Dynamic Tests

Investigations to establish design accelerations for static design of cargo securing arrangements for intermodal rail transports

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Contents

Introduction

The basic design accelerations for road and intermodal rail transports are currently not the same, which is an unfavourable situation for intermodal traffic. The question has therefore been raised whether cargo securing arrangements designed according to the road principles also can withstand the accelerations that may occur during an intermodal rail transport.

The following horizontal static acceleration values expressed in parts of the gravity acceleration g = 9.81 m/s^2 is valid for the design of securing arrangements for road transport:

- Forward in the driving direction of the vehicle: 0.8 g
- Backwards: 0.5 g
- Sideways: 0.5 g

For design purposes these acceleration values are combined with the gravity acceleration 1 g acting downward. It is assumed that the horizontal accelerations do not act simultaneously in the different directions.

To establish if these accelerations are sufficient also for the design of securing arrangements for combined rail transports, it was decided jointly by UIC, UIRR and MariTerm AB on a meeting at UIC in Paris 2014-02-27, that dynamic test transports between selected terminals in Europe should carried out jointly as part of the European project Destiny.

Test setup

Test transports were performed by identical cargo items secured to withstand different acceleration levels. The cargo items were stowed and secured in a trailer and a swap body respectively. The cargo transport units were sent between different terminals in Europe to cover different rail nets, wagon types and handling equipment.

The trailer was supplied by DHL and the swap body was supplied by DFDS. Hupac and Kombiverkehr arranged the transports of the loading units and access to the terminals.

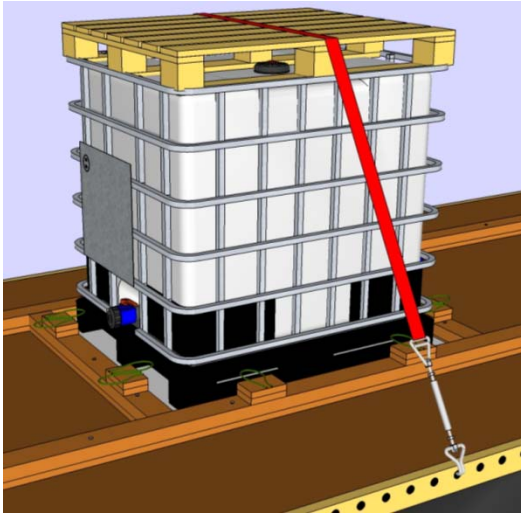
It was important that the friction factor between the cargo items and the platform was constant for the cargo items and to the lowest extent possible sensitive for different moisture levels. To fulfil these requirements goods on plastic pallets standing on laminate sheets with and without friction rubber in-between were used. The different cargo items were secured with different numbers of top-over lashings set to established pre-tensions to withstand a selection of different acceleration values.

To get identical weight of all cargo items, IBCs of 1 m^2 filled with water were used. However, for reference one of the IBCs was instead filled with concrete. The weight of each cargo item was about 1000 kg. The dimensions of the IBCs were L × B × H = 1200 × 1000 × 1170 mm.

On all sides of the 16 mm laminate sheets used under the IBCs, timber, 25 × 100 mm and 50 × 100 mm, was nailed to the floor to prevent the IBCs from moving without control on the platform. Each IBC had a freedom to move about 75 mm in any horizontal directions.

The actual friction factor between the plastic pallets and the laminate sheets with and without rubber were measured in accordance with standard EN 12195-1:2010 upon loading and was found to be μ = 0.23 without rubber and μ = 0.75 with rubber.

The width between the lashing points on the cargo transport units was about 2400 mm. With a laminate sheet of the size L × B × H = 1150 × 1350 × 16 mm placed underneath the IBCs and an empty pallet on top, the lashing angles (α) of the top-over lashings was about 60 degrees.



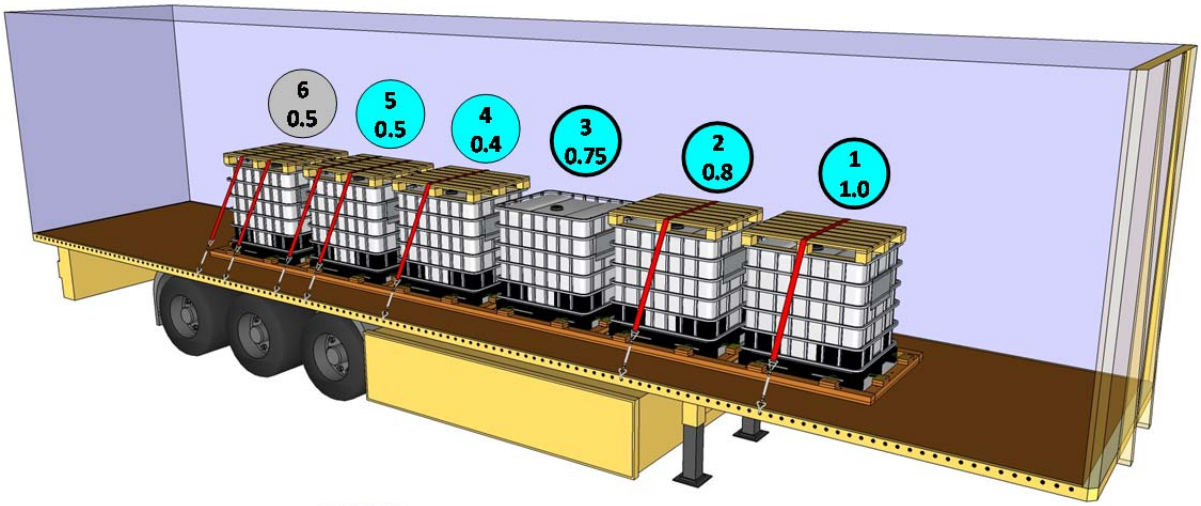
The following horizontal accelerations were obtained as function of the number of lashings, item weight and pre-tension with the lashing angle α = 60 degrees and the friction factors μ = 0.23 and 0.75 respectively:

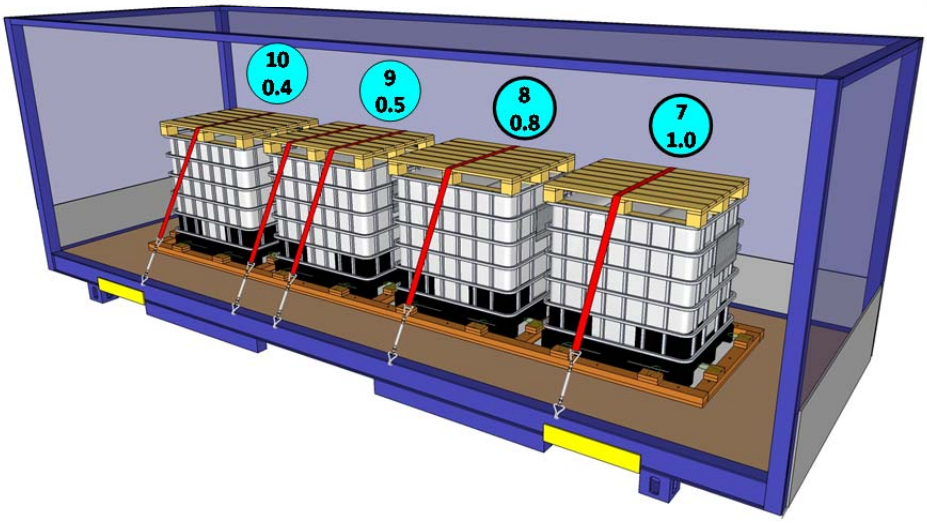
Trailer

IBC no	Lashings	Weight [kg]	Friction factor μ	Horizontal acceleration [g]	Lashing angle [°]	Pre-tension [kg]	Cargo	Rubber
1	1	1102	0,75	1,0	60	208	Water	yes
2	1	1105	0,75	0,8	60	39	Water	yes
3	0	1089	0,75	0,75			Water	yes
4	1	1100	0,23	0,4	60	481	Water	no
5	2	1111	0,23	0,5	60	383	Water	no
6	2	1039	0,23	0,5	60	359	Concrete	no

Swap Body

IBC no	Lashings	Weight [kg]	Friction factor μ	Horizontal acceleration [g]	Lashing angle [°]	Pre-tension [kg]	Cargo	Rubber
7	1	1099	0,75	1,0	60	207	Water	yes
8	1	1098	0,75	0,8	60	39	Water	yes
9	2	1107	0,23	0,5	60	380	Water	no
10	1	1098	0,23	0,4	60	477	Water	no

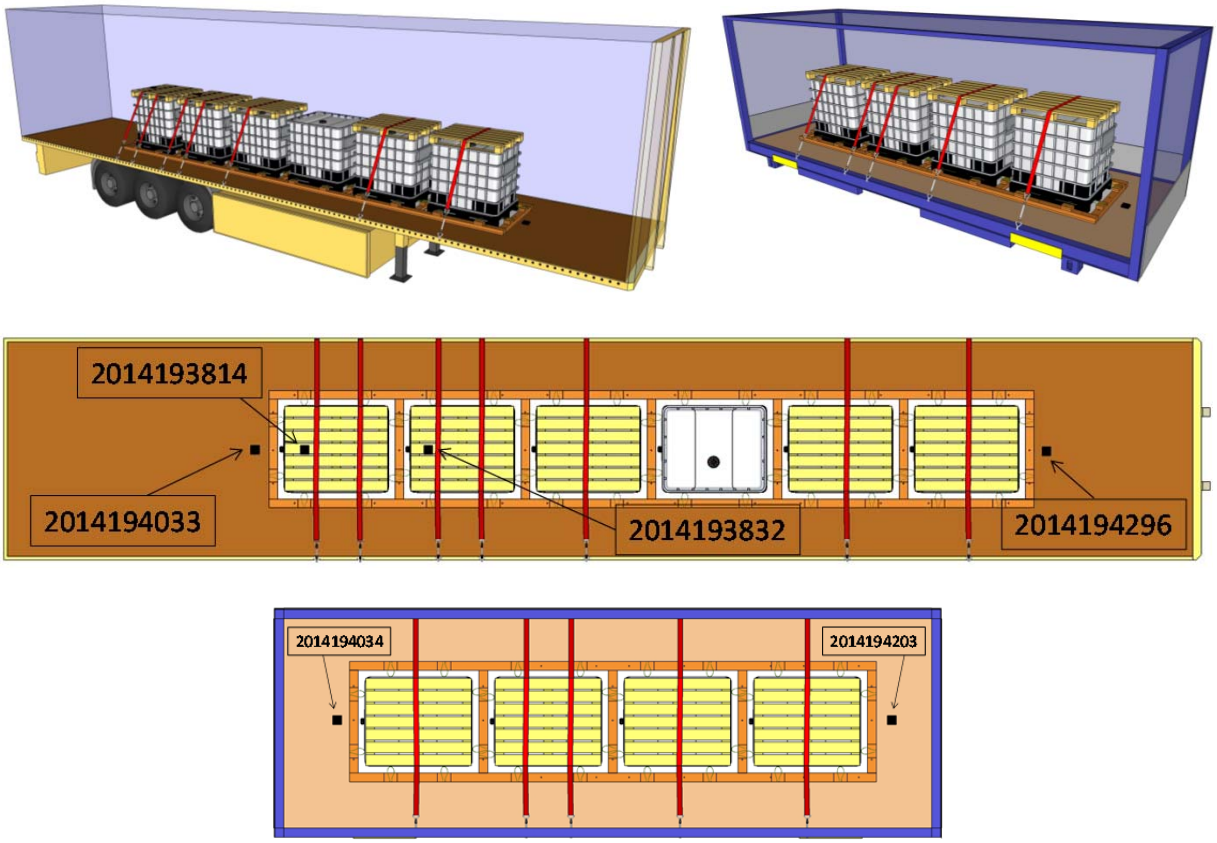




The actual pre-tension in the lashings was checked by a Delog instrument at each inspection. The pre-tension was adjusted by turnbuckles on both sides to the exact required value. Adjustments were done throughout the tests to maintain the correct pre-tension in each lashing.

Accelerometers

In order to record significant shocks that the units have been subjected to, accelerometers were fitted on the floor of the two units, one in front of the cargo and one behind it. Furthermore, accelerometers were fitted on top of the two IBCs in the trailer that had been secured against a horizontal acceleration of 0.5 g. One of these IBCs was filled with water and the other with concrete.



Position of accelerometers

Position and identification numbers for the six accelerometers

Device number	Load unit	Position
201419 - 4296	Trailer	Floor - front
201419 - 4033	Trailer	Floor - rear
201419 - 3832	Trailer	On IBC with water
201419 - 3814	Trailer	On IBC with concrete
201419 - 4203	Swap body	Floor - front
201419 - 4034	Swap body	Floor - rear

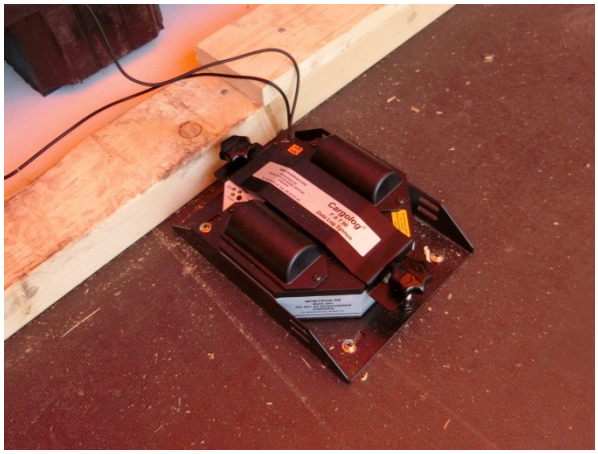
In each loading unit, one accelerometer was placed on the floor at the front end to record the average acceleration and duration of each significant shock throughout the voyage.

Additional accelerometers were placed on the floor at the back of each loading unit and on top of two IBCs (no. 5 and 6). These were used to record detailed acceleration graphs of

some shocks. The purpose of the two devices that were placed on top of the cargo was to compare the response of an IBC filled with water to that of the IBC filled with concrete.

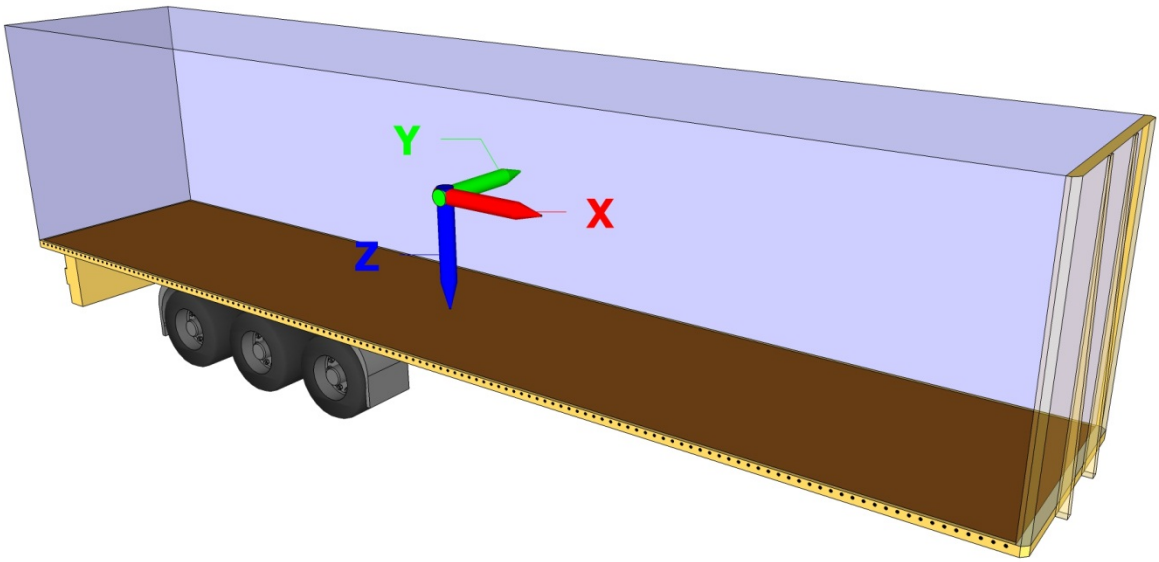
The accelerometers were set up to record shocks with peaks above 0.5 g only. Due to the memory capacity, the accelerometers that recorded continuously throughout the shocks were on some legs not capable to make recordings the whole journey.

In each loading unit, two accelerometers were also equipped with GPS receivers in order to record the position of the units.



Accelerometers:
Make: MOBITRON
Model: CARGOLOG FAT 90

The illustration below show the definition of the axis along which shocks were recorded.



Definition of axis for measurement of accelerations.

Route and Train details

Legend

Red line: *Trailer and common track*

Blue line: *Swap body*

Trailer - DHLE 150024-6

The route details for the trailer are found in the tables below.

Leg	From	To	Path	Wagon	Wagon type	Train	Pos. in train
1	Helsingborg Stockholm	Stockholm Malmö		31744955070-4 31744955070-4		04240 04415	
2	Malmoe Taulov	Taulov Verona	 Via Brennero	33854506359-0 33854506359-0	Pocket Pocket	38111 40545	10 21
3	Verona	Rotterdam	Via Brennero	33854506454-9	Pocket	40558	18
4	Rotterdam	Novara	Via Simplon	33854506746-8	Pocket	43663	23
5	Novara	Koeln	Via Simplon	33854506670-0	Pocket	43682	18
6	Koeln	Lübeck		31844955943		50095	

Leg	from	to	Departure	Arrival	Travel time in hours	Distance in km
1	Helsingborg Stockholm	Stockholm Malmö	2014-05-15 17:48 2014-05-16 17:00	2014-05-16 02:00 2014-05-17 01:00	8,20 8,00	1108
2	Malmö Taulov	Taulov Verona	2014-05-19 16:19 2014-05-20 22:25	2014-05-19 21:30 2014-05-22 01:38	5,18 27,22	1667
3	Verona	Rotterdam	2014-05-24 08:45	2014-05-25 14:01	29,27	1198
4	Rotterdam	Novara	2014-05-26 22:43	2014-05-28 05:40	30,95	1044
5	Novara	Koeln	2014-05-30 00:57	2014-05-30 16:55	15,97	723
6	Koeln	Lübeck	2014-06-04 22:25	2014-06-05 09:10	10,75	488
					136	**6229**

Swap body - NFL2588

The route details for the swap body are found in the tables below.

Leg	From	To	Path	Wagon	Wagon type	Train	Pos. in train
1	Helsingborg Stockholm	Stockholm Malmö		31744955070-4 31744955070-4		04240 04415	
2	Malmö Taulov	Taulov Verona	 Via Brennero	83854555574-3 83854555574-3	Container Container	38111 38111	12 23
3	Verona	Rotterdam	Via Brennero	83854933288-3	8 axes mixed	40558	6
4	Rotterdam	Busto	Via Gotthard	33854575272-1	Container	40201	6
5	Busto	Koeln	Via Gotthard	83854512009-2	Pocket	42018	1
6	Koeln	Lübeck		31804992141-0		50095	

Leg	From	To	Departure	Arrival	Travel time in hours	Distance in km
1	Helsingborg	Stockholm	2014-05-15 17:48	2014-05-16 02:00	8,20	1108
	Stockholm	Malmö	2014-05-16 17:00	2014-05-17 01:00	8,00	
2	Malmö	Taulov	2014-05-19 16:19	2014-05-19 21:30	5,18	1667
	Taulov	Verona	2014-05-20 22:25	2014-05-22 01:38	27,22	
3	Verona	Rotterdam	2014-05-24 08:45	2014-05-25 14:01	29,27	1198
4	Rotterdam	Busto	2014-05-27 01:35	2014-05-28 01:10	23,58	973
5	Busto	Koeln	2014-05-30 16:50	2014-05-31 07:08	14,30	726
6	Koeln	Lübeck	2014-06-04 22:25	2014-06-05 09:10	10,75	488
					126	**6161**

Participation and contributions

The tests have been made possible by the kind and much appreciated contribution and participation by UIRR, UIC, Hupac, Kombiverkehr, Green Cargo, DHL, DFDS, GDL, Mobitron, Forankra, Cordstrap and the Swedish Transport Administration.

The following persons have been attending the inspections of the dynamic test units:

Setup – Helsingborg 2014-05-15
Olle Berntstaf DHL
Sven-Olof Olsson Mobitron
Peter Andersson MariTerm AB
Sven Sökjer-Petersen MariTerm AB

Leg 1 – Malmö 2014-05-19
François Crelo CFL Cargo
Stanley Öberg Green Cargo
Nils Andersson MariTerm AB
Sven Sökjer-Petersen MariTerm AB

Leg 2 – Verona 2014-05-22
Marco Battilana Hupaq
Michele Trainotti Tranitalia
Federica Ceccato Cemat Spa
Sven Sökjer-Petersen MariTerm AB

Leg 3 – Rotterdam 2014-05-26
Sven Sökjer-Petersen MariTerm AB

Leg 4 – Busto/Novara 2014-05-29
Marco Battilana Hupaq
Onorato Zanini Hupac

Francesco Garrisi	Trenitalia
Quirico Pizzutoli	Tranitalia
Juraj Jagelcak	University of Žilina
Sven Sökjer-Petersen	MariTerm AB

Leg 5 – Cologne 2014-06-02

Eric Feyen	UIRR
Ullrich Lück	Kombiverkehr
Kristian Kölsche	Kombiverkehr
Sven Sökjer-Petersen	MariTerm AB

Leg 6 – Lübeck 2014-06-11

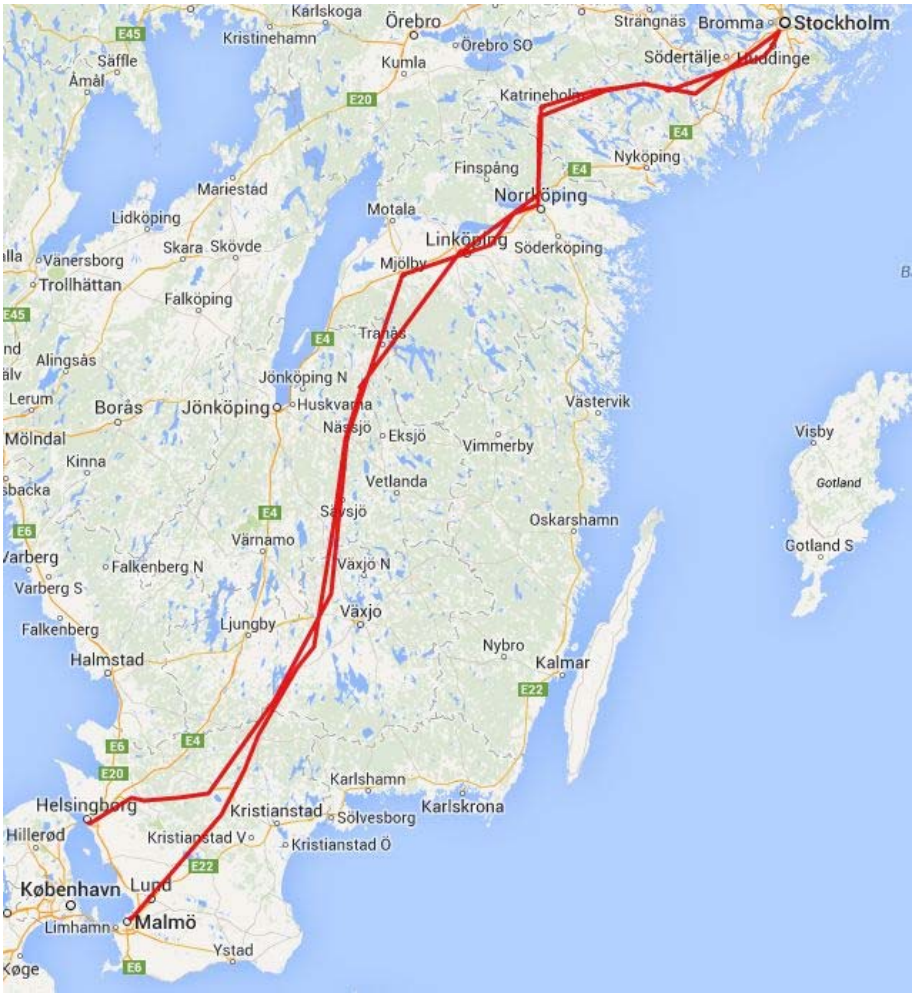
Eric Feyen	UIRR
Francois Crelo	CFL Cargo
Antje Falk	Baltic Rail Gate
Francesco Garrisi	Trenitalia
Jens Taron	DB Schenker
Roman Embacher	RCA
Urs Dannenhauer	SBB Cargo
Sven Sökjer-Petersen	MariTerm AB

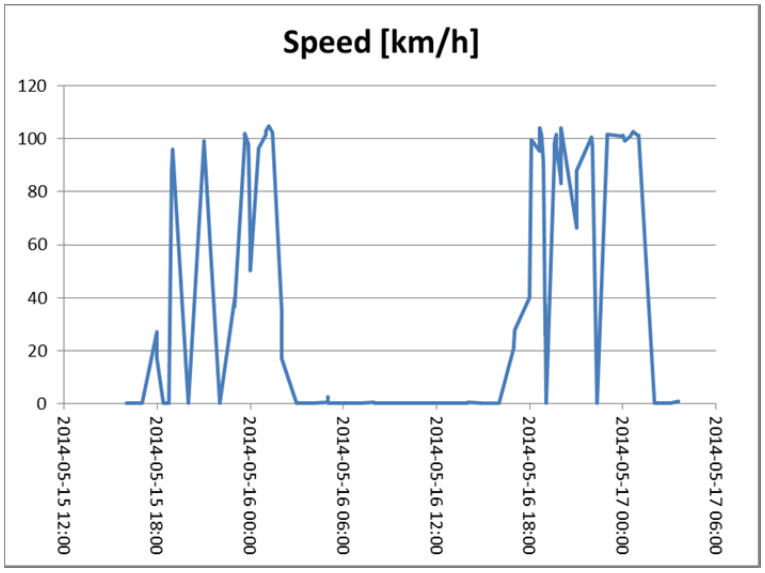
Dismantling – Malmö 2014-06-15

Olle Berntstaf	DHL
Peter Andersson	MariTerm AB
Sven Sökjer-Petersen	MariTerm AB

Leg 1: Helsingborg-Årsta-Malmö

During this leg, both loading units were transported on the same train.





Comments

- The units were transported in a regular freight train and were subjected to shunting in both Helsingborg and Malmö.
- The shocks recorded in Helsingborg peaked at 3.6 g in the swap body and 1.0 g in the trailer. These are levels typical for hump and fly shunting.
- All IBCs secured for accelerations up to 0.5 g had moved the full distance towards the bottom blocking frame, i.e. abt. 75 mm. They had however moved in one direction only, even though shocks in both directions have been recorded.
- All units secured for more than 0.5 g remained in their original position.

During Leg 1, the accelerometer on top of the concrete IBC was unfortunately malfunctioning.

Recorded shocks

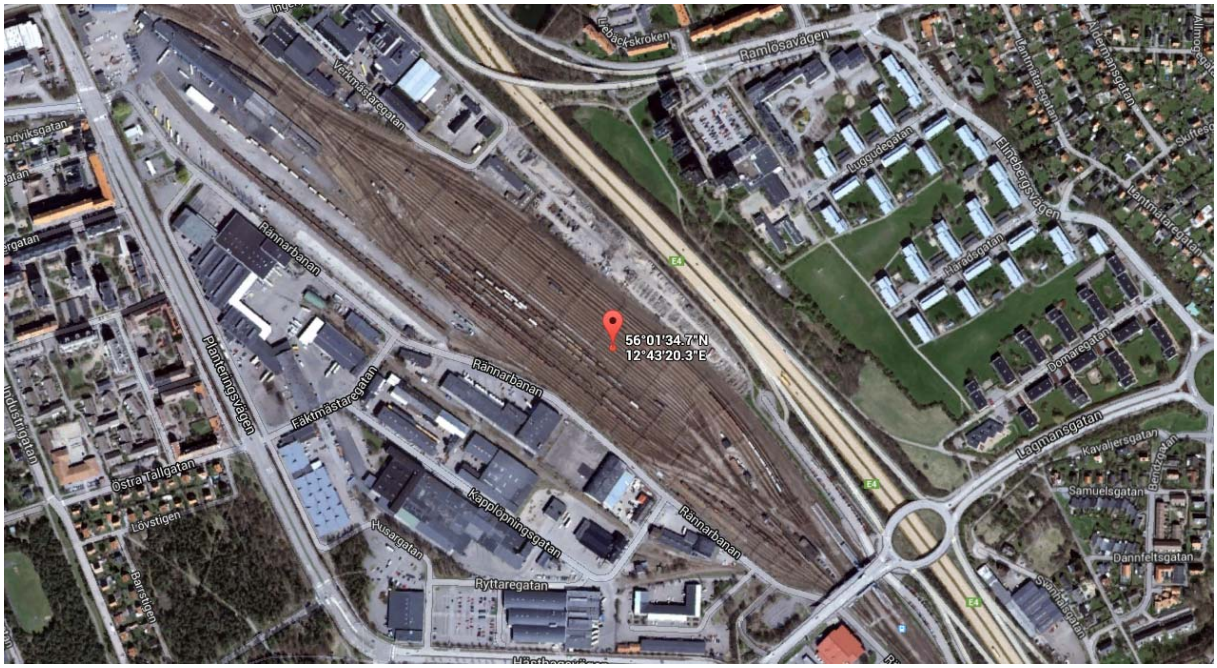
All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg are listed in the tables below. The magnitude of the shocks are given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4096	2014-05-15 16:54	0,81	125	0	0	0	0	Helsingborg - terminal
3832	2014-05-15 16:54	1,05	81	-0,56	8	0,77	15	Helsingborg - terminal
4033	2014-05-15 16:54	0,81	90	0	0	-0,74	112	Helsingborg - terminal
3832	2014-05-15 17:00	-0,59	36	0	0	-0,49	7	Helsingborg - terminal
4096	2014-05-15 17:00	-0,71	60	0	0	0	0	Helsingborg - terminal
4033	2014-05-15 22:56	0,55	28	0	0	-0,72	42	Mjölby
4096	2014-05-17 03:33	0,63	94	0	0	0	0	Malmö - terminal

Significant chocks due to shunting were recorded both in Helsingborg and Malmö terminals. The most significant longitudinal chock in the trailer recorded by the accelerometer at the rear (4033) at 2014-05-15 16:54 had an average value of 0.81 g (while above 0.5 g) but a peak value of 0.9 g.

*Trailer rear **4033** - 2014-05-15 16:54:22*



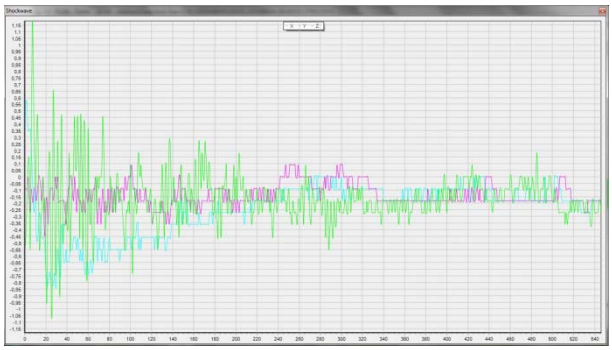
Position for the largest shock recorded at Helsingborg terminal at 2014-05-15 16:54.

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4034	2014-05-15 16:44	-0,63	94	0	0	0	0	Helsingborg - terminal
4203	2014-05-15 16:44	-0,61	95	0	0	0	0	Helsingborg - terminal
4034	2014-05-15 16:54	-1,53	121	-0,49	18	0	0	Helsingborg - terminal
4203	2014-05-15 16:54	-1,42	93	0	0	0	0	Helsingborg - terminal
4203	2014-05-15 17:00	0,72	22	0	0	0	0	Helsingborg - terminal
4203	2014-05-15 20:30	0,66	33	0	0	-0,5	3	Alvesta
4203	2014-05-15 22:26	0,5	18	0	0	-0,65	35	Alvesta
4203	2014-05-16 21:50	0,54	25	0	0	-0,7	38	Tranås
4203	2014-05-16 22:20	0,58	33	0	0	-0,59	19	Tranås
4203	2014-05-17 03:33	-1,38	56	0	0	-0,75	5	Malmö - Terminal
4203	2014-05-17 09:08	0	0	-0,48	6	0,55	12	Malmö - Terminal

Significant chocks due to shunting were recorded both in Helsingborg and Malmö terminals.

The most significant longitudinal chock in the swap body at 2014-05-15 16:54 had an average value of 1.53 g (while above 0.5 g) but a peak value of 3.6 g.



*Swap Body rear **4034** - 2014-05-15 16:44:46*

*Swap Body rear **4034** - 2014-05-15 16:54:22*

Movements

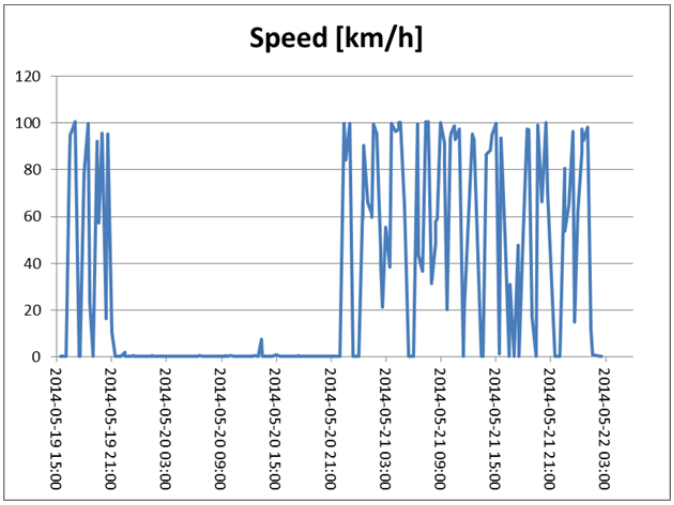
Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A **negative** value indicates movement rearward or to the right.

IBC	Acceleration	Forward [mm]	Left [mm]
Trailer			
1	**1.0**	5	-9
2	**0.8**	5	1
3	**0.75**	16	0
4	**0.4**	72	-1
5	**0.5**	72	3
6	**0.5**	61	1
Swap body			
7	**1.0**	-7	1
8	**0.8**	-5	2
9	**0.5**	-69	3
10	**0.4**	-71	11

It can be noted that all cargo units secured for 0.5 g or less moved significantly due to the shunting chocks in Helsingborg as well as Malmö. In preparation of the next leg, the IBC were repositioned to the centre of the laminate boards after the displacement had been measured.

Leg 2: Malmö – Taulov - Verona

During leg 2, both loading units were transported on the same train.



Recorded shocks

All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg are listed in the tables below. The magnitude of the shocks is given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
3814	2014-05-19 18:43	-0,54	18	0	0	0	0	Korsör
3832	2014-05-19 20:36	0	0	-0,5	48	0	0	Taulov
3814	2014-05-21 04:13	-0,5	11	0	0	0	0	Celle
3814	2014-05-21 06:30	-0,5	8	0	0	0	0	Hannover
4296	2014-05-21 10:04	0	0	-0,5	22	0	0	Fulda
3814	2014-05-21 11:48	0	0	-0,61	58	-0,69	35	Würtzburg
3814	2014-05-21 12:51	0	0	-0,51	33	0	0	Ansbach
4296	2014-05-21 22:13	0,55	25	0	0	0	0	Vipiteno
4033	2014-05-22 03:08	0	0	-0,57	62	0	0	Verona - Terminal

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4203	2014-05-19 19:10	0,54	23	0	0	0	0	Korsör
4203	2014-05-19 19:10	-0,62	43	0	0	0	0	Korsör

Movements

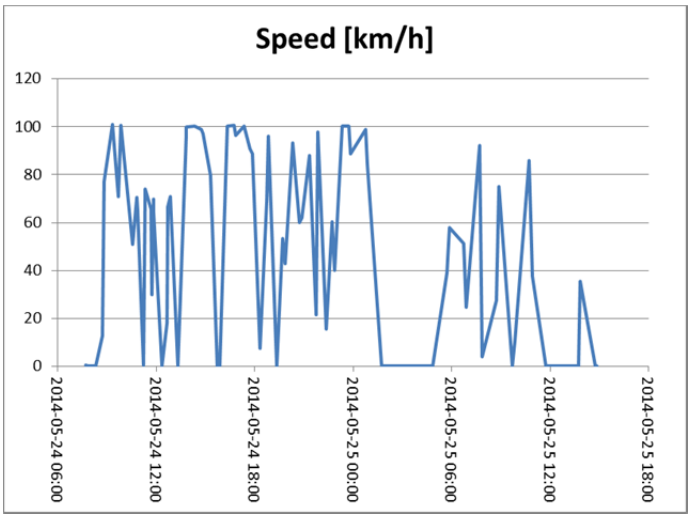
Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A **negative** value indicates movement rearward or to the right.

IBC	Acceleration	Forward [mm]	Left [mm]
Trailer			
1	**1.0**	0	0
2	**0.8**	1	-1
3	**0.75**	0	0
4	**0.4**	2	-1
5	**0.5**	-1	-1
6	**0.5**	-1	1
Swap body			
7	**1.0**	0	0
8	**0.8**	1	0
9	**0.5**	0	-1
10	**0.4**	-16	0

After this leg, only the IBC secured for 0.4 g in the Swap Body showed any noticeable movement. It had moved 16 mm towards the rear.

Leg 3: Verona-Rotherdam

During leg 3, both loading units were transported on the same train.



Recorded shocks

All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg are listed in the tables below. The magnitude of the shocks is given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4296	2014-05-24 11:39	0,54	26	0	0	0	0	Frankfurt am Main

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4203	2014-05-24 09:38	0,6	28	0	0	-0,98	35	Trento (Brenner)
4203	2014-05-24 09:53	0,67	32	0	0	0	0	Bolzano (Brenner)
4203	2014-05-24 11:08	0,77	42	0	0	-1,03	30	Bressanone (Brenner)
4203	2014-05-24 11:37	0,78	39	0	0	0	0	Vipiteno (Brenner)
4203	2014-05-24 11:45	0,9	47	0	0	-0,92	29	Brennerbad (Brenner)
4203	2014-05-24 16:16	0	0	-0,5	18	0	0	Augsburg
4203	2014-05-24 16:29	0	0	-0,51	29	0	0	Augsburg
4203	2014-05-24 16:56	0	0	-0,5	20	0	0	Augsburg
4203	2014-05-24 17:24	0	0	-0,51	14	0	0	Augsburg
4203	2014-05-24 17:44	0,69	38	0	0	-0,78	7	Ansbach
4203	2014-05-24 17:44	0	0	-0,53	18	0	0	Ansbach
4203	2014-05-24 17:47	0	0	-0,53	29	0	0	Ansbach
4203	2014-05-24 17:48	0	0	-0,55	35	0	0	Ansbach
4203	2014-05-24 17:48	0	0	-0,53	31	0	0	Ansbach
4203	2014-05-24 21:51	0,56	31	0	0	-0,8	36	Frankfurt
4203	2014-05-24 23:18	0	0	-0,54	13	0	0	Wiesbaden

Movements

Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A **negative** value indicates movement rearward or to the right.

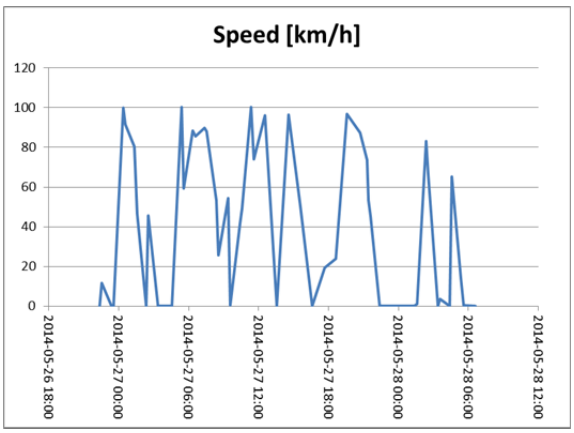
IBC	Acceleration	Forward [mm]	Left [mm]
Trailer			
1	**1.0**	0	1
2	**0.8**	0	0
3	**0.75**	0	0
4	**0.4**	-1	-1
5	**0.5**	1	-1
6	**0.5**	0	-1
Swap body			
7	**1.0**	0	0
8	**0.8**	1	0
9	**0.5**	-2	-1
10	**0.4**	-49	0

After this leg, only the IBC secured for 0.4 g in the Swap Body showed any noticeable movement. It had moved 49 mm towards the rear. This IBC was repositioned at the centre of the laminate board before departure from Rotterdam.

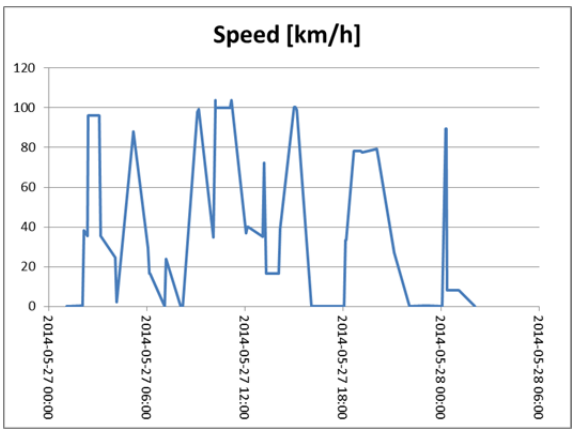
Leg 4: Rotterdam – Novara/Busto

During leg 4, the loading units were transported on separate trains.

Red line indicate trailer route. Blue line indicate swap body route.



Trailer



Swap body

Recorded shocks

All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg are listed in the tables below. The magnitude of the shocks is given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
3814	2014-05-26 18:35	-0,8	25	0	0	0	0	Rotterdam - terminal
3832	2014-05-26 18:35	-0,72	23	0	0	0	0	Rotterdam - terminal
4296	2014-05-26 18:36	0,67	31	0	0	0	0	Rotterdam - terminal
3814	2014-05-26 23:44	-0,6	12	0	0	0	0	Dordrecht
3814	2014-05-26 23:44	-0,5	7	0	0	0	0	Dordrecht
3832	2014-05-27 00:05	0	0	-0,5	12	0	0	Dordrecht
3814	2014-05-27 01:26	-0,5	24	0	0	-0,79	51	Arnhem
4296	2014-05-27 01:27	0	0	-0,51	30	0	0	Arnhem
3814	2014-05-27 02:00	-0,45	4	0	0	-0,87	38	Duisburg
3814	2014-05-27 02:14	-0,48	34	0	0	-0,76	50	Duisburg
3832	2014-05-27 06:31	0	0	-0,51	20	0	0	Köln
4296	2014-05-27 11:21	0	0	-0,57	48	0	0	Karlsruhe
3832	2014-05-27 15:56	0	0	-0,52	22	0	0	Basel
4033	2014-05-27 21:13	0,76	40	0	0	-0,93	48	Domodosolla

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4034	2014-05-26 22:00	0,66	18	0	0	0	0	Rotterdam - Terminal
4203	2014-05-26 22:01	0,56	10	0	0	0	0	Rotterdam - Terminal
4203	2014-05-26 22:03	0	0	-0,65	54	0	0	Rotterdam - Terminal

Movements

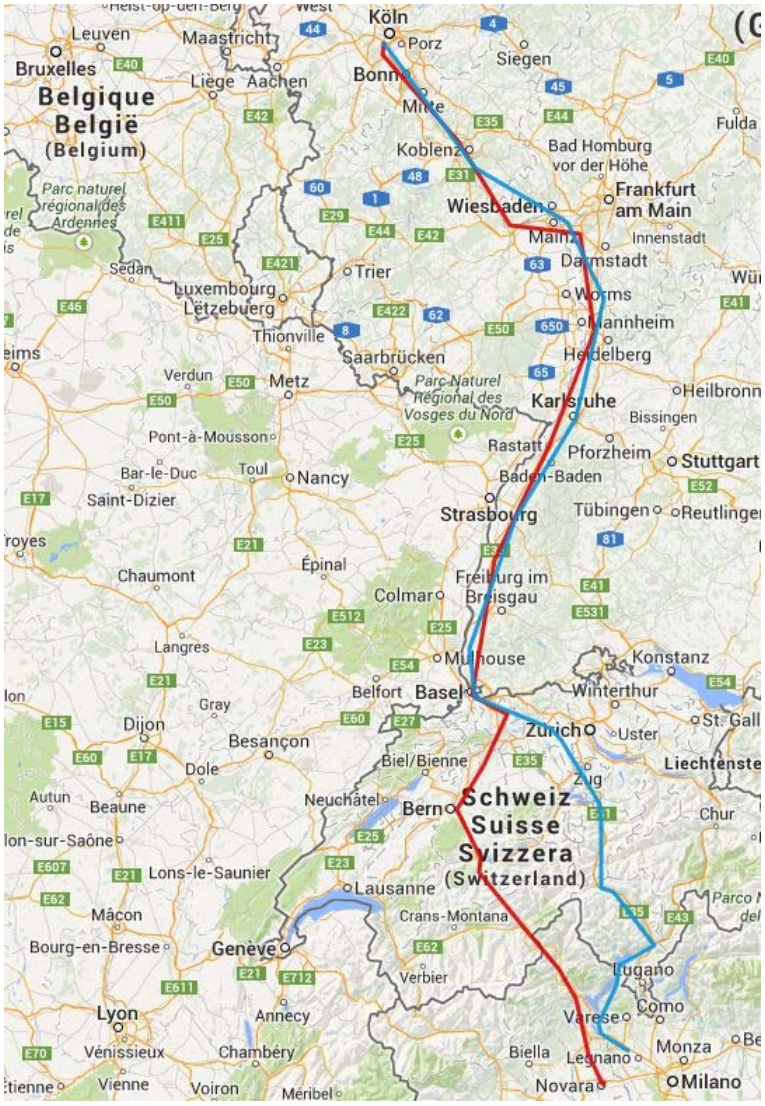
Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A negative value indicates movement rearward or to the right.

IBC	Acceleration	Forward	Left
Trailer			
1	**1.0**	1	-1
2	**0.8**	0	1
3	**0.75**	0	0
4	**0.4**	1	1
5	**0.5**	-1	0
6	**0.5**	2	0
Swap body			
7	**1.0**	-1	0
8	**0.8**	-1	0
9	**0.5**	3	0
10	**0.4**	-23	3

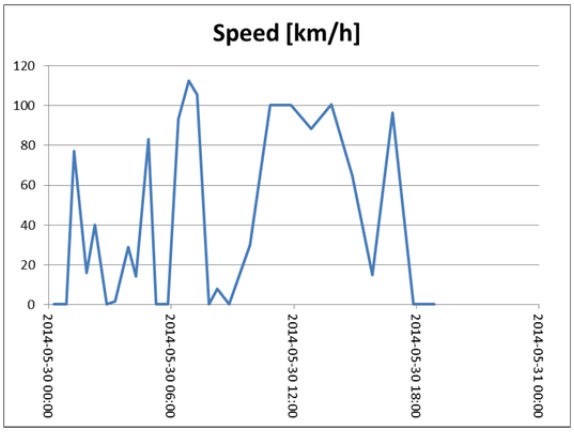
After this leg as well, only the IBC secured for 0.4 g in the Swap Body showed any noticeable movement. It had moved 23 mm towards the rear.

Leg 5: Novara/Busto - Cologne

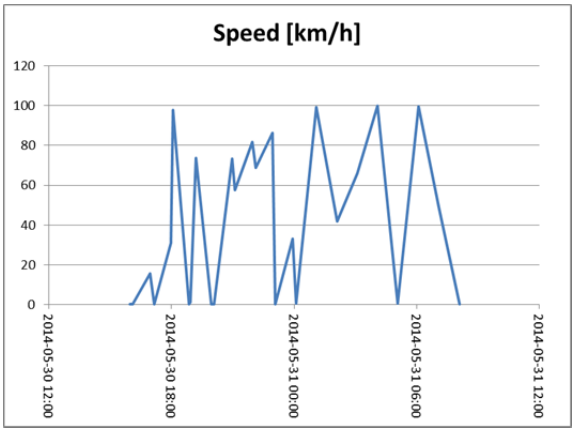
During this leg, the loading units were transported on separate trains.



Red line indicate trailer route. Blue line indicate swap body route.



Trailer



Swap body

Recorded shocks

All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg are listed in the tables below. The magnitude of the shocks is given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
3814	2014-05-29 20:21	-0,5	19	0	0	0	0	Novara - terminal
3814	2014-05-29 20:21	-0,45	3	-0,45	2	-0,81	66	Novara - terminal
3814	2014-05-29 20:21	-0,61	48	-0,52	26	-1,03	58	Novara - terminal
3814	2014-05-29 20:21	-0,55	37	0	0	0	0	Novara - terminal
3814	2014-05-29 20:21	-0,6	35	-0,49	23	-0,85	73	Novara - terminal
3832	2014-05-29 20:21	-0,49	12	0	0	-0,85	7	Novara - terminal
3814	2014-05-29 20:21	0	0	-0,85	39	-0,68	67	Novara - terminal
3832	2014-05-29 20:21	0	0	-0,53	28	-0,7	5	Novara - terminal
3814	2014-05-29 20:21	-0,55	33	0	0	-0,66	18	Novara - terminal
3814	2014-05-29 20:21	-0,58	48	-0,72	41	-0,87	64	Novara - terminal
3814	2014-05-29 21:16	0	0	-0,61	9	0	0	Novara - terminal
3814	2014-05-29 21:18	-0,61	11	0	0	0	0	Novara - terminal
3814	2014-05-30 01:01	0	0	-0,52	30	0	0	Novara (after departure)
3814	2014-05-30 06:09	-0,49	11	0	0	-1,01	97	Bern
3814	2014-05-30 06:15	-0,48	17	0	0	-0,8	58	Bern
3814	2014-05-30 06:15	-0,48	10	0	0	0,92	84	Bern
4296	2014-05-30 20:56	-0,48	1	0	0	-1,48	5	Cologne - terminal

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4034	2014-05-30 19:02	0	0	-0,45	6	-0,75	32	Luino
4203	2014-05-30 19:03	0	0	-0,62	36	0	0	Caviano

Movements

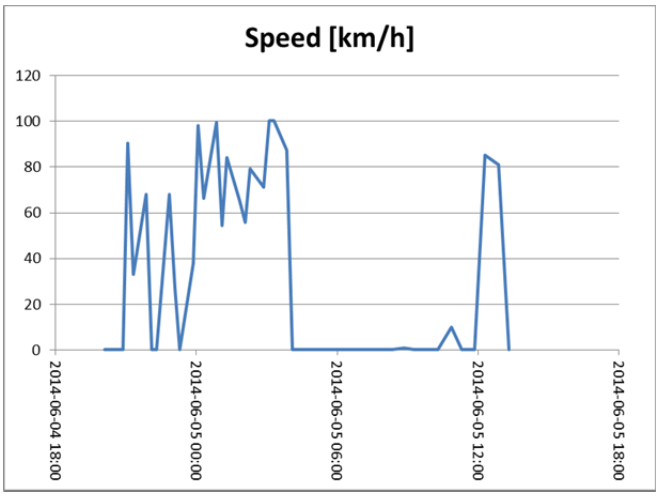
Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A negative value indicates movement rearward or to the right.

IBC	Acceleration	Forward [mm]	Left [mm]
Trailer			
1	**1.0**	0	1
2	**0.8**	0	-1
3	**0.75**	0	1
4	**0.4**	2	-1
5	**0.5**	0	0
6	**0.5**	-3	2
Swap body			
7	**1.0**	2	0
8	**0.8**	1	-1
9	**0.5**	-1	-3
10	**0.4**	-40	-1

After this leg as well, only the IBC secured for 0.4 g in the Swap Body showed any noticeable movement. It had moved 40 mm towards the rear.

Leg 6: Cologne - Lübeck

During leg 6, both loading units were transported the same train.



Recorded shocks

All shocks above 0.5 g recorded in lengthwise and sideways directions during this leg is listed in the tables below. The magnitude of the shocks is given in parts of the g as the average value of the shock while above 0.5 g. The duration of the shocks while above 0.5 g is given in milliseconds.

Trailer

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
3814	2014-06-04 10:15	0	0	-0,52	9	0	0	Cologne - Terminal
3814	2014-06-04 10:16	0	0	-0,65	37	0	0	Cologne - Terminal
3814	2014-06-04 10:16	0	0	-0,54	22	0	0	Cologne - Terminal
3832	2014-06-04 10:16	0	0	-0,51	8	0	0	Cologne - Terminal
3814	2014-06-04 10:16	-0,66	16	-0,67	22	0	0	Cologne - Terminal
3814	2014-06-04 10:16	0	0	-0,56	23	-0,66	5	Cologne - Terminal
3814	2014-06-04 21:03	-0,57	22	0	0	0	0	Düsseldorf
3832	2014-06-04 21:07	-0,51	10	0	0	0	0	Düsseldorf
3814	2014-06-04 21:07	-0,68	42	0	0	-0,78	43	Düsseldorf
3832	2014-06-04 21:08	-0,52	13	0	0	0	0	Düsseldorf
3814	2014-06-04 21:08	-0,69	37	0	0	-0,72	15	Düsseldorf
4033	2014-06-04 21:08	-0,5	25	0	0	-0,68	13	Düsseldorf
3814	2014-06-04 21:12	-0,57	14	0	0	0	0	Düsseldorf
3814	2014-06-04 21:30	-0,65	21	0	0	-0,77	52	Duisburg
3814	2014-06-04 21:30	-0,6	24	0	0	0	0	Duisburg
3814	2014-06-04 21:30	-0,51	33	0	0	-0,71	47	Duisburg
3814	2014-06-04 21:43	-0,51	7	0	0	0	0	Duisburg
3814	2014-06-04 22:45	-0,45	7	0	0	-0,79	45	Gladbeck
3814	2014-06-04 22:45	-0,5	19	0	0	-0,71	37	Gladbeck
3814	2014-06-04 22:51	-0,48	20	0	0	-0,77	72	Gladbeck
3832	2014-06-05 00:08	-0,5	12	0	0	0	0	Münster
3832	2014-06-05 03:34	-0,52	10	0	0	0	0	Hamburg
3832	2014-06-05 03:48	0	0	-0,57	31	-0,71	5	Hamburg
3832	2014-06-05 03:48	0	0	-0,51	32	0	0	Hamburg
3832	2014-06-08 16:29	0	0	-0,64	32	0	0	Lübeck - Terminal

Swap Body

Device	Date – Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]	Place
4203	2014-06-04 21:45	0,68	34	0	0	-0,87	40	Duisburg

Movements

Each unit was free to move about 75 mm in any horizontal direction. The mean movement forward and to the left in mm of each unit in the trailer and swap body respectively during Leg 1 is shown below. A negative value indicates movement rearward or to the right.

IBC	Acceleration	Forward [mm]	Left [mm]
Trailer			
1	**1.0**	0	-1
2	**0.8**	0	0
3	**0.75**	0	-1
4	**0.4**	-1	0
5	**0.5**	1	0
6	**0.5**	0	-1
Swap body			
7	**1.0**	0	0
8	**0.8**	0	1
9	**0.5**	0	1
10	**0.4**	8	-1

After this leg as well, only the IBC secured for 0.4 g in the Swap Body showed any noticeable movement. It had moved 8 mm slightly forward.

Analysis of shocks

By analysis of the collected data comparisons have been made between accelerations registered in the two different types of units, as well as on the IBC filled with water and concrete respectively. The examples in this chapter of the report are limited to those shocks recorded simultaneously by two or more accelerometers. Due to the following causes not all shocks were registered simultaneously by all devices:

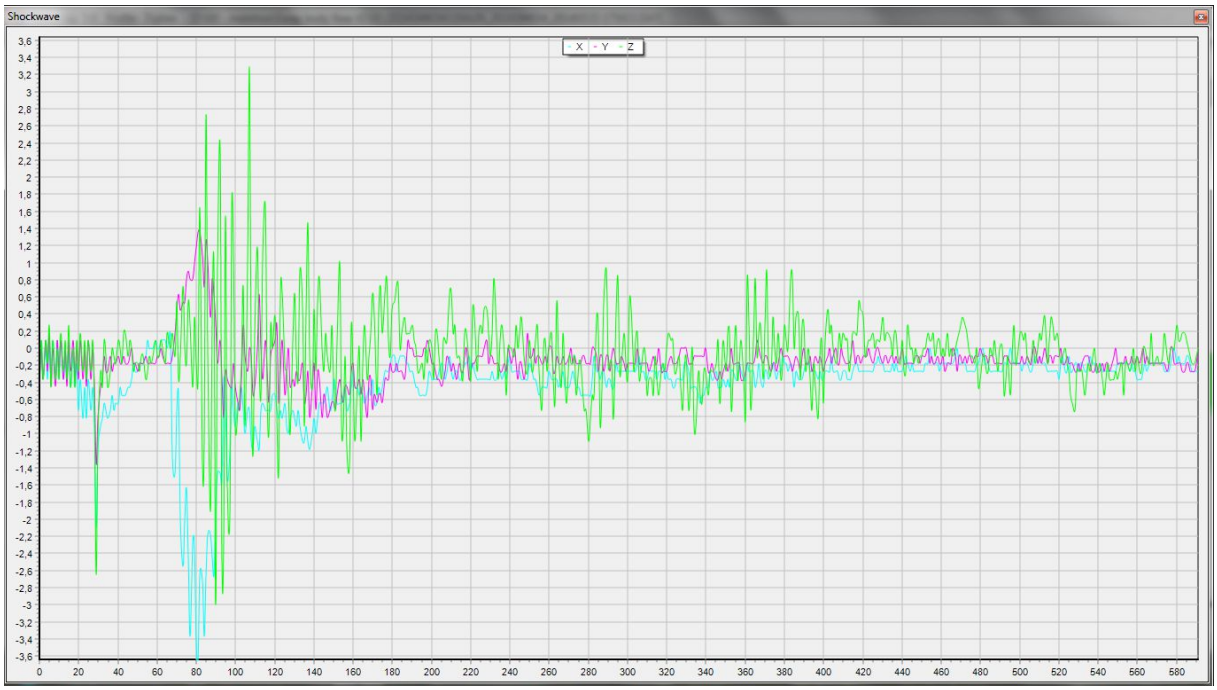
- The two units were sent on different routes between Rotterdam – Busto/Novara – Cologna.
- The accelerometers were set to record shocks when the trigger value of 0.5 g was exceeded for more than 15 ms. They were however not connected to trigger simultaneously. Many of the recorded shocks were just above the trigger value on one or a few of the devices but below the trigger value on the others.
- Four of the six units were set to make detailed recordings of the shocks. However, due to memory capacity, they did not record all the shocks for every leg. When the memory was nearly full the accelerometers only recorded the average values for the shocks and when it was completely full it stopped recording until the memory had been emptied at inspection of through data delivery via the GSM network. Thus, in most cases, detailed shock data is available only at the first part of most legs.
- Some of the accelerometers were not properly set up on a few legs.

Peak acceleration versus shock impulse

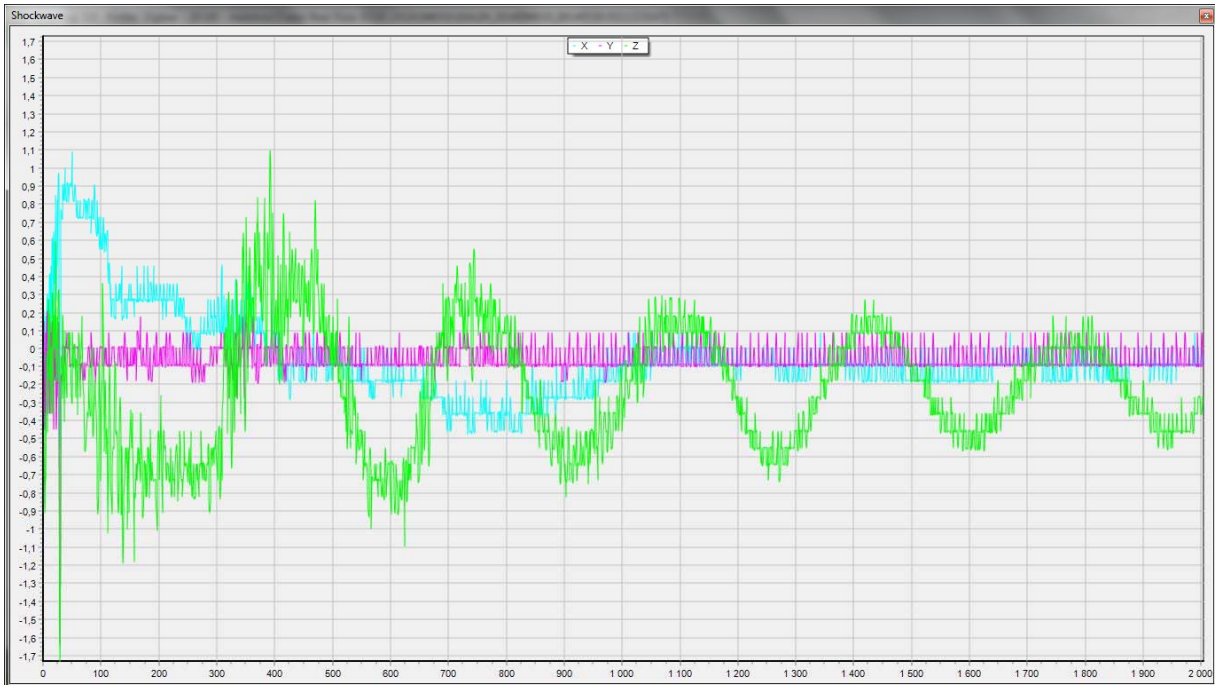
In order for cargo to move, the acceleration level during shocks must exceed the threshold value set by the friction factor and other cargo securing measures. However, a shock's ability to move cargo is not only given by the peak value of the acceleration, but also by its duration. These factors are together determining the impulse on the cargo. The cargo may experience significant peak values for horizontal acceleration during rail transport, but these are typically experienced during a fraction of a second and do not generate a large enough impulse to move the cargo any noticeable distance.

During shunting at the start of Leg 1 in Helsingborg 2014-05-15 the following average accelerations were registered:

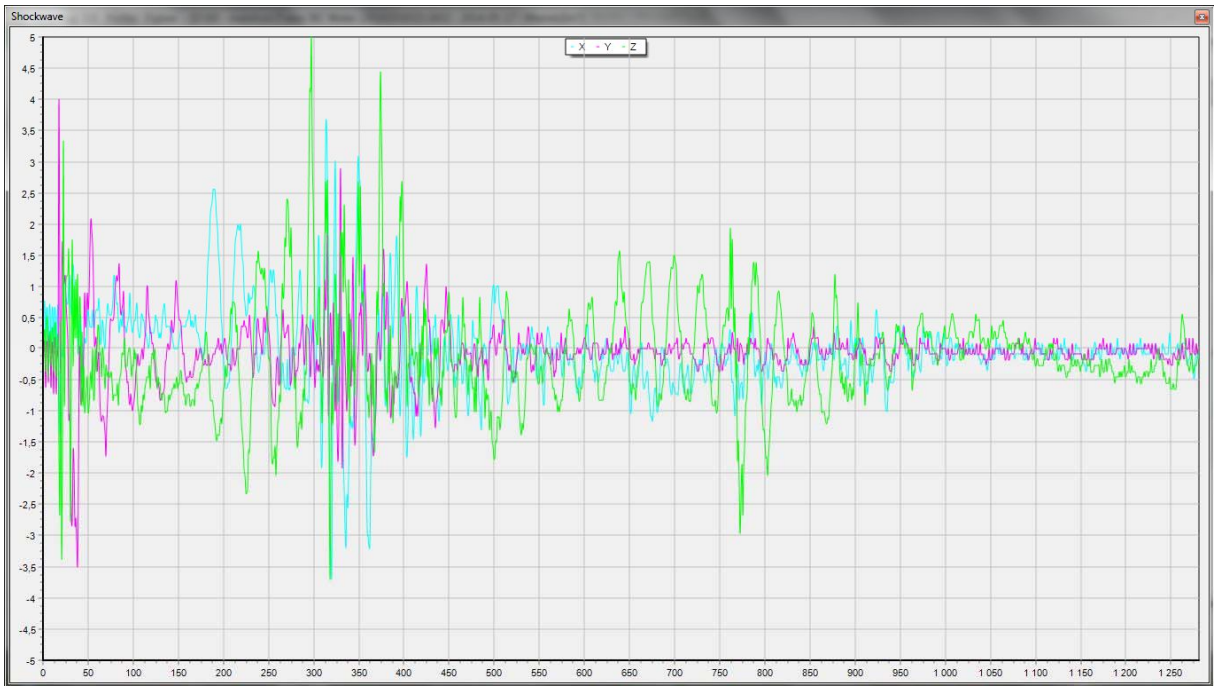
Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
4203	Swap body	Front - floor	2014-05-15 16:54	-1,42	93	0	0	0	0
4034	Swap body	Rear - floor	2014-05-15 16:54	-1,53	121	-0,49	18	0	0
4096	Trailer	Front - floor	2014-05-15 16:54	0,81	125	0	0	0	0
4033	Trailer	Rear - floor	2014-05-15 16:54	0,81	90	0	0	-0,74	112
3832	Trailer	On water IBC	2014-05-15 16:54	1,05	81	-0,56	8	0,77	15



Device 4034 - Swap body – On floor – Rear: Peak acceleration: -3.6 g



Device 4033 - Trailer – On floor – Rear: Peak acceleration: 1.1 g



Device 3832 - Trailer – On water IBC: Peak acceleration: 3.5 g

While the peak values have been very high, some 3.5 g, these have been experienced by the cargo momentarily only, and the recorded average vales of 0.8 to 1.5 g maintained over the full shock, gives a better indication on the impulse of the shock.

At this shock, all cargo units secured for 0.5 g or less moved significantly while the movement for cargo units secured for 0.8 g or more was negligible. The cargo unit secured for 0.75 g moved only 16 mm and this seems to represent the limiting acceleration during this shock. It must be noted however, that this shock was caused by a hump and fly shunting procedure which should not be used for combined transports.

Swab body versus trailer

The example above also illustrates that the peak values were higher in the swap body than in the trailer. This is most likely due a stiffer connection between the railway car and the load unit. The same pattern also is seen in the following two examples:

Arrival Malmö yard 2014-05-17:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
4203	Swap body	Front - floor	2014-05-17 03:33	-1,38	56	0	0	-0,75	5
4096	Trailer	Front - floor	2014-05-17 03:33	0,63	94	0	0	0	0

En route near Duisburg 2014-06-04:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
4203	Swap body	Front - floor	2014-06-04 21:45	0,68	34	0	0	-0,87	40
3814	Trailer	Concrete IBC	2014-06-04 22:45	-0,45	7	0	0	-0,79	45
3814	Trailer	Concrete IBC	2014-06-04 22:45	-0,5	19	0	0	-0,71	37

Based on the comparison of recorded shocks and the movement of the IBCs that was secured for 0.4 g only in the trailer and the swap body respectively, it can be concluded that cargo in swap bodies and similar units may be slightly more sensitive to wandering due to vibrations and low impulse shocks than cargo in trailers. However, this phenomenon was only observed for the cargo units secured for less than 0.5 g.

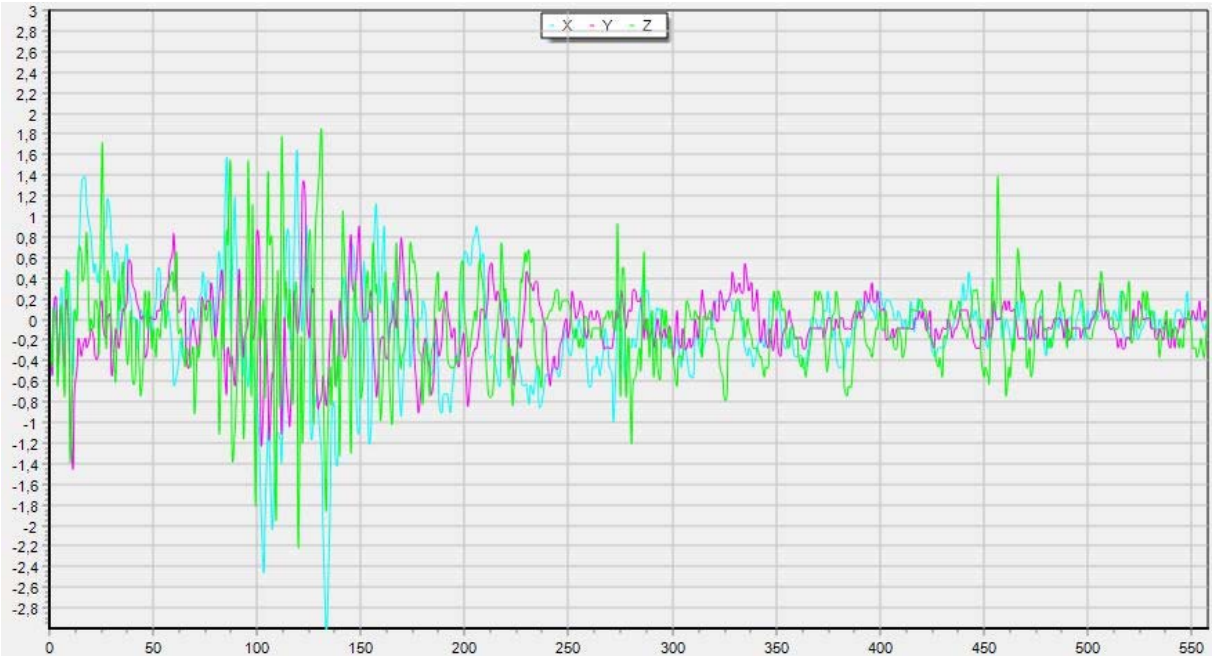
Rigidity of test cargo - IBC with water versus concrete

In order to compare the rigidity and behavior of the IBC filled with concrete and one filled with the same weight of water, they were secured to cope with the same acceleration, 0.5 g, and fitted with accelerometers on top.

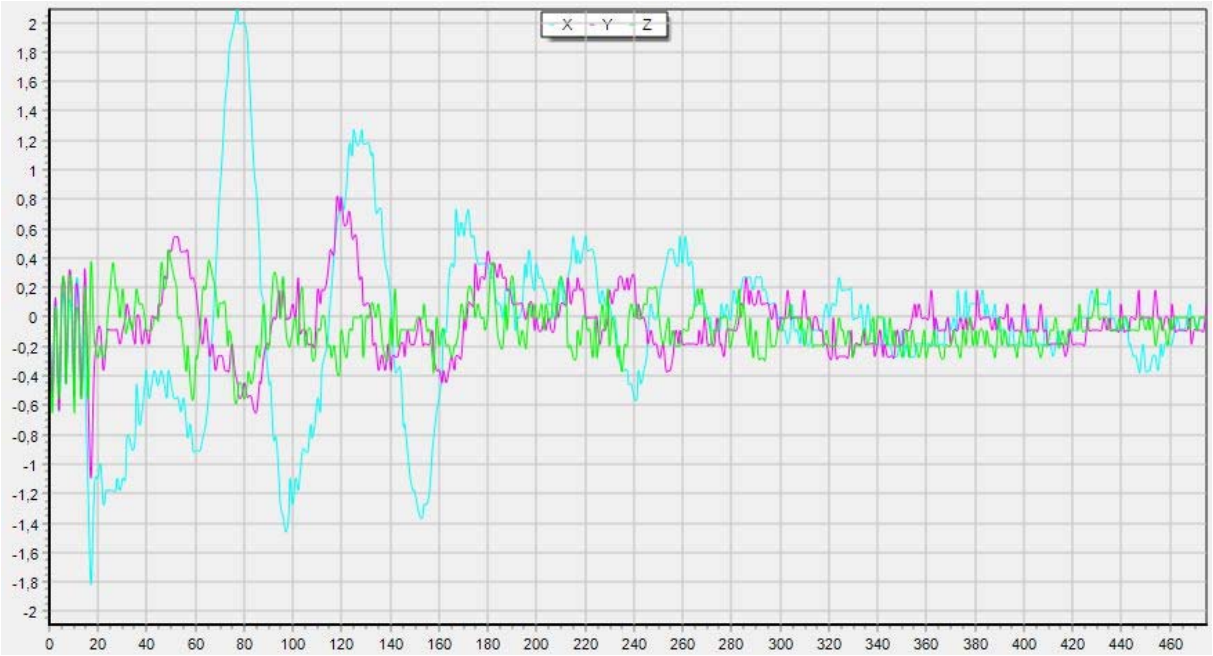
Below is listed a few examples were shocks have been recorded in detail at the same instances.

Departure Rotterdam terminal 2014-05-26:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-05-26 18:35	-0,72	23	0	0	0	0
3814	Trailer	Concrete IBC	2014-05-26 18:35	-0,8	25	0	0	0	0



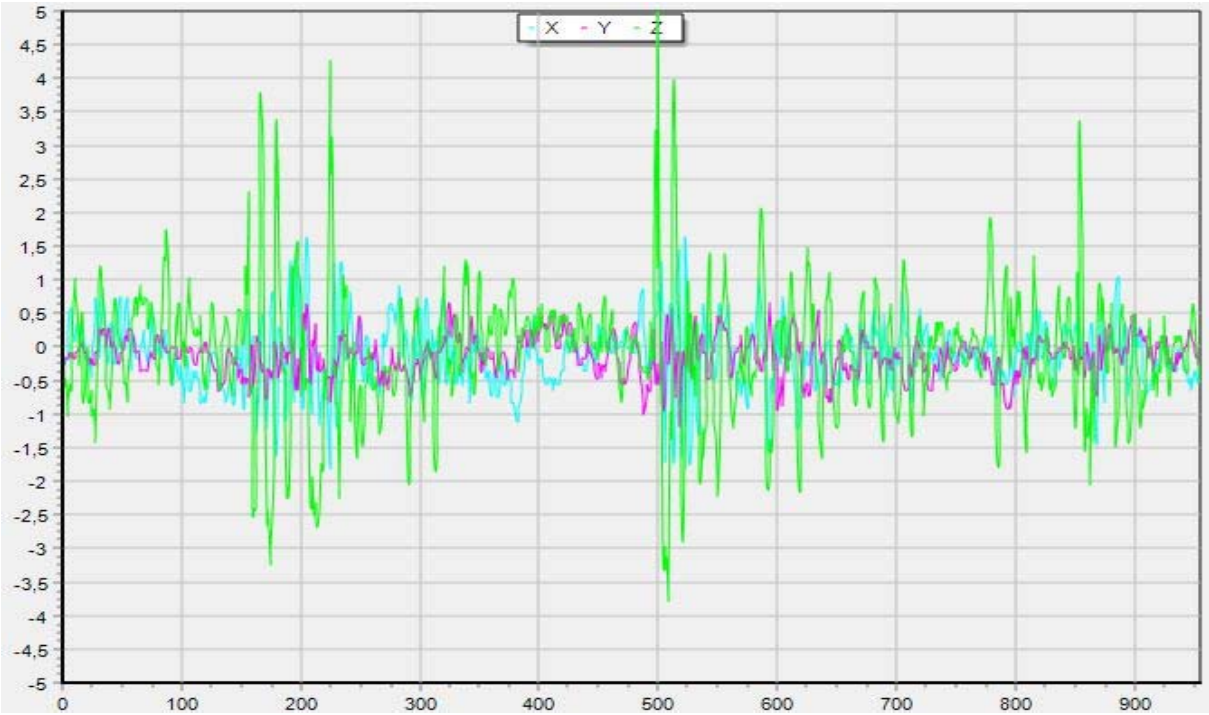
Device 3832 – Trailer – on water IBC



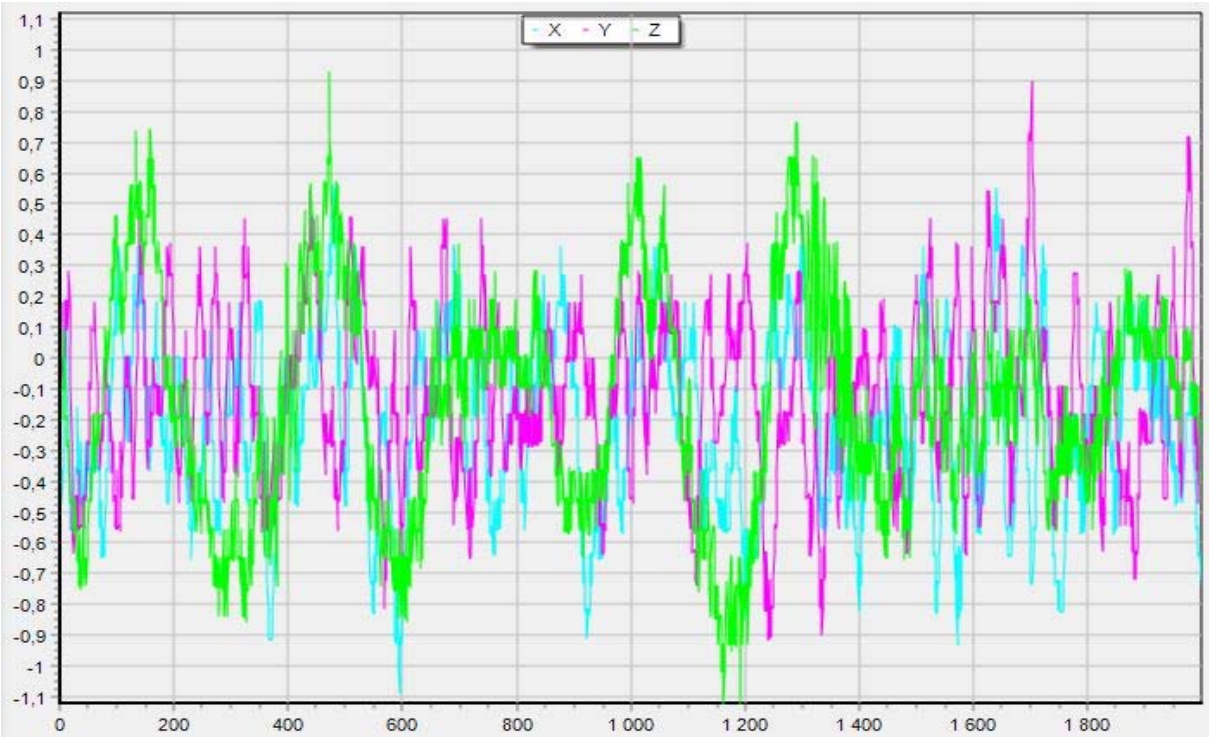
Device 3814 – Trailer – on concrete IBC

Departure Novara terminal 2014-05-29:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-05-29 20:21	-0,49	12	0	0	-0,85	7
3814	Trailer	Concrete IBC	2014-05-29 20:21	-0,6	35	-0,49	23	-0,85	73



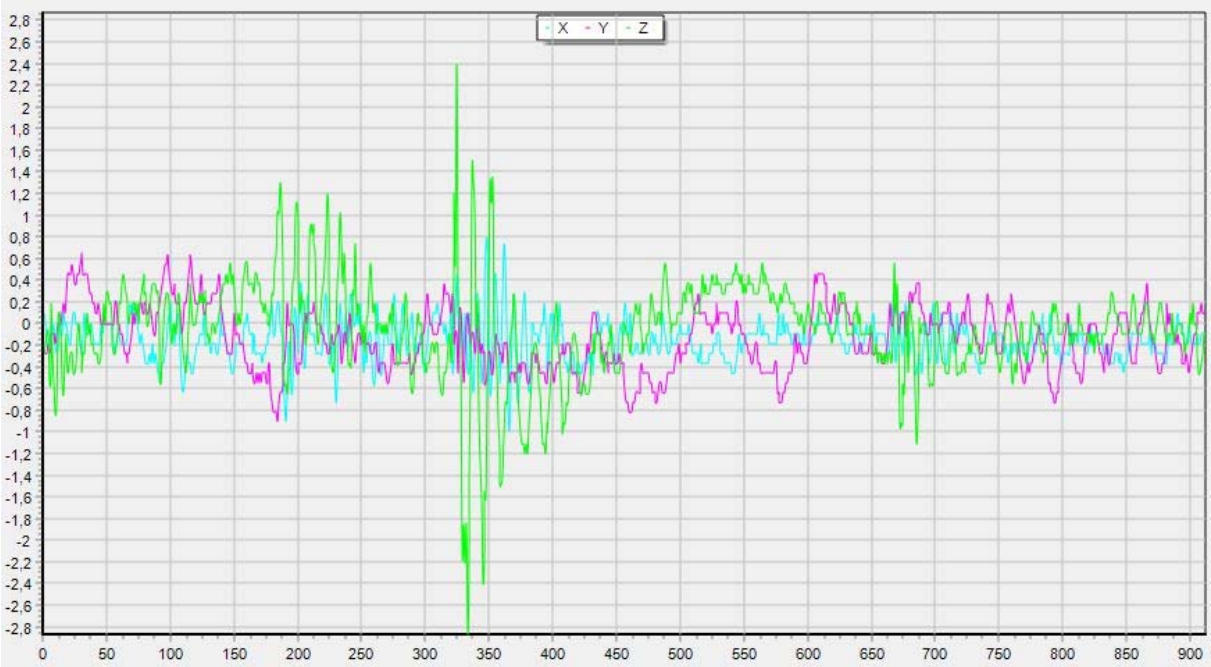
Device 3832 – Trailer – on water IBC



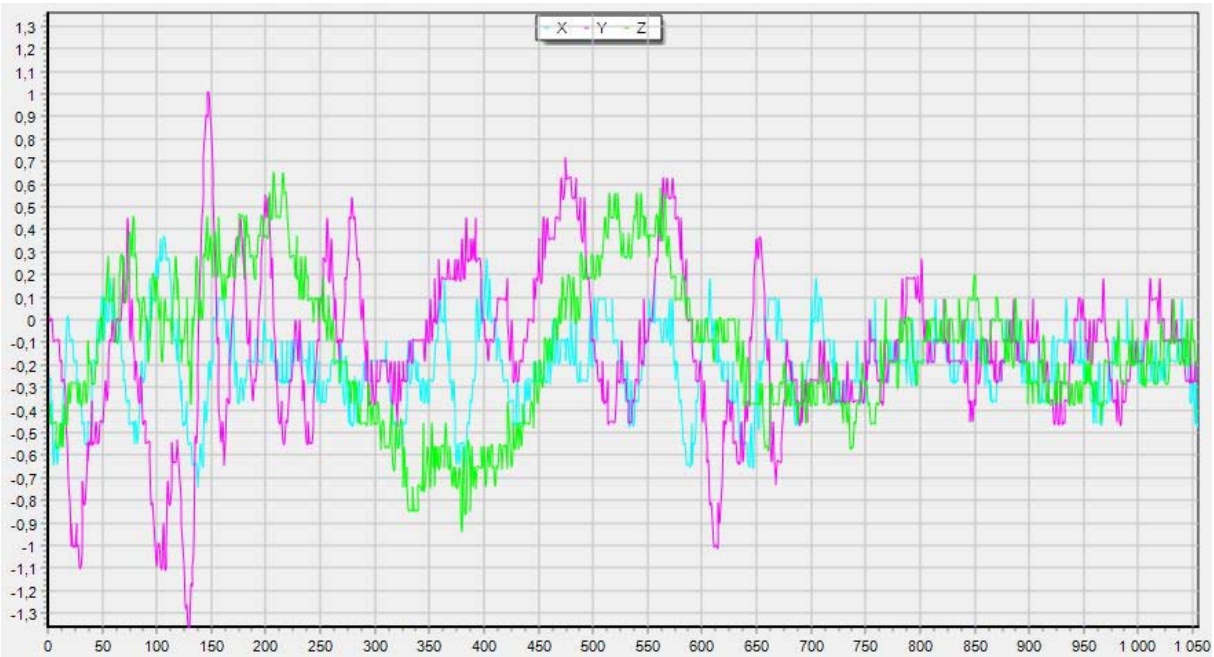
Device 3814 – Trailer – on concrete IBC

Departure Novara terminal 2014-05-29:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-05-29 20:21	0	0	-0,53	28	-0,7	5
3814	Trailer	Concrete IBC	2014-05-29 20:21	0	0	-0,85	39	-0,68	67



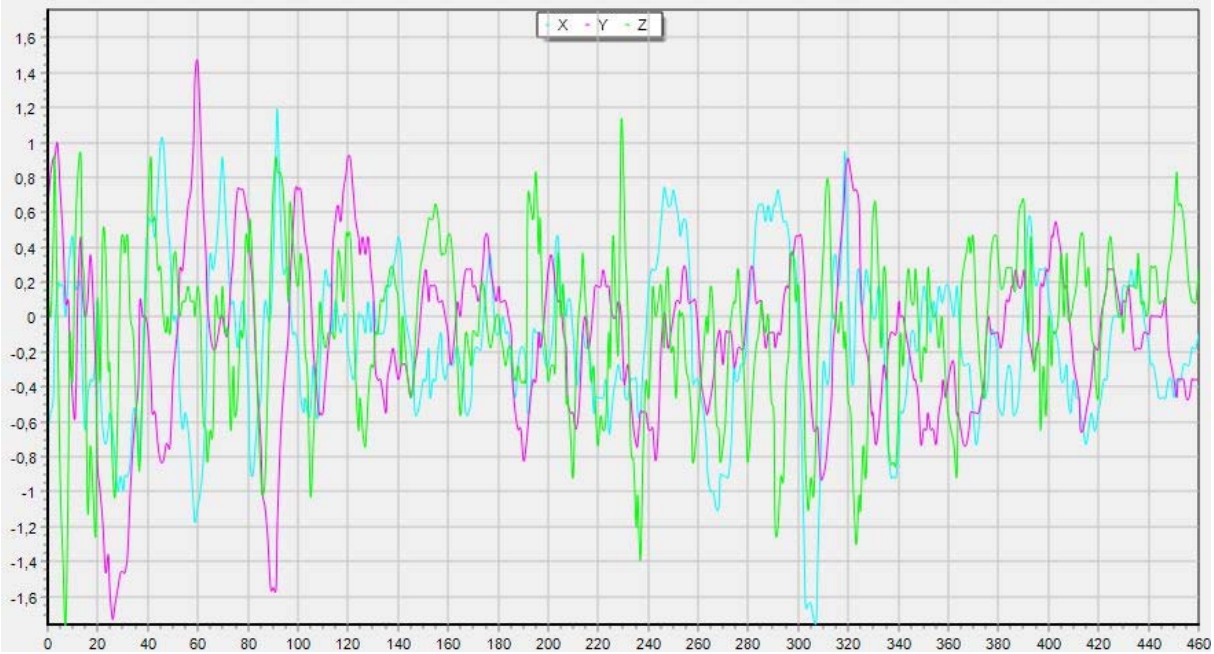
Device 3832 – Trailer – on water IBC



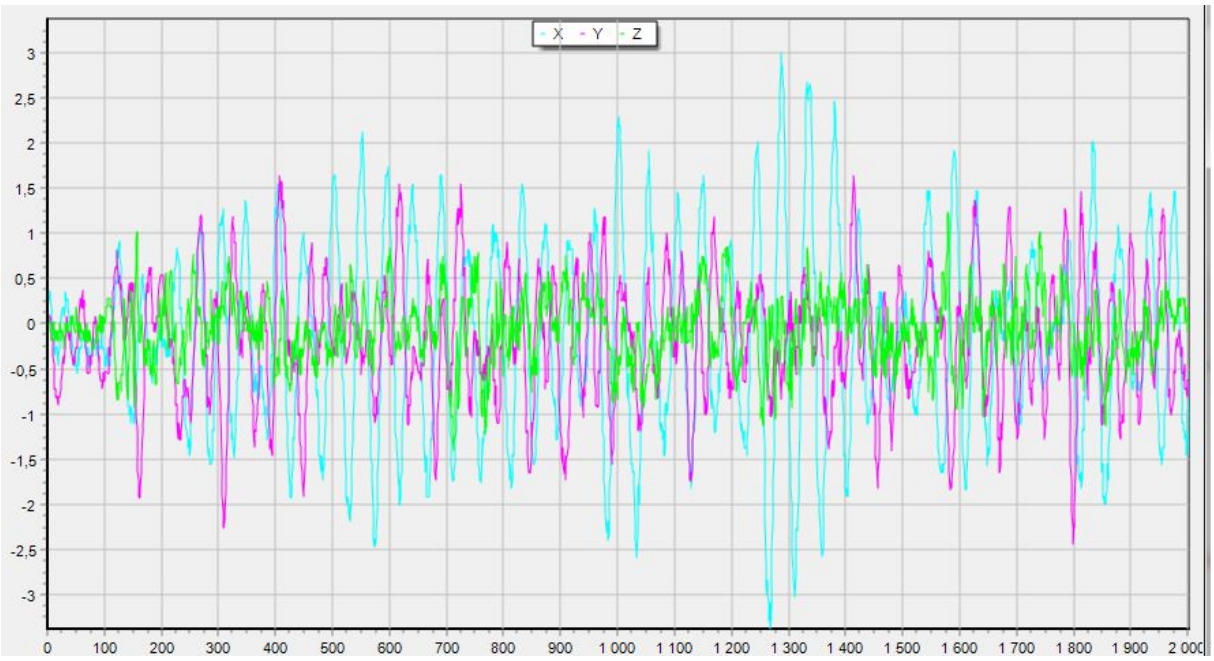
Device 3814 – Trailer – on concrete IBC

Departure Cologne terminal 2014-06-04:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-06-04 10:16	0	0	-0,51	8	0	0
3814	Trailer	Concrete IBC	2014-06-04 10:16	-0,66	16	-0,67	22	0	0



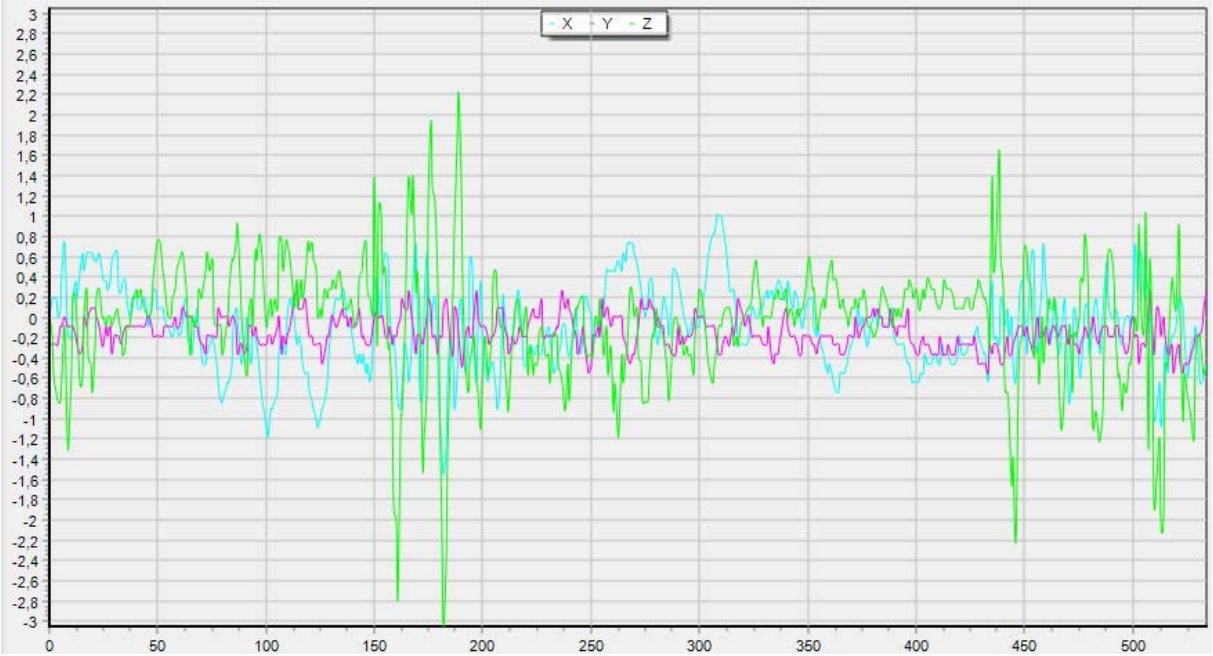
Device 3832 – Trailer – on water IBC



Device 3814 – Trailer – on concrete IBC

En route near Düsseldorf 2014-06-04:

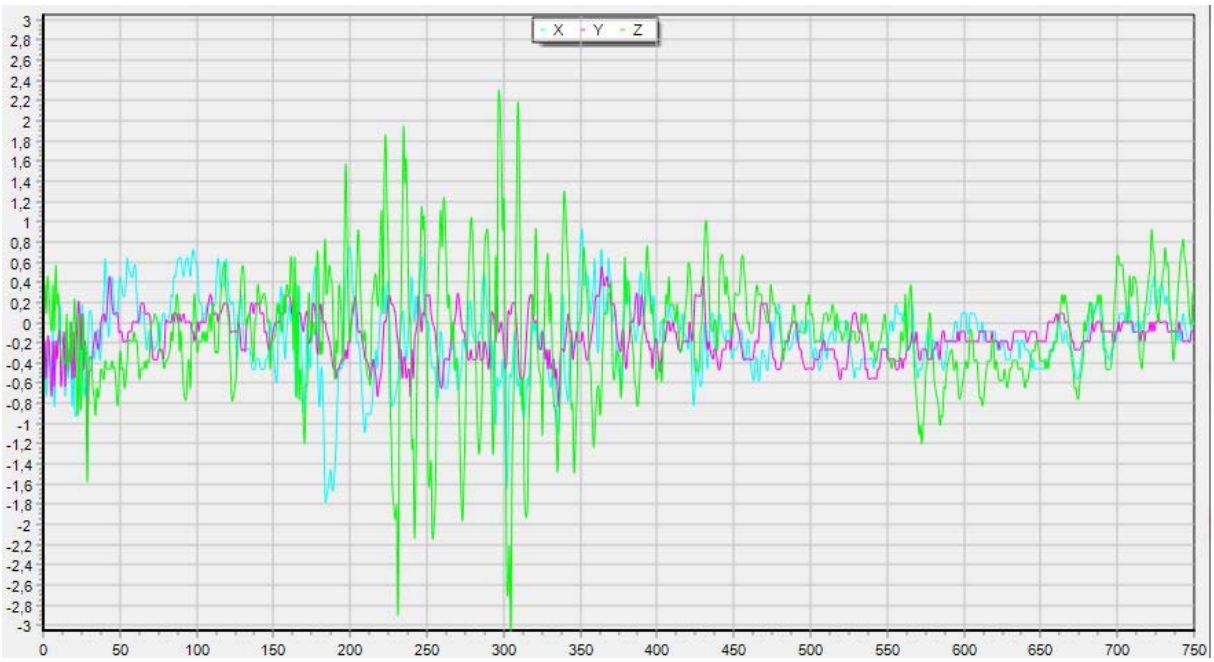
Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-06-04 21:07	-0,51	10	0	0	0	0
3814	Trailer	Concrete IBC	2014-06-04 21:07	-0,68	42	0	0	-0,78	43



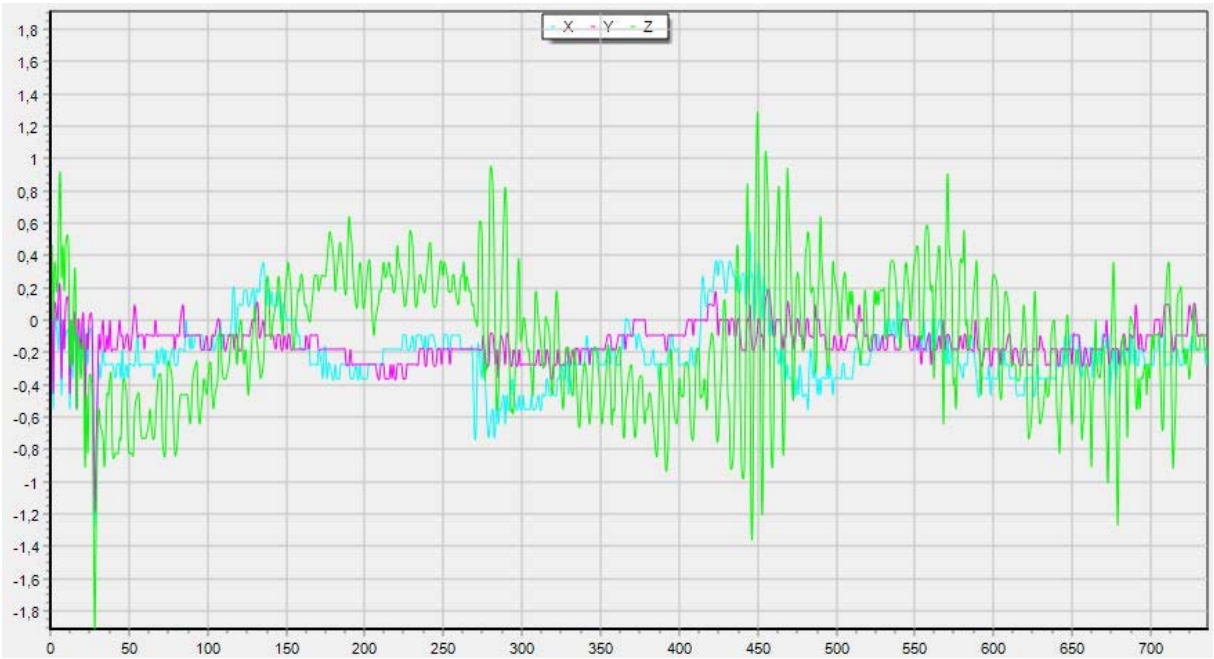
Device 3832 – Trailer – on water IBC

En route near Düsseldorf 2014-06-04:

Device	Unit	Position	Date - Time	Acc X [g]	Len X [ms]	Acc Y [g]	Len Y [ms]	Acc Z [g]	Len Z [ms]
3832	Trailer	Water IBC	2014-06-04 21:08	-0,52	13	0	0	0	0
3814	Trailer	Concrete IBC	2014-06-04 21:08	-0,69	37	0	0	-0,72	15
4033	Trailer	On floor rear	2014-06-04 21:08	-0,5	25	0	0	-0,68	13



Device 3832 – Trailer – on water IBC



Device 4033 – Trailer – on floor rear

The accelerometer on top of the concrete IBC has in general recorded slightly higher peak accelerations. Also, it can be noted that in most but not all instances, the accelerations recorded on top of the IBC filled with water show a higher frequency oscillation in response to the shocks. However, this foremost applies to the vertical acceleration (green lines).

Although slight differences can be seen, the measurements of displacement of the cargo units show that they have responded identically to the shocks experienced throughout the test. It can then be concluded that the impulse on the two units have been very similar and the IBCs with water is sufficiently rigid to be representative for most types of rigid cargoes.

Conclusions

The result of the tests supports the current wording regarding accelerations during intermodal transports in the IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units, i.e. accelerations with peaks around 1.0 g may occur during normal intermodal transports but these peaks have such a short duration that **for cargo securing purposes** a design acceleration of 0.5 g in the longitudinal as well as in the transverse direction provides a safe level.

The only cargo item that moved significantly was the IBC in the swap body secured for 0.4 g. The other units were displaced a few millimeters only. Furthermore, there was no noticeable difference between the two IBC in trailer that were secured for 0.5 g. One of these was completely filled with water and the other with a corresponding weight of concrete. Since they responded identically to all the impulses during the test transports, it can be concluded that the water filled IBCs were sufficiently rigid to be representative for rigid cargoes.

The tests have clearly shown that a design acceleration of 0.5 g for cargo securing arrangements can however only be applied to cargo in load units not subjected to hump and fly shunting or shunting by power engine at excessive speeds. In such cases a higher level is needed.

Due to how the load units are fitted to the railway wagon, cargo in swap bodies may be more sensitive to wandering due to vibrations and low impulse shocks. This phenomenon was however only noticed for cargo secured for less than 0.5 g.