A METHODOLOGY FOR ASSESSMENT OF ROAD STRUCTURES FOR THE PBS PILOT PROJECT IN SOUTH AFRICA

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Abstract

This paper describes the methodology that is being used for the performance assessment of PBS vehicles in terms of road structures as part of the PBS pilot project in South Africa. The assessment approach has evolved from the standard “bridge formula” contained in the National Road Traffic Regulations that is applicable to legal heavy vehicles, to the less conservative “Abnormal Load” bridge formula that is used to evaluate permit applications for the movement of indivisible loads with a total combination mass of up to 125 tonnes. Since 2012, a more performance-based approach has been adopted, which involved the comparison of maximum bending moment (BM) and shear forces (SF) generated by the proposed PBS vehicle with a reference bridge design load (NA and NB30 from the South African bridge design code). Span lengths assessed range from a 5m simply-supported span to 2- and 3-span continuous structures up to 120m. The requirement for the PBS pilot project is that the maximum BM or SF generated by the PBS vehicle may not exceed 85% of the corresponding effects generated by the reference design load. The paper shows the results of a number of the current PBS vehicles and compares the BM and SF effects with a range of legal heavy vehicles. This assessment methodology could form the basis of a performance standard for road structures should the PBS approach for heavy vehicles be adopted in South Africa.

Keywords: Performance-based standards, Smart Trucks, heavy vehicles, road structures, bridge design loading

1 INTRODUCTION

As a result of successful initiatives in Australia, New Zealand and Canada, the introduction of a Smart Truck or performance-based standards (PBS) approach in the heavy vehicle sector in South Africa was identified by the CSIR as a research area warranting funding because of the potential benefits in terms of transport efficiency, road/vehicle safety and the protection of road infrastructure. The PBS approach involves setting standards to specify the performance required from the operation of a vehicle on a network rather than prescribing how the specified level of performance is to be achieved. The PBS approach allows a more optimum "match" between vehicles and the road infrastructure.

A need was identified to design, manufacture and operate a number of PBS demonstration projects in South Africa in order to gain practical experience in the PBS approach and to quantify and evaluate the potential benefits. Operators of Smart Trucks are required to be certified through the Road Transport Management System (RTMS) self-regulation accreditation scheme (Nordengen and Oberholzer, 2006; Standards South Africa, 2007). The RTMS originated from recommendations of the South African National Overload Strategy (Steyn *et al.*, 2004), which sought to address the problem of heavy vehicle overloading and constraints regarding overload control enforcement. The report proposed the introduction of self-regulation as part of a comprehensive long-term solution: a scheme by which initiatives are implemented by industry to establish sound vehicle management practices. Positive outcomes in terms of vehicle load control would complement existing overload control enforcement. Initially, two PBS demonstration projects were implemented in the forestry industry, which were designed and manufactured to comply with Level 2 safety standards of the Australian PBS system (Nordengen *et al.*, 2008). These include directional and non-directional manoeuvres such as acceleration capability, slow speed swept path, static rollover threshold and rearward amplification. The positive performance of the demonstration project (Nordengen, 2010) has resulted in the approval to date of more than 160 additional permits for PBS demonstration vehicles. Guidelines for participation in the Smart Truck demonstration project have been developed by the national Department of Transport's Smart Truck Review Panel (CSIR, 2013). The infrastructure performance standards for the PBS demonstration project are based on South African methodologies for pavement and bridge design loading analyses. For road pavements, the current South African Mechanistic-Empirical Design and Analysis Methodology (SAMDM) (Theyse *et al.*, 1996), which is the basis of the South African pavement design manual for flexible pavements, TRH4 (DoT, 1996), is used to assess the relative road wear of the proposed PBS vehicle combination and a representative baseline vehicle. The requirement for PBS demonstration vehicles is that the roar wear per tonne of payload of the PBS vehicle must be less than the equivalent road wear of the baseline vehicle. As the number of different PBS demonstration vehicles increases, the intention is to develop a set of road wear benchmarks (for different vehicle configuration categories) against which proposed PBS vehicles can be assessed. This paper outlines the methodology used for assessing proposed PBS vehicles in terms of road structures and provides a summary of the assessment of the operational PBS vehicles. Comparisons with the maximum bending moment and shear force effects of a worst case legal vehicle as well as 5% and 10% overloaded legal vehicles are also provided.

2 RESEARCH METHOD

Initially, PBS vehicles were required to comply with Regulation 241 of the National Road Traffic Regulations (DoT, 2000), the "bridge formula", which limits the load intensity of a vehicle and any part of a vehicle. This requirement was only applied to the first two PBS vehicle designs; other performance-based approaches have been introduced. At the beginning of 2010, the national DoT's Smart Truck Review Panel decided to apply the more complex, but less conservative "Abnormal Load" bridge formula (ALBF) (DoT, 2010), which is based on South African bridge design loading, TMH7 NA and NB30 (DoT, 1981), to PBS vehicles rather than the standard bridge formula that is applicable to all legal heavy vehicles. The adoption of the ALBF for PBS demonstration projects is based on the premise that the PBS vehicles operate in a more controlled environment (including the RTMS self-regulation accreditation requirement) than the general heavy vehicle fleet. Hence the risk of overloading and speeding is considerably reduced. In fact, it is likely that the operations involving PBS vehicles are more controlled and compliant than many abnormal load operations. However, a minimum factor of safety of 35% was suggested as a guideline i.e. the PBS vehicles were limited to 65% of the load intensity permitted by the ALBF for abnormal load vehicles.

The adoption of the ALBF enabled one of the original PBS vehicles to be shortened by 1.24 m from 27.00 m to 25.76 m by reducing the length of the trailer drawbar without compromising on the permissible maximum payload. This combination, at 67 500 kg, has a minimum factor of safety of 44.8% in terms of the ALBF. A reassessment of the safety standards showed an improved performance in terms of Tracking Ability on a Straight Path, Low Speed Swept Path, Steer Tyre Friction Demand and Static Rollover Threshold. Although there was a reduced performance in terms of Rearward Amplification (2.8%), High Speed Transient Offtracking (5.6%) and Yaw Damping Coefficient (15%), the modified vehicle combination still meets all the requirements of a Level 2 PBS vehicle. The Australian PBS scheme has four categories of PBS vehicles (Levels 1 to 4). Compliance with the Level 1 standards allows the PBS vehicle general accessibility to the entire network whereas Level 4 PBS vehicles (typically “road trains”) are restricted to remote routes with low traffic volumes and many overtaking opportunities. Level 2, 3 and 4 PBS vehicles may only operate on routes approved by the relevant provincial road authorities.

During 2012, the Smart Truck Review Panel decided to investigate the use of another more fundamental approach for assessing the safety of structures. A computer application, “ACV Checker”, that was originally developed for assessing the effect of abnormal load all-terrain mobile cranes on structures, compares maximum bending moments and shear forces generated on a range of span lengths (including two- and three-span continuous structures) by the vehicle being assessed with those of a reference load, in this case the TMH7 NA and NB30 design load (DoT, 1981). This methodology is described in detail in the report “Load Effects of Mobile Crane Vehicles on Bridge and Culvert Structures” (Anderson, 2011). Currently all proposed PBS projects are assessed in terms of structures using both methods. It is likely that the assessment approach comparing maximum bending moments and shear forces will be adopted for the PBS assessment of structures.

The next three sections provide an overview of the assessment results of the Smart Trucks approved to date in terms of structures. Comparisons are made with (a) the Abnormal Load Bridge Formula, (b) the NA and NB30 bridge design reference load (bending moment and shear force ratios) and (c) typical worst case South African legal heavy vehicles (bending moment and shear force factors). In the latter case, legal vehicles that are overloaded by 5 and 10% respectively are also considered for comparison with the Smart Trucks.

3 RESULTS

3.1 Comparison of load effects of current PBS pilot project vehicles with the Abnormal Load Bridge Formula, TMH7 Bridge Design Reference Load and a range of Legal Heavy Vehicles

Abnormal Load Bridge Formula

Table 1 and Figure 1 show the minimum factors of safety in terms of the abnormal load bridge formula (Table 3.1 in the TRH11) for all PBS vehicles participating in the pilot project. It can be seen that the minimum factor of safety in terms of the ALBF is 34.8%.

Table 1: Minimum Abnormal Load Bridge Formula Factors of Safety for operational PBS vehicles

Operator/Description	Vehicle Combination Description	Max Combination Mass (kg)	Vehicle Length (mm)	Minimum Factor of Safety (%)
Barloword Sugar Bottom Dumper	Sugar Bottom Dumper-3-Axle truck tractor with a tandem drive axle, a tri-axle lead semi traliler and twin-axle follower semi trailer.	65 590	22 981	47.2%
Barloworld Platinum side tipper	3-axle truck-tractor (MB3350S) with a tandem drive axle, 2 axle semi trailer and 4 axle full-trailer	73 400	21 976	40.3%
Beefmaster	B-Double Tautliner- 3 axle truck-tractor with tandem drive axle, tri-axle lead and follow trailers	72 400	29 730	52.3%
Buhle Betfu	MAN TGS 41.480 8x4 BB Freight Carrier with Twin Steer Axles and Tandem Drive Axle, a 2-Axle Dolly and 2-Axle Semi-Trailer	67 050	21 981	39.6%
Gaskells/Unitrans Timber	Scania R500 CB 8x4 Truck with a 5-Axle Trailer	70 000	25 076	42.3%
Ngululu Bulk Carriers	Interlink combination- 3-axle truck tractor with tandem drive axle, tri-axle lead and tag trailer	71 900	21 529	34.8%
Timber Logistics Services	MAN TGS 33.480 6x4 Truck with 2+3 axle full trailer combination	67 300	23 183	41.9%
Timber24/Zabalaza	Merc Benz Actros 3350 3-Axle Truck with Tandem Drive Axle and 5-Axle Trailer	67 500	22 880	41.5%
Timbernology	Merc Benz Actros 3250/54 FC truck-tractor with 4-axle drawbar trailer	63 000	22 000	40.7%
Unitrans Quad fuel	3-axle truck-tractor (MB) with tandem drive axle, and quad semi trailer-	56 800	18 630	40.2%

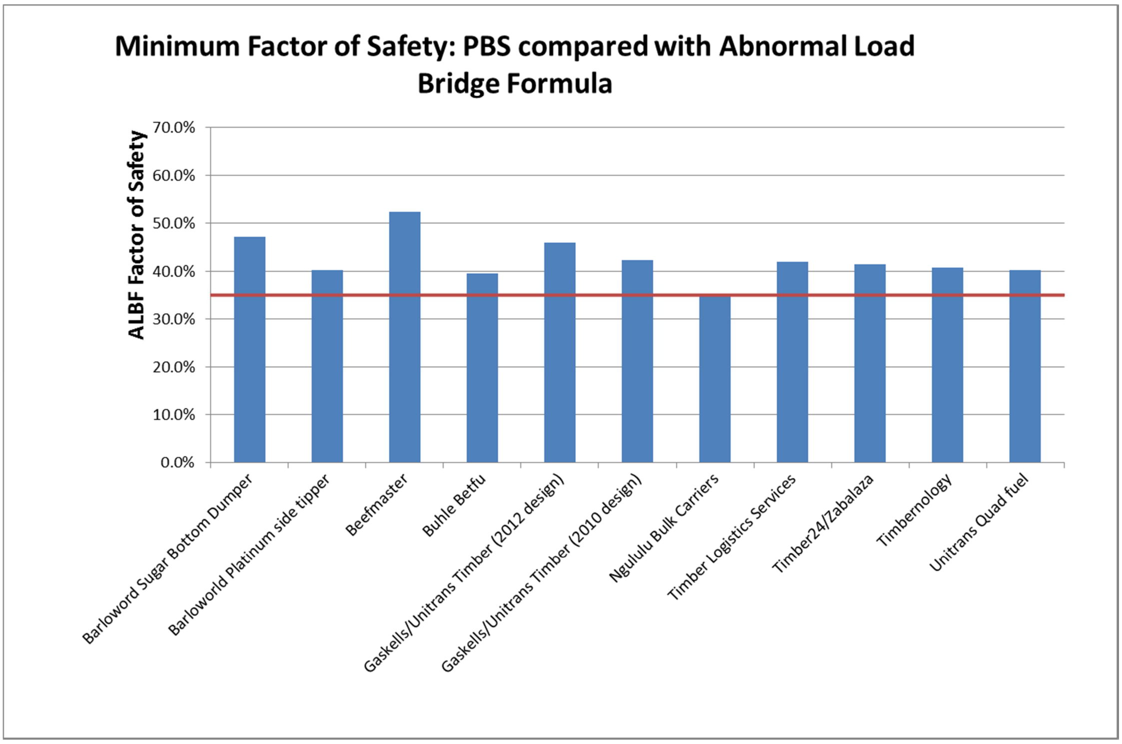

Figure 1: Minimum Factors of Safety - PBS vehicles compared with the Abnormal Load Bridge Formula (Table 3.1, TRH11, 2010) – showing minimum allowable Factor of Safety

South African TMH7 Bridge Design Reference Load

Table 2 provides the maximum bending moment and shear force ratios for a worst-case legal (56 tonne) vehicle as well as the PBS vehicles compared with the NA and NB30 bridge design loads. The results are illustrated graphically in Figures 2 and 3.

As indicated in Section 1, details of the methodology are provided in the report "Load Effects of Mobile Crane Vehicles on Bridge and Culvert Structures" (Anderson, 2011). The approach was originally developed for assessing all-terrain mobile cranes in terms of structures, as they cannot be evaluated using Table 3.1 of the TRH11 as in many cases the axle group distances on mobile cranes exceed the maximum distance of 6.0 m provided for in Table 3.1 (TRH11). It should be noted that in the case of the new methodology for assessing all-terrain mobile cranes, if either the maximum bending moment or shear force ratio exceeds 0.85, the mobile crane operator's fleet is required to become RTMS-certified. In the case of the PBS pilot project, the fleets of **all** operators participating in the PBS project are required to be RTMS-certified, irrespective of the maximum bending moment or shear force ratios. Furthermore, the maximum bending moment and shear force ratios are not permitted to exceed a value of 0.85. This limiting value could be adjusted in the future.

Table 2: Maximum Bending Moment and Shear Force Load Ratios: NA and NB30 compared with PBS Vehicles

Operator/Description	Max Combination Mass (kg)	Vehicle Length (mm)	Maximum Bending Moment Ratio	Maximum Shear Force Ratio
LEGAL VEHICLE	56 000	22 000	0.74	0.42
Barloword Sugar Bottom Dumper	65 590	22 981	0.76	0.43
Barloworld Platinum side tipper	73 400	21 976	0.78	0.50
Beefmaster	72 400	29 730	0.78	0.40
Buhle Betfu	67 050	21 981	0.77	0.44
Gaskells/Unitrans Timber	70 000	25 076	0.78	0.41
Ngululu Bulk Carriers	71 900	21 529	0.81	0.50
Timber Logistics Services	67 300	23 183	0.77	0.45
Timber24/Zabalaza	67 500	22 880	0.77	0.45
Timbernology	63 000	22 000	0.77	0.42
Unitrans Quad fuel	56 800	18 630	0.74	0.46

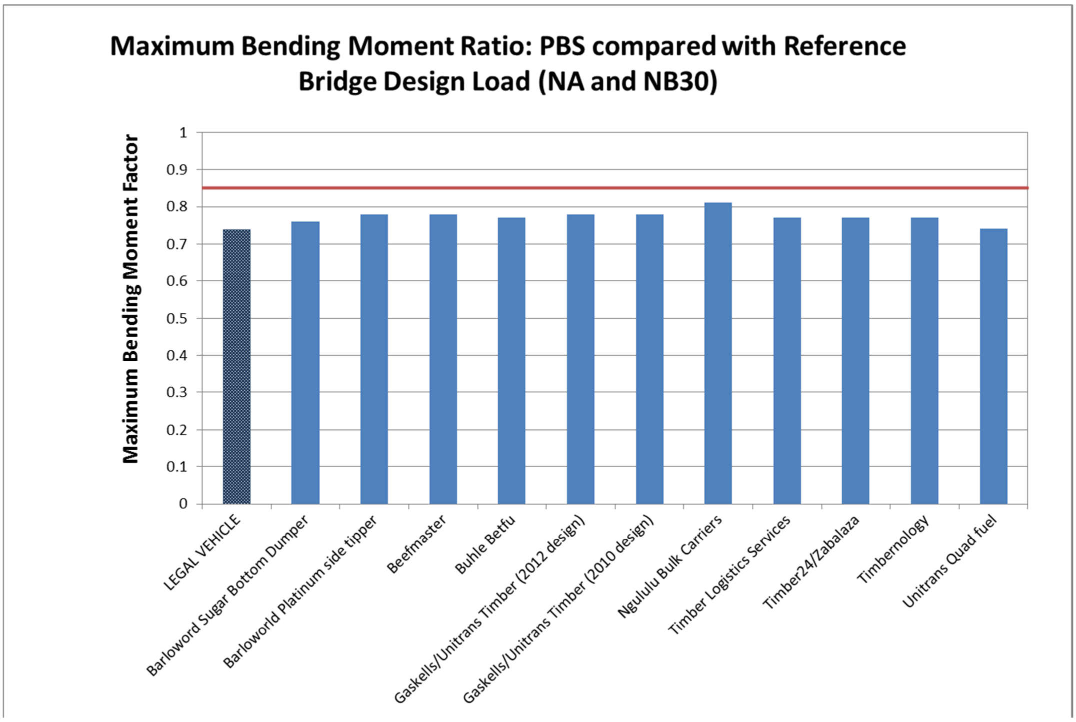

Figure 2: **Maximum bending moment ratios – PBS compared with reference bridge design load (NA and NB30) – showing maximum allowable ratio**

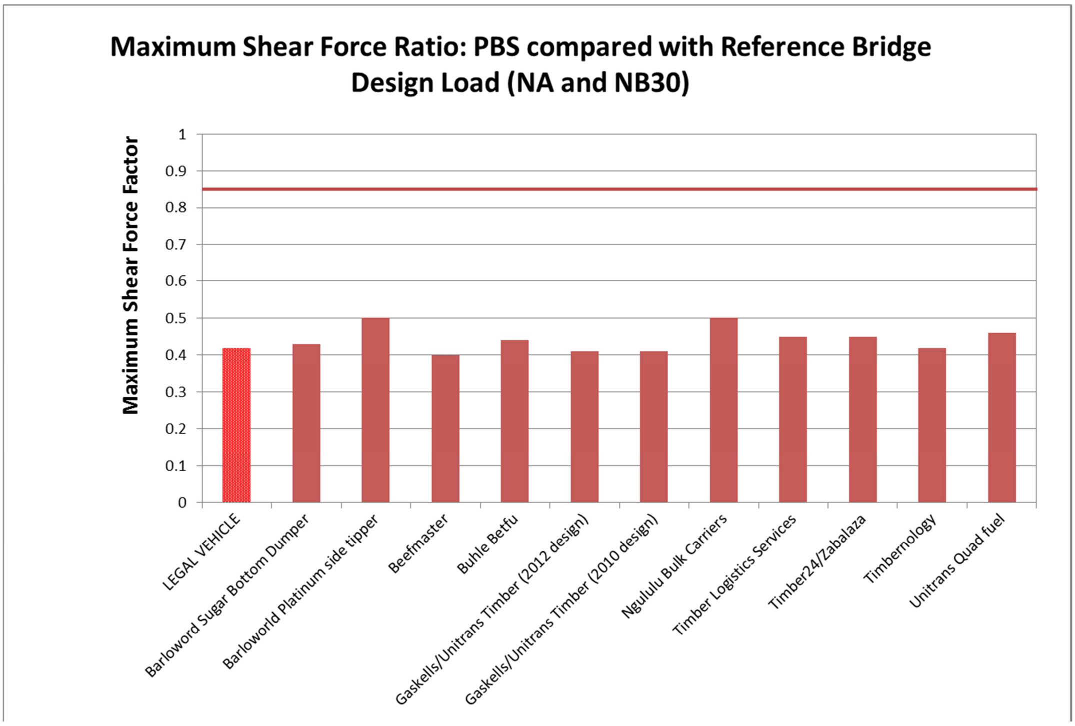

Figure 3: **Maximum shear force ratios - PBS compared with reference bridge design load (NA and NB30) – showing maximum allowable ration**

Legal heavy vehicles

Table 3 and Figures 4 and 5 provide a comparison between the operational PBS vehicles and a worst case 56-tonne legal baseline vehicle. As indicated in Table 3, the worst performing baseline vehicle generated a maximum bending moment ratio of 0.74 and a maximum shear force ratio of 0.42 when compared with the NA and NB30 design loading. It can be seen that in most cases, the maximum bending moment generated by the PBS vehicles exceeds that of the legal vehicle by less than 6%. In one case, the increase in maximum bending moments is 9.5%. In the case of shear force, in most cases the increase is less than 10%, but in two cases the increase is 19%.

Table 3: Bending moment and shear force ratios: PBS compared with Worst Case (legal) baseline vehicle

Operator/Description	Max Combination Mass (kg)	Vehicle Length (mm)	Bending Moment Ratio (PBS vs Legal vehicle)	Shear Force Ratio (PBS vs Legal vehicle)
Barloword Sugar Bottom Dumper	65 590	22 981	2.7%	2.4%
Barloworld Platinum side tipper	73 400	21 976	5.4%	19.0%
Beefmaster	72 400	29 730	5.4%	-4.8%
Buhle Betfu	67 050	21 981	4.1%	4.8%
Gaskells/Unitrans Timber	70 000	25 076	5.4%	-2.4%
Ngululu Bulk Carriers	71 900	21 529	9.5%	19.0%
Timber Logistics Services	67 300	23 183	4.1%	7.1%
Timber24/Zabalaza	67 500	22 880	4.1%	7.1%
Timbernology	63 000	22 000	4.1%	0.0%
Unitrans Quad fuel	56 800	18 630	0.0%	9.5%

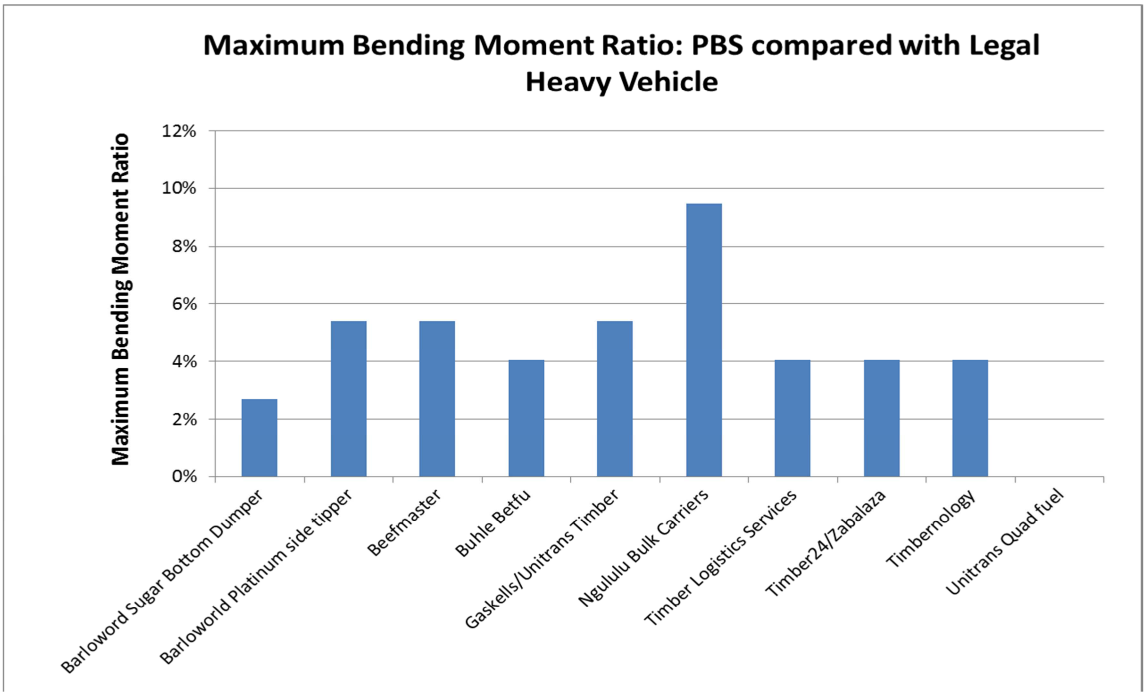

Figure 4: Maximum Bending Moment Ratio: PBS compared with legal heavy vehicle

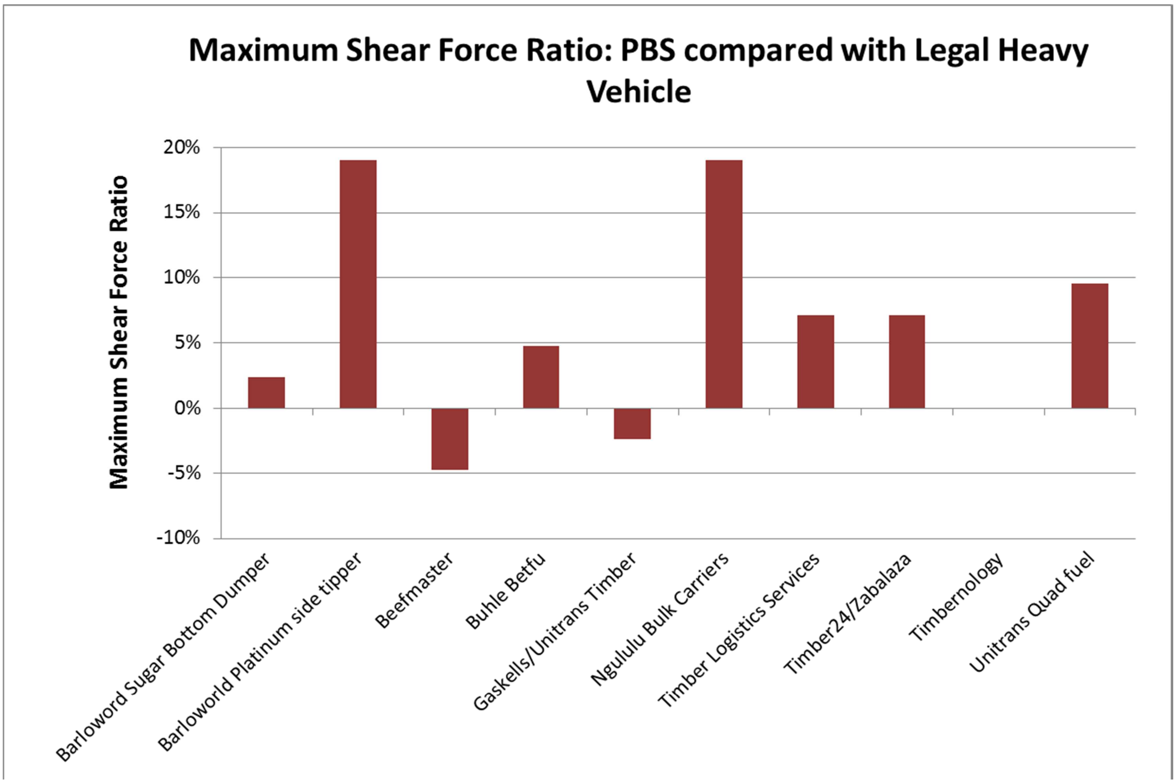

Figure 5: Maximum Shear Force Ratio: PBS compared with legal heavy vehicle

Given that many heavy vehicles operate in an overloaded state, either on routes with weighbridges after operational hours or on routes where no weighbridges for law enforcement exist, a comparison was also done between the PBS vehicles and the worst case legal vehicle overloaded by 5% and 10% respectively. The mass overload was evenly distributed over all axles. The results are illustrated in Table 4. The maximum bending moment and shear force comparisons between the PBS vehicles and a 10% overloaded legal vehicle are provided in Figure 6 and 7. It should also be noted that legal vehicles are permitted a 2% tolerance above the permissible maximum combination mass before prosecution is instituted. For PBS vehicles there is no provision for a tolerance. This means that the operator has to build the required mass tolerance into the PBS application i.e. the tolerance is included in the permissible maximum mass as specified on the exemption permit. It should further be noted that prior to June 2006 the tolerance on total combination mass was 5% (Nordengen *et al*., 2016), and in previous years a tolerance of 10% was permitted in certain provinces before prosecution for overloading was instituted.

In the case of the overloaded vehicles (5 and 10%), the maximum bending moment and shear force ratios obviously decrease when compared with the PBS vehicles. The maximum bending moment of the "worst" PBS vehicle is 6.6% and 3.8% more than the 5% and 10% overloaded legal vehicles respectively. In the case of maximum shear force, these maximum increases are 13.6% and 8.7%.

Table 4: Bending moment and shear force ratios: PBS compared with Worst Case (legal) baseline vehicle with overloads of 5% and 10%

Operator/Description	5% Overload		10% Overload	
	Bending Moment Ratio (PBS vs Legal vehicle)	Shear Force Ratio (PBS vs Legal vehicle)	Bending Moment Ratio (PBS vs Legal vehicle)	Shear Force Ratio (PBS vs Legal vehicle)
Barloword Sugar Bottom Dumper	0.0%	-2.3%	-2.6%	-6.5%
Barloworld Platinum side tipper	2.6%	13.6%	0.0%	8.7%
Beefmaster	2.6%	-9.1%	0.0%	-13.0%
Buhle Betfu	1.3%	0.0%	-1.3%	-4.3%
Gaskells/Unitrans Timber	2.6%	-6.8%	0.0%	-10.9%
Ngululu Bulk Carriers	6.6%	13.6%	3.8%	8.7%
Timber Logistics Services	1.3%	2.3%	-1.3%	-2.2%
Timber24/Zabalaza	1.3%	2.3%	-1.3%	-2.2%
Timbernology	1.3%	-4.5%	-1.3%	-8.7%
Unitrans Quad fuel	-2.6%	4.5%	-5.1%	0.0%

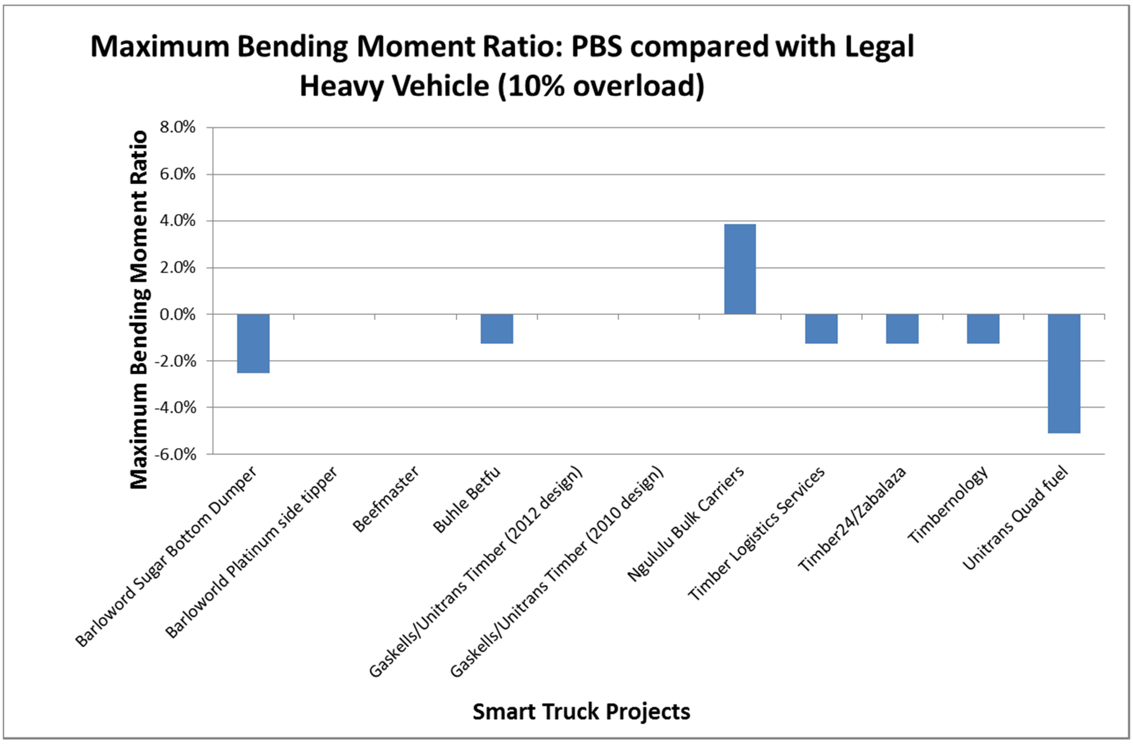

Figure 6: Maximum Bending Moment Ratio: PBS compared with legal heavy vehicle (10% overload)

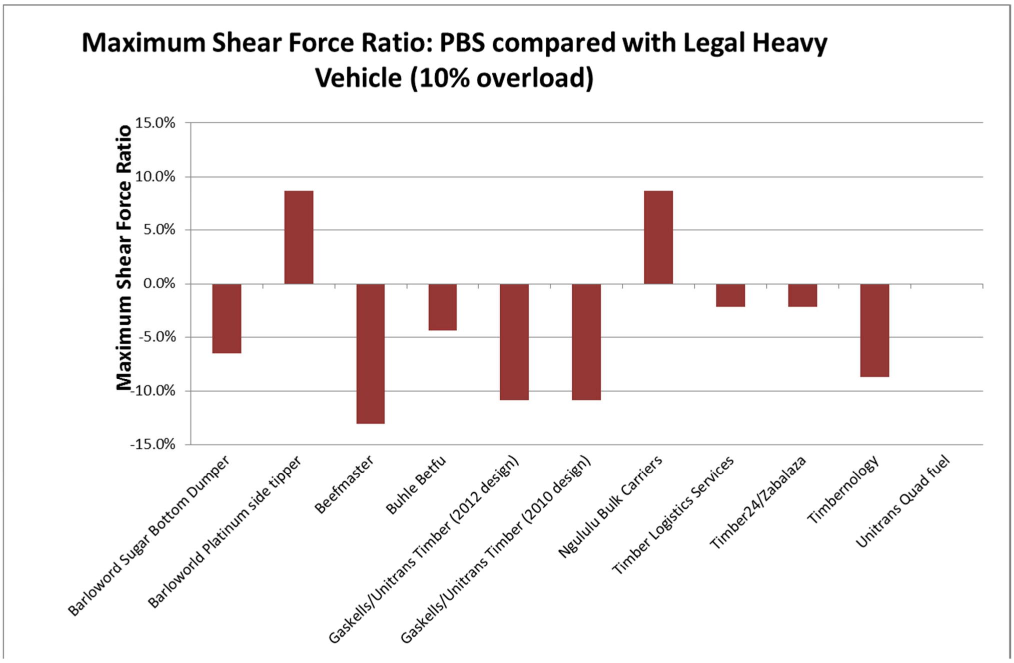

Figure 7: **Maximum Bending Moment Ratio: PBS compared with legal heavy vehicle (10% overload)**

Tables 2 to 4 and Figures 2 to 7 only show the maximum bending moments and shear forces for the worst case legal vehicle and various PBS vehicles. Figure 8 shows the variation of the maximum negative bending moment (as a percentage of the reference load) for the range of two-span continuous bridge spans evaluated. It can be seen that for very short spans as well as for longer spans, the PBS vehicles generate similar maximum negative moments as the worst case legal vehicles (with a 10% overload). In this case (two-span continuous structures), the most significant variation between the legal and PBS vehicles occur for overall structure lengths of between 20 and 40 m (10 to 20 m per span).

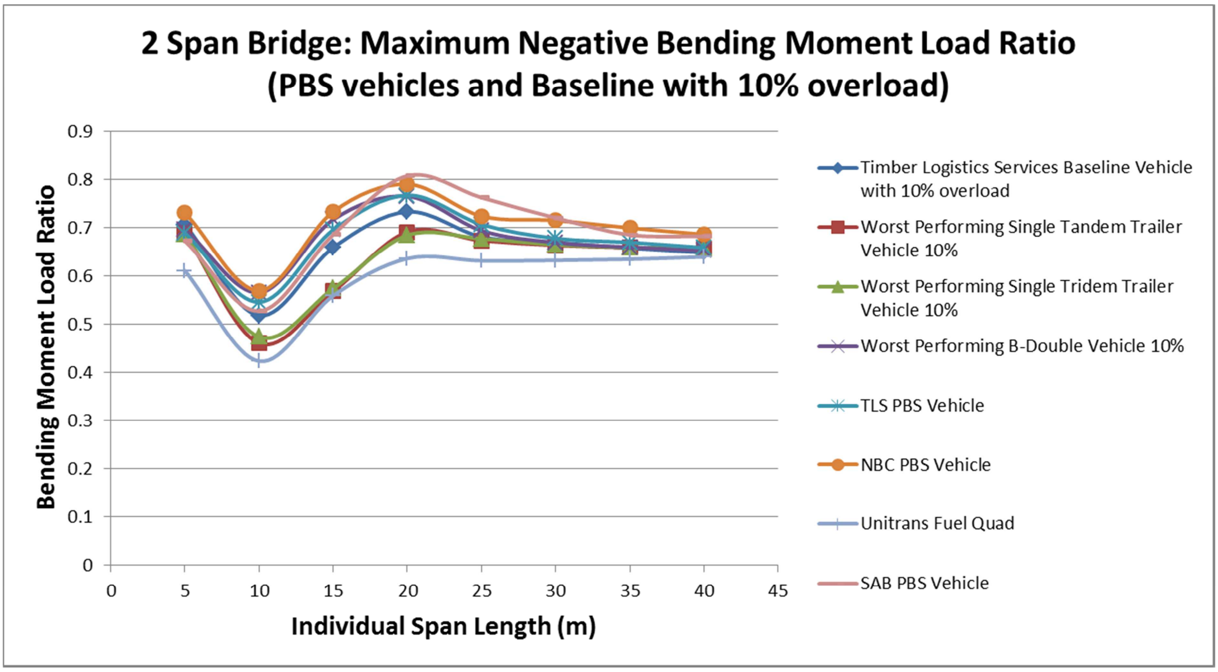

Figure 8: **Maximum Negative Bending Moment Ratios for a two-span structure: PBS compared with various legal heavy vehicles (10% overload)**

4 CONCLUSIONS

A methodology for assessing the impact of PBS vehicles participating in the PBS pilot project in South Africa on road structures has been developed. The methodology involves comparing maximum bending moments and shear forces generated by a PBS vehicle with those generated by a reference bridge design load. In addition, PBS vehicles are also checked against the South African Abnormal Load Bridge Formula with a required minimum factor of safety of 35%. The research also compared the maximum effects of the PBS vehicles with various legal vehicles as well as legal vehicles overloaded by 5 and 10%. Should the PBS approach for heavy vehicles be accepted by the road authorities in South Africa, the methodology being used in the pilot project will need to be refined and finally approved by the Department of Transport's structures sub-committee.

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