at Roosboom

By observing the GVM distribution it can be said that:

- 11% of fully laden 7 axle vehicles exceed the legal limit of 56 tonnes.
- 20% of fully laden 8 axle vehicles exceed the legal limit of 56 tonnes.
- 56% of 9 axle vehicles exceed the legal limit of 56 tonnes.

3. CHARACTERISTIC LOAD EFFECTS

3.1 Span Lengths Investigated

Short to medium span lengths between 5 m and 50 m are reported since they, by inspection, form most highway bridges in South Africa. Moreover these bridges are governed by free flowing traffic (Caprani & OBrien, 2010). For span lengths exceeding this range, the characteristic load effects are caused by congested traffic, rather than free flowing traffic with dynamic amplification. Current ongoing research shows that congested traffic could govern from span lengths as short as 30 m. This could make a free flow model less conservative at longer spans.

3.2 Load Effects Investigated

LEs refer to bending moments and shear forces in a structure. When deriving traffic load models for bridges, it is common to investigate hogging moments for two span structures as well as sagging moments and shear forces for single span structures (Caprani, 2005). Nowak & Hong (1991) also consider shear on two span structures, but this is less onerous than for single span structures. Each axle in the convoy is treated individually and LEs from all axles on a bridge simultaneously are added together.

3.3 Return Period for Characteristic Loads

TMH7 does not specify a return period nor a probability of exceedance. A 5 % probability of exceedance (p = 0.05 fractile) in a 50-year reference period, or design working life, was used in this study for characteristic values, similar to EN1990. This is also the approach which is adopted in the South African building design codes. This return period is essential for characteristic values and the characteristic return period, *R*, is determined as

$$R = \frac{1}{1-(1-0.05)^{\frac{1}{50}}}$$

$$= 975\ years$$

A Generalised Extreme Value (GEV) distribution is used to extrapolate measured values to the 975 year return period (Van der Spuy, 2020; Van der Spuy & Lenner, 2021).

3.4 Characteristic Load Effects for All Load Effects and Span Lengths

A summary of the characteristic load effects for bending moments and shear at various span lengths is provided in Table 1 for the censored GEV distribution for the Roosboom station.

Table 1: Roosboom characteristic load effects

Span Length (m)	Hogging (kNm)	Sagging (kNm)	Shear (kN)
5	250	401	336
10	841	1 269	485
15	1 779	2 034	566
20	2 490	3 315	722
25	3 160	4 729	819
30	3 178	6 121	890
35	3 907	7 808	976
40	4 547	9 461	1 045
45	5 557	11 459	1 130
50	6 749	13 061	1 151

Table 2 provides the characteristic load effects as calculated for NA loading, with dynamic effects removed for comparison with the calibrated characteristic load effects from the WIM measurements.

Table 2: Load effects for static NA loading

Span Length (m)	Hogging (kNm)	Sagging (kNm)	Shear (kN)
5	125	217	173
10	441	635	254
15	959	1 262	337
20	1 702	2 100	420
25	2 437	3 150	504
30	3 275	4 413	588
35	4 203	5 889	673
40	5 230	7 913	791
45	6 324	9 508	845
50	7 521	11 212	897

4. COMPARISON BETWEEN MEASURED DATA AND TMH7 NA LOADING

Table 1 and Table 2 are shown graphically in Figure 3 and normalised with regards to TMH7 NA loading.

The following observations are made:

- The measured load effects exceed static NA loading for all load effects and span lengths, except for hogging on span lengths of 30 m and longer.
- The exceedance is most pronounced in shorter spans where the measured load effects are up to twice those predicted by NA loading.

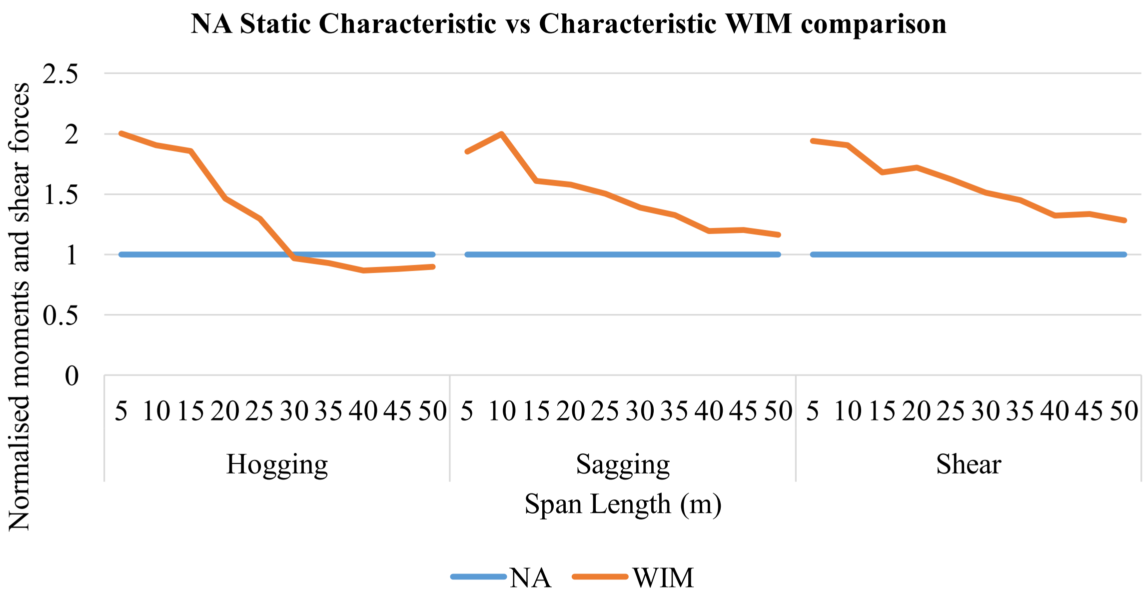

Figure 3: Comparison between measured and NA load effects

This confirms the findings of previous authors, discussed in Chapter 1, that there are deficiencies in TMH7 NA loading at characteristic level. However, these results show that the situation may be more onerous than previously thought. This study was done almost 30 years after the previous studies and it is plausible that the traffic volumes, dimensions and weight of the vehicles on South African roads have increased since then, leading to the more onerous results. This is supported by findings of Bosman (2004) and the deregulation of the South African road freight industry in the 1980's. This is further substantiated if one considers the poor state of the freight rail system in South Africa, leading to 70 % of cargo being transported by road. It is further not clear what level of safety was assumed in the derivation of TMH7 and it is possible that the 5 % probability of exceedance in 50 years used in this study for characteristic values has a lower probability of failure than that used for TMH7, and hence larger LEs.

At the same time, it must be highlighted that this is a comparison between an actual traffic lane and a notional lane in TMH7, which over exaggerates the ratio in the comparison, especially for shorter spans. TMH7 employs a variable width notional lane model and for narrow bridges it often occurs that a bridge which can realistically only accommodate two lanes of traffic is designed for three notional lanes. This can, in part, explain why TMH7 is still performing reasonably well (Lenner et al., 2021). It is worth noting that the study by Lenner et al. (2021) shows that the smallest reliability is found for short spans where the largest deficiencies are found.

5. CONCLUSIONS

This paper shows that there are deficiencies in the magnitude of TMH7 NA loading when compared to modern measured traffic data. This is most prevalent for shorter spans, which has been confirmed by previous studies. Although abnormal loads were not included in this comparison, it is not expected to have a notable effect for shorter spans and the deficiency will remain.

The local bridge design community is of the opinion that TMH7 is difficult to apply in practice and may lead to inconsistent design practice. There has long been a call from industry to adopt the Eurocode load model. Van der Spuy (2020) and Van der Spuy &

Lenner (2019) showed that this is not advisable due to the substantial difference in vehicle characteristics between Europe and South Africa.

It is advisable to derive a new bridge live load model for South Africa, which will not only be based on measured traffic data and modern traffic load theory, but also be simple to apply in practice. Significant work has been performed at Stellenbosch University to this end, but it will require a close collaboration between academia and industry to arrive at an implementable load model.

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