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Field test for the comparison of LNG static and dynamic mass measurement methods

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Content

1. Introduction

This paper summarizes the results of a series of measuring comparisons for LNG static and dynamic mass measurements performed onsite. The comparison consists of observing the difference in indicated and measured LNG mass from several measurement systems. Measurement systems belong in one of the two categories:

1) Static mass measuring system by the use of a scale (truck weighbridge) and
2) Dynamic mass measuring system (coriolis mass flow (CMF) meter).

A LNG road tanker is utilized to transfer the mass of LNG between the two categories of measurement systems. The dynamic measurement from simultaneously unloading of a road tanker semi-trailer filled with LNG through a coriolis flow meter is compared to the measuring results of a static non-automatic weighbridge used before and after the unloading of the road tanker. The differences in measured mass are noted. A specification of the test procedure and a description of the different measuring instruments involved are given in chapter 2, *test specification*.

A total of 5 reproduced tests were conducted, one on each of the days 5/9, 10/9, 18/9, 8/10 and 15/10 in the year 2012 and the results are given in chapter 4. In one of the tests (10/9) some additional observations related to repeatability of the weighbridge and the stability of the flow during unloading was obtained. A summary of these observations are given in appendix A.1.

There are different and to some degree incomplete traceability chains for the measuring instruments that have been tested. The weighbridge utilized for testing was calibrated by Justervesenet and is traceable to national weight standards. The result from the weighbridge calibration is given in appendix A.3.

The results of the reproduced testing will indicate the degree of agreement between the CMF meter under test and the weighbridge. More important, the testing that was performed also demonstrates and provides experience with the measurement capability for meter comparison and a method for validation in field.

2. Test specification

Access to facilities for testing was obtained in cooperation with the Norwegian gas company Gasnor. Gasnor manages in addition to LNG production also distribution of LNG by use of ship tankers as well as road tankers.

The Gasnor LNG production facility where the road tanker semi-trailer is filled with LNG is located at Kollsnes, close to Bergen on the west coast of Norway. The receiving terminal where the LNG is transferred from the road tanker to a stationary storage tank is located at Haukås approximately 70 km by road east of the production facility location. Access to a weighbridge was obtained at the premises of the company Stena Recycling located on the route between the LNG production facility and the LNG receiving terminal.

For the testing procedure the road tanker is first filled at the production location for LNG at Kollsnes and then the complete mass of road tanker semi-trailer and LNG is measured using the weighbridge at Stena Recycling. After the weighing the driver takes the road tanker to Haukås and the LNG bulk cargo is transferred to the storage tank at the LNG terminal. In the transfer line between the road tanker and the terminal storage tank there is a coriolis mass flow meter. The rate of flow of LNG is approximately constant throughout the transfer. When the LNG transfer is complete the driver takes the road tanker to Laksevågneset and the mass of the now empty road tanker semi-trailer is measured using the same weighbridge at Stena Recycling. The mass difference from the weighing which equals the LNG transferred at the terminal is compared to the mass measurement result from the coriolis mass flow meter. A step by step description of the test procedure is given in the next section. The next few sections also gives more details and characteristics on the different elements employed in the testing.

2.1 Test procedure (measurement related)

1. Mass of road tanker semi-trailer with LNG is measured using weighbridge at Stena Recycling [$M_{full,WB}$]
2. LNG transferred from road tanker to storage tank is measured using the coriolis meter installed at the Haukås terminal [M_{CMF}]
3. Mass of empty road tanker semi-trailer is measured using weighbridge at Stena Recycling [$M_{empty,WB}$]

2.2 Road Tanker

A road tanker tractor of make Scania was utilized to transport the LNG between the production facility, the weighbridge and the receiving terminal. The particular road tanker semi-trailer has a capacity of approximately 45 m^3 (or 22 ton) of LNG. The tractor itself has a weight of 10 ton while the net weight of the semi-trailer is 17 ton.

All measurements were performed using the same road tanker operated by the same driver. The driver was made familiar with the test procedure before the testing commenced and he was also trained for the measurements and the use of the elements involved with the measurements.

The mass of the tractor will change during transport due to consumption of fuel, oil, etc. To eliminate this type of error in the measurements the tractor was disconnected from the semi-trailer during weighing on the weighbridge. An alternative method would be to estimate the amount of mass consumed during transport or to top off fluid at every weighing but the tractor being the front of the vehicle is also more exposed to road debris so this method was preferred. To analyse the effect of road debris on the road tanker a “dummy” test was performed where the weighing took place as for a normal test and the road tanker was driven the regular route as for the testing but no transfer of LNG cargo took place at the LNG terminal. A description of this “dummy” test and its result can be found in appendix A.2.

Also for the measurement of the road tanker LNG mass it is important to note that the semi-trailer cargo tank represents a closed system. Between the full and empty weighing at the Stena Recycling weighbridge there is no flaring or escape of gas from cargo weight. This is possible due to the prominent isolated tanks on this type of vehicle. The pressure buildup under normal circumstances is less than 0.3 bar per 24-hour period and the excess pressure buildup is released during transfer at the receiving terminal.

Figure 1: LNG road tanker (tractor plus semi-trailer) on weighbridge at Stena Recycling, Laksevågneset.

2.3 Weighbridge

The weighbridge at Stena Recycling is located approximately 21 kilometers away from the Haukås LNG terminal. The location and the weighbridge load plate has good shield against wind so that unstable weighing conditions are avoided as far as possible. A scale indicator with an optional resolution of 2 kg of type Flintab 47-10 was connected to the weighing cells of the weighbridge. The load plate consists of two separate 2 x 9 meter cast sections resting on a total of 6 weighing cells. To establish traceability for the weighbridge it was calibrated both before and after the 5 series of tests with weights traceable to national weight standards. Result from the calibration is given in appendix A.3.

For the weighing procedure the road tanker initially drives onto the weighbridge. Then the road tanker semi-trailer is disconnected from the tractor and the tractor is driven off the weighbridge leaving only the disconnected semi-trailer to be weighed. The hysteresis effects of the weighbridge have to be considered in the calculation of the weighting result.

Figure 2: Weighbridge at Stena Recycling. The weighbridge and its load plate has good shield against moderate wind.

2.4 LNG terminal (LCNG refuelling station)

The LNG terminal located at Haukås is a LCNG (liquefied-compressed natural gas) refuelling station for city buses in the Bergen area. Approximate capacity of stationary vertical LNG storage tank located at the terminal is 80 m^3. At the terminal, on the LNG inlet side of the storage tank, there is a stationary mounted coriolis meter of make Emerson Micro Motion that may be used for billing purposes.

Figure 3: LCNG terminal at Haukås. Transfer of LNG from road tanker to storage tank.

3. Measuring instrument specifications and traceability

Weighbridge:

Indicator	Flintab 47-10
Weighing cells	6x Landgraff & Flintab N.A.
Capacity	60 ton
Resolution	20 kg (2 kg option)
Load plate	2x9 meter cast sections

Traceability:
Weighbridge was calibrated by Justervesenet before testing commenced on the 30th of May 2012 and again after the testing was ended on the 27th of November. (See also appendix A.3). All indications of weight are either in the range 39.5 to 40.1 ton (full semi-trailer, $M_{full,WB}$) or in the range 17.3 to 20.0 ton (empty semi-trailer, $M_{empty,WB}$). The actual weighbridge corrections ($c_{\Delta WB}$) for the 5 measurements of mass difference weighing ($M_{\Delta WB} = M_{full,WB} - M_{empty,WB}$) are listed below:

Weighbridge corrections (actual):

Indicator mass difference reading ($M_{full,WB} - M_{empty,WB} = M_{\Delta WB}$)	Correction ($c_{\Delta WB}$)
20 050 kg (5/9)	+2 kg
22 561 kg (10/9)	+3 kg
22 202 kg (18/9)	+3 kg
22 384 kg (8/10)	+3 kg
22 168 kg (15/10)	+3 kg

Coriolis Mass Flow Meter:

Sensor	2 inch Emerson Micro Motion Elite
Transmitter	Micro Motion model 1700

Traceability:
No information available for cryogenic application.

4. Results

Using the weighbridge as the reference, the result of the comparison of the mass metering systems can be summarized as shown in table 1 and figure 5 below."M_{CMF}" is the mass measurement results from dynamic measuring of LNG by coriolis meter and the "$M_{c,\Delta WB}$" is the corrected static mass measurement difference (full semi-trailer minus empty semi-trailer) from weighbridge readings.

The percent error of mass, E_{CMF}, is calculated according to the formula:

$$E_{CMF} = \frac{M_{CMF} - M_{c,\Delta WB}}{M_{c,\Delta WB}} \; x \; 100\%$$

Table 1: Relative mass measurement differences from comparison results

Date:	**20120905**	**20120910**	**20120918**	**20121008**	**20121015**	**Average**	**MAD**
E_{CMF}	-0,12 %	-0,08 %	-0,19 %	-0,03 %	-0,13 %	-0,11 %	0,05 %

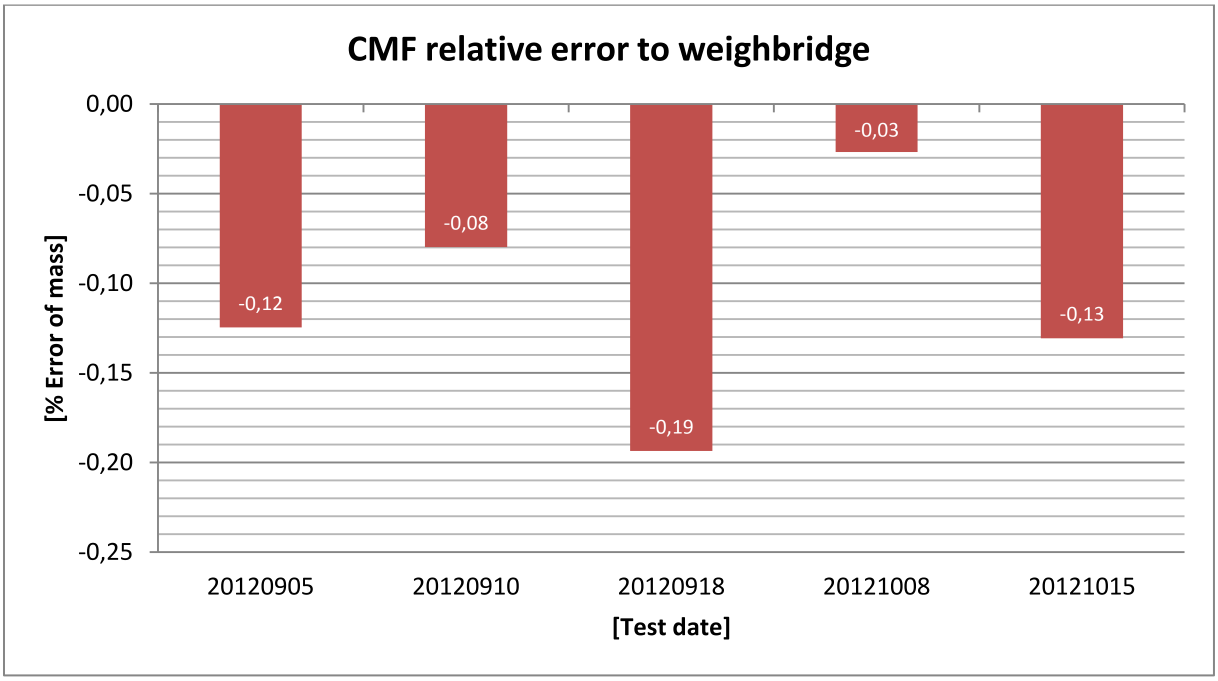

Figure 5: CMF relative error compared to weighbridge

As can be seen from table 1 and figure 5 above the results shows good agreement between the weighbridge and the Emerson Micro Motion coriolis mass flow meter as the error is relatively small. The mean error of measured relative mass difference is -0.11% with a mean absolute deviation (MAD) of 0.05%.

Measurement uncertainty
This report has no calculation of measurement uncertainty. The possibility to make validations have been limited but still the list below should indicate possible significant influences for the readings of transferred mass.

Comparison CMF meter vs. weighing result

- Uncertainty in calibration value of weighbridge (significant)
- Stability of weighbridge (significant)
- Loading effect and hysteresis of weighbridge (significant)
- Change in mass of the road tanker related to water (rain), dust and road debris (may be significant)
- Startup conditions (may be significant)
- Different operating conditions regarding temperature and pressure (minor)
- Flow profile (minor)
- Mechanical installation effects (minor)

5. Conclusion

The results of the comparisons indicate good consistency of data between the dynamic metering method of the coriolis mass flow meter (-0.11% error, 0.05% MAD) with the static metering method of weighing.

The low spread and relatively small value of MAD (0.05%) indicates that the influences from random errors are low. This shows that the method of using road tanker on weighbridge as reference for LNG mass can be performed by careful measurements and that the method gives good results in field.

6. Acknowledgements

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7. References

[1] EMRP 2009, Joint Research Project Protocol, Annex Ia
www.lngmetrology.info

A.1. Detailed observations from testing 10/9

In one of the tests (10/9) some additional observations related to repeatability of the weighbridge and the stability of the flow when unloading was done.

General

The test included three different major phases:

- **Phase no. 1:** Filled road tanker semi-trailer (tractor disconnected and excluded) was weighed at a non-automatic weighbridge at Stena Recycling.

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Figure 6: Weighing of road tanker semi-trailer at Stena Recycling

- **Phase no. 2:** The road tanker semi-trailer delivered LNG at Haukås bus terminal into a vertical storage tank.

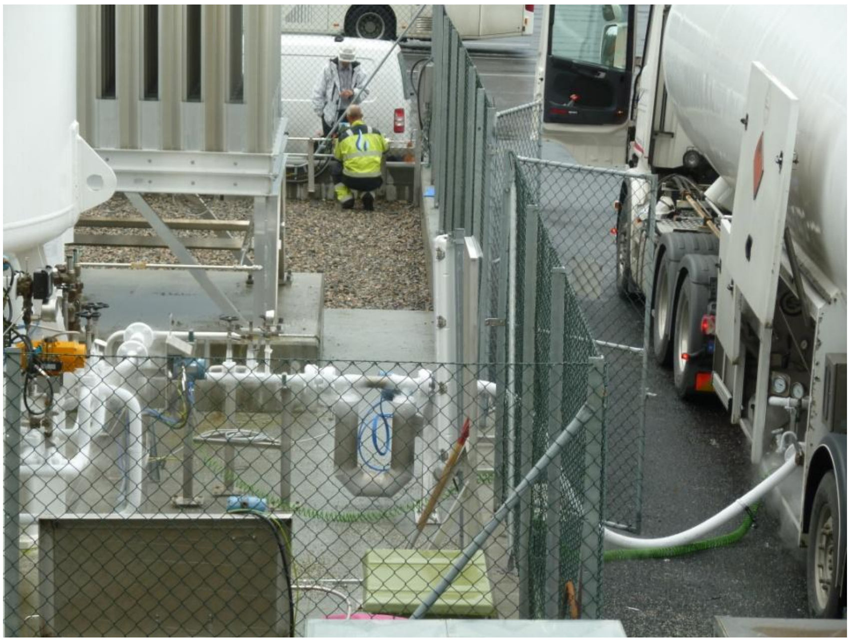

Figure 7: LNG transfer from road tanker to stationary tank at LNG terminal

- **Phase no. 3:** Empty semi-trailer (excluded the tractor) was again weighed at the non-automatic weighbridge at Stena Recycling.

Additional activity:
Prior to phase no. 1 the non-automatic weighbridge was calibrated. The calibration is documented in chapter 3 and A.3 in this report. During phase 1 three additional readings of the total mass of the road tanker was made.

Below follows detailed description and observations from the different phases:

Phase no. 1: First weighing
The road tanker was placed on the non-automatic weighbridge and the tractor was removed from the load plate and the weighbridge.

Between each of the three readings the tractor drove on and then off the load plate to obtain a significant change in the load of the weighbridge.

The following observations were made:

Weighing of just the road tanker semi-trailer (d=2 kg)	
Weighing no.	Indication
Observation 1	39 958 kg
Observation 2	39 954 kg
Observation 3	39 952 kg
Mean of observation	39 954.7 kg
Std. Dev.	3.1 kg
Std. dev. of mean	1.8 kg
Weighing of complete vehicle including tractor and semi-trailer (without driver)	
Total mass of vehicle	50 060 kg
Estimated mass of tractor	10 105.3 kg

Some remarks:

- During this phase there were no rainfall and the surface of the vehicle was free from droplets.
- The platform was relatively clean and free from significant objects.

Phase no. 2: Flow metering
At the LNG terminal there is a coriolis mass flow meter available:

- **CMF**: As part of the fixed installation of the storage tank, there is a 2 inch mass flow meter of type Micro Motion CMF200 which may be used for billing purpose.

The meter is read at the start and end of the filling.

Readings of meter (uncorrected)

	Start	End	Difference (End- Start)
CMF	1 490 736	1 513 282	22 546

During the filling of the tank, several parameters were observed and noted:

Filling (approx.) [ton]	CMF				Pressure		
	Mass flow [kg/h]	Volume flow [m^3/h]	Density σ [kg/m3]	T [°C]	Semi-trailer [bar]	In front of CMF [bar]	Top of tank [bar]
2	15 550	35.2	439.7	-148.7	8.2		4.37
7.9	15 840	35.6	440.1	-149.1	7.6		3.5
13	15 404	34.8	440.2	-149.1	7.8		3.3
17.5	15 140	34.2	440.3	-148.9	7.8	6.6	3.3
21.5	15 220	34.5	439.9	-147.9	7.6	6.6	3.3
Average	15 431	34.9	440.0	-148.7	7.8	6.6	3.4

The observations were made sequentially, so they cannot be compared directly. The data shows the typical conditions during the filling. The readings at each degree of filling were done within approx. 40 sec.

Each minute there was a reading of the flow rate of the CMF. The average flow rate (86 readings) was 251 kg/min, standard deviation was 6.7 kg/min, minimum flow rate 239 kg/min and maximum flow rate 263 kg/min (one initial reading and three readings at the end are removed). This indicates a stable flow rate. The observations in the table were not done simultaneously.

Phase 3: Last weighing
The semi-trailer was again placed on the non-automatic weight and the tractor was removed from the load plate of the weighbridge.

Again there were made 3 observations, and between each of the three readings the tractor again drove on and off the load plate to obtain a significant change in the load of the weighbridge.

The following observations were made:

Weighing of just the tank semi-trailer (d=2 kg)	
Weighing no.	Indication
Observation 1	17 394 kg
Observation 2	17 396 kg
Observation 3	17 392 kg
Average of observations	17 394.0 kg
Std. Dev.	2.0 kg
Std. Dev. Of Mean	1.2 kg
Weighing of complete vehicle included tractor and semi-trailer (without driver)	
Total mass of vehicle	27 490 kg
Estimated mass of tractor	10 096.0 kg
Estimated change in mass of tractor	9.3 kg

Some remarks:

- During this phase there were no rainfall and the surface of the vehicle was free from droplets.
- The platform was relatively clean and free from significant objects.

Summary of observations

The table below shows all the readings uncorrected from errors:

	Start	End	Difference uncorrected
CMF	1 490 736	1 513 282	22 546
Mass tanker	39 954,7	17 394,0	22 560,7
Mass total	50 060	27 490	
Mass tractor	10 105,3	10 096,0	9,3

The weight readings from the 3 repetitions both in filled and empty condition have relatively small values for the repeatability.

General comments on different Influences

Stability of flow:

The flow rate was quite stable around 250 kg/min during the transfer. Both readings of the volume flow rate, the density and temperature indicated stable conditions during the filling.

Weather conditions:

The temperature was approximately 15 °C, moderate wind conditions and showers. During the weighing, the vehicle was almost dry and free from visible water on the surface.

The time schedule:

Weighing of filled tanker:	11:30 to 12:00
Delivery of LNG at bus terminal:	12:30 to 14:40
Weighing of empty tanker:	15:20 to 15:40

A.2. Road debris and road tanker semi-trailer weight (Dummy test)

To investigate the likely but unwanted influence of road debris on road tanker semi-trailer weight during transport the following additional test was performed:

1. Weighing of road tanker semi-trailer using weighbridge as described earlier in this report.
2. Road tanker is driven to Haukås LNG terminal but no mass transfer is performed, then back again to weighbridge location at Stena Recycling.
3. Weighing of road tanker semi-trailer as in 1.

Since there is no transfer of LNG mass from the road tanker during this additional test any change of mass of the semi-trailer as observed from the weighbridge readings has to be due to road debris during transport or instability of the weighbridge. As described in appendix A1 were three repeated observations of semi-trailer weight readings were performed the repeatability of the weighbridge is relatively good with a standard deviation at about 2 kg so we expect that any significant mass difference is related to road debris during transport.

Results:

Weighbridge reading before transport to LNG terminal at Haukås:	17 466 kg
Weighbridge reading after driving to terminal and back to Stena Recycling:	17 460 kg

There is an observed 6 kg difference in LNG semi-trailer weight from weighbridge readings. The difference is in the upper range of the weighbridge repeatability so it is expected that part of the difference is related to road debris. More measurement data on this effect is needed in order to estimate the size of this contribution and its uncertainty. A 6 kg difference is equal to 0.03% in the relative error of CMF related to weighbridge.

A.3. Weighbridge calibration

The weighbridge used for the testing described in this report was calibrated both before and after the 5 reproduced tests. The calibration was performed by Justervesenet on the 30th of May and the 27th of November 2012. Result from the calibrations is given in figure 8 and table 2 below.

During the tests with the road tanker there were a total of 10 readings of the weighbridge, the full and the empty semi-trailer for the 5 reproduced tests. All of the readings are in the "unload" category as the tractor is driven of the weighbridge after it is disconnected from the semi-trailer. Table 2 below shows the 10 readings and the absolute corrections as seen from the result of calibration for the unloading data from 30/5 and 27/11 in figure 8.

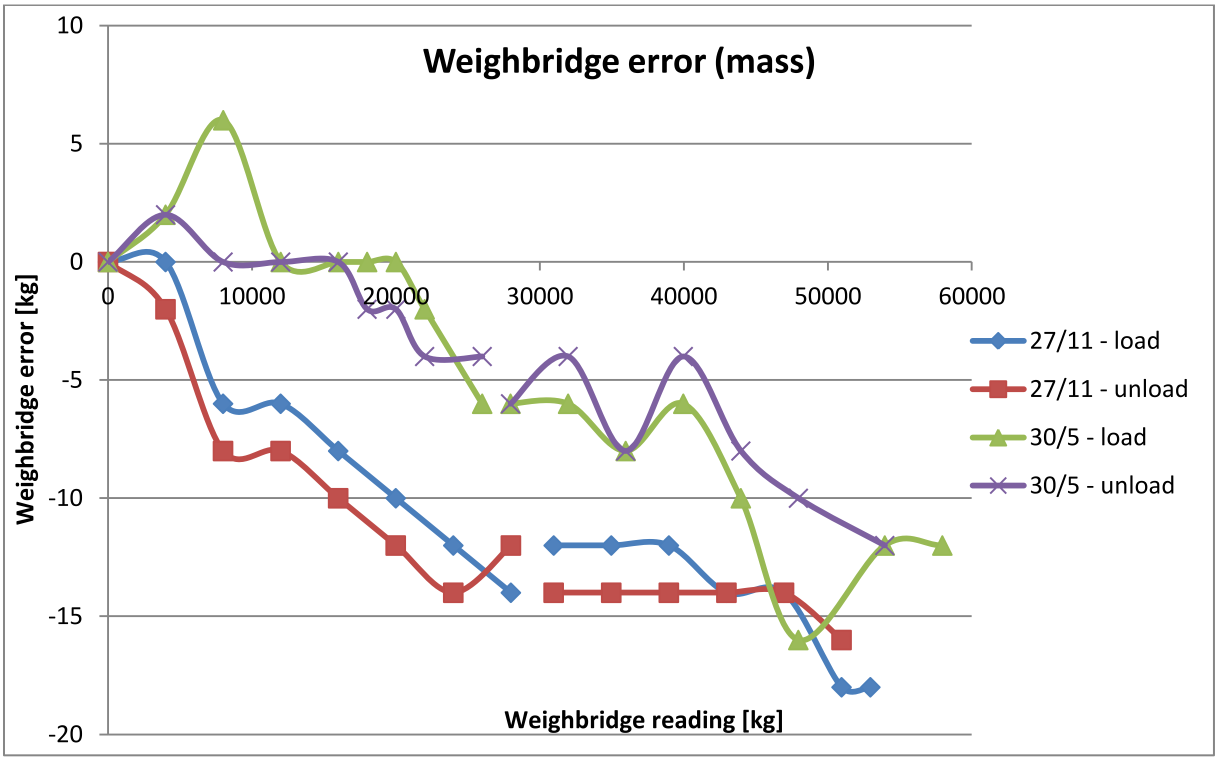

Figure 8: The weighbridge error calculated as weighbridge reading minus mass of reference weights.

Table 2: Weighbridge error for the 10 readings of weighbridge indications. Absolute errors of single weighing and mass difference error for full minus empty weighing.

Date and type of weighing	**Weighbridge reading**	**Absolute error [kg]**		**Mass difference error [kg]**	
		30/5	27/11	30/5	27/11
5/9 full	40088	-4	-14	-2	-2
5/9 empty	20038	-2	-12		
10/9 full	39955	-4	-14	-3	-3
10/9 empty	17394	-1	-11		
18/9 full	39594	-4	-14	-3	-3
18/9 empty	17392	-1	-11		
8/10 full	39868	-4	-14	-3	-3
8/10 empty	17484	-1	-11		
15/10 full	39606	-4	-14	-3	-3
15/10 empty	17438	-1	-11		

As can be seen from table 2 the error in the semi-trailer mass difference measurement is for this data independent of the calibration date. This can also be seen from figure 8 as the calibration curves from 30/5 and 27/11 have the same shape in the 17 000 to 40 000 kg range. The weighbridge error as the distance between the curves is close to constant at 10 kg in this range.

The discontinuity of the calibration curves just below 30 000 kg is due to the use of tare weight used during the calibration. There is a good overlap in the transition area so this is of minimal concern for the calibration result.