Part 2: Experiments with the portcullises

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Contents

Measurements, data processing and single rope control

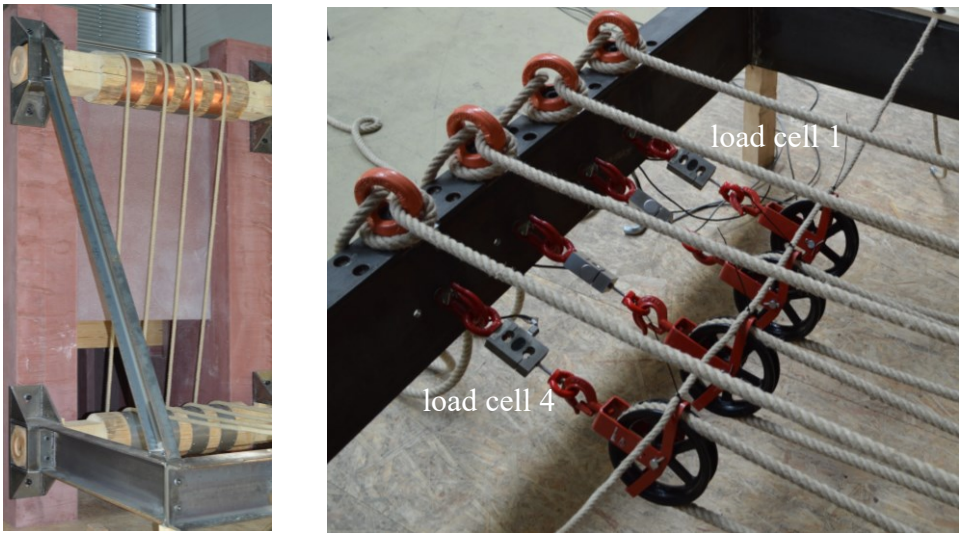


Fig. 1. Measurement system for rope forces attached to the northern front of the replica. The load cells measure twice the force in each rope before it goes to a handler through one of the red hoops. (photos by C. Nguyen)

To measure the forces that appear at the ends of each rope, a system was developed that uses high-resolution load cells (Hottinger Baldwin HBMS9/S9M, range +/- 10 kN, resolution +/- 2N) in the setting shown in Fig. 1.

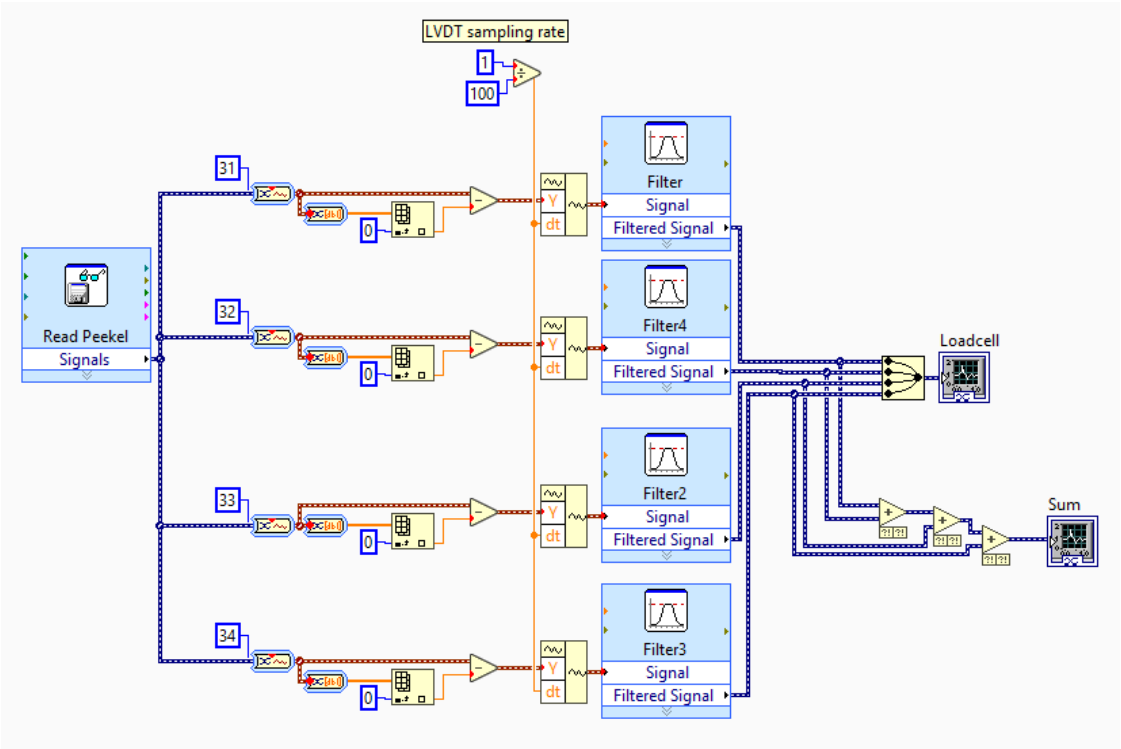


Fig. 2. Labview process used for force measurement and data processing. The sampling rate was 100 Hz. A Butterworth filter was applied with 0-1 Hz cut-off frequencies. The processed data was charted in real time during the tests.

In this system, the ropes are guided around two more logs (Fig. 1) that are fixed to a steel frame attached to the northern front of the replica. This arrangement brings the ropes to ground level for force measurements and handling. On these logs, the ropes run over metal plates, which

reduce the friction to negligible levels so that, the forces arriving at the measurement system are essentially the same as the ones on top. Each rope then runs through a roller, is reversed by the lower log and finally runs through a hoop (red hoops in Fig. 1) in an "8" configuration similar to the one used in climbing. That way, a handler can control it even if the force is very large. The roller is hooked to the steel frame, with a load cell in-between (Fig. 1). Thus, the load cell measures twice the force that is in the rope before it enters the red hoop. A single person handled one rope when measurements were taken.

The load cells were connected to an Autolog 3000 system[1], where the raw data was digitized at 100 points/sec, calibrated to represent the forces in Newton, and sent to a Laptop where the measurements were stored in separate files for each test. Using the program Labview Version 2015[2] from National Instruments, the raw data was processed in a standard fashion (Fig. 2). Real-time charts of the processed data allowed immediate interpretation and actions by the handlers during the tests.

A number of trials were done without the measurement system after test no. 9. At this point, we knew that the forces are small, but could not be handled without suitable control. We used the red hoops to test several possible control devices (Fig. 3).

Fig. 3. Rope setting during trials to develop a suitable rope control device. The measurement system is removed so that the controller (here a double loop in the red hoop) receives the full force. (photo by C. Nguyen)

The final control device emerged from this experience and considering appropriate archaeological evidence (see fig. 10 in Part 1).

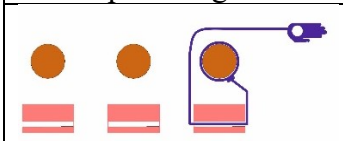
The testing process and the development of the testing program are described in Part 1. There, tables 2 and 3 describe the tests where force measurements were possible. These measurements are reported in detail in the following chapter. The data files are available on request for those who need them for further scientific studies.

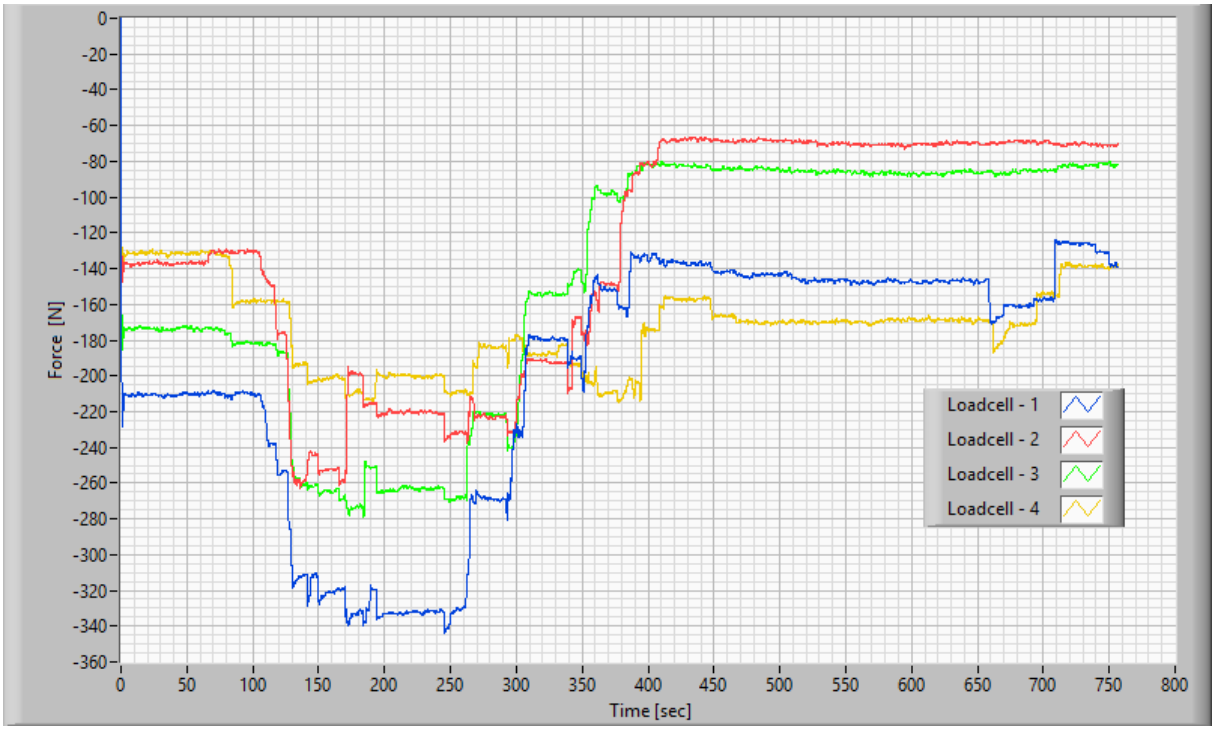
[1] Autolog 3000 Specification
[2] Labview V 2015

Test results

Test 1

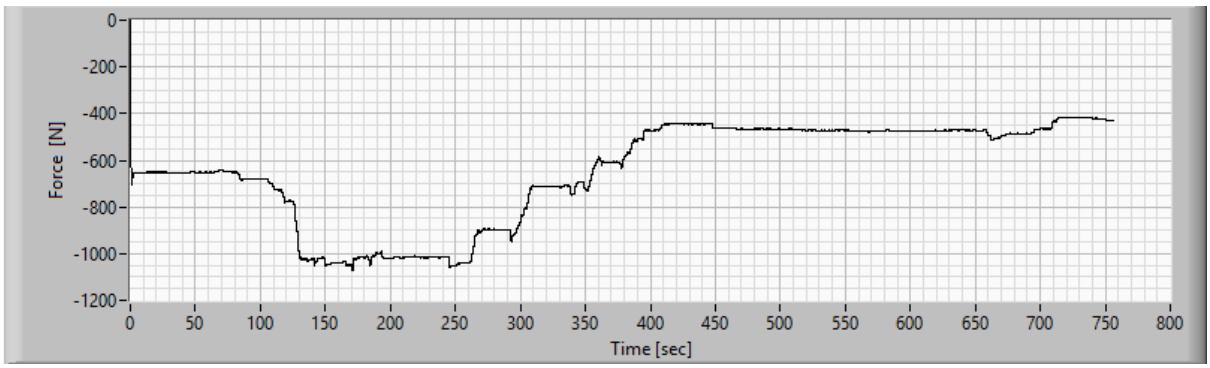
Date 14.06.2017

Rope configuration	Remarks	Data File
	Forces are surprisingly low. Measurement system checked and o.k. 2-stage rope brakes on North log almost prevent operation. $F_1 = 172$ N, $F_2 = 131$ N, $F_3 = 140$ N, $F_4 = 107$ N	Cheops_Test_1



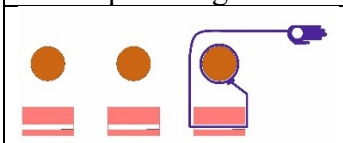
Total force ca. 500 N

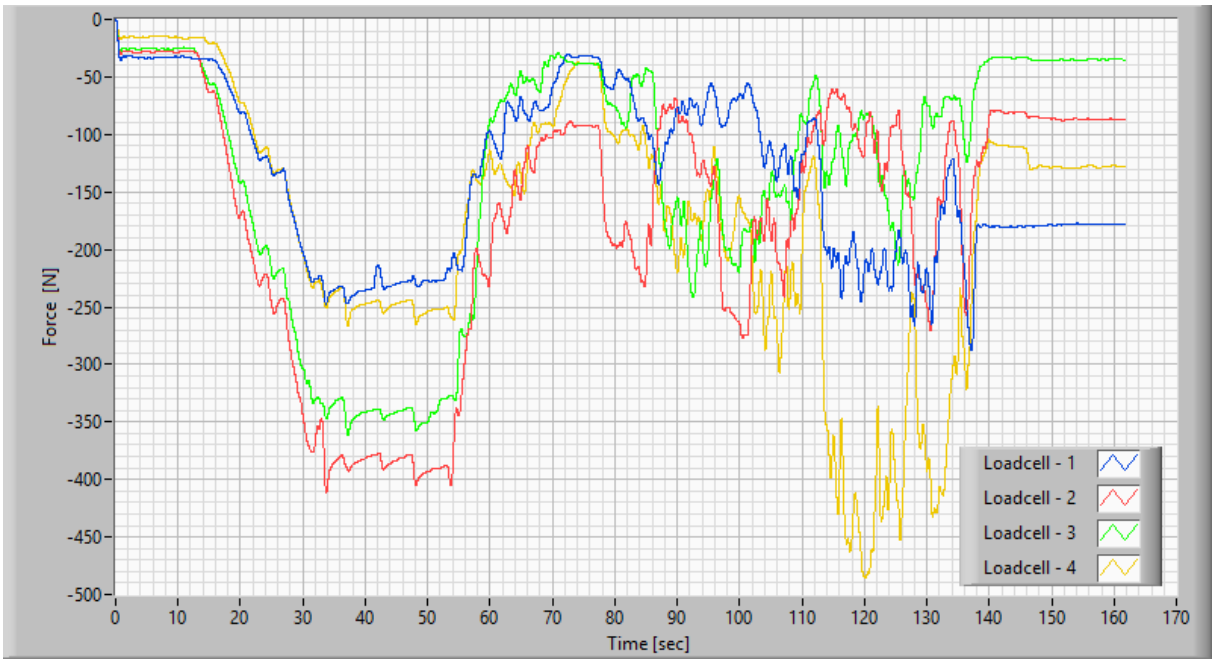
Rest 240 N



Test_2

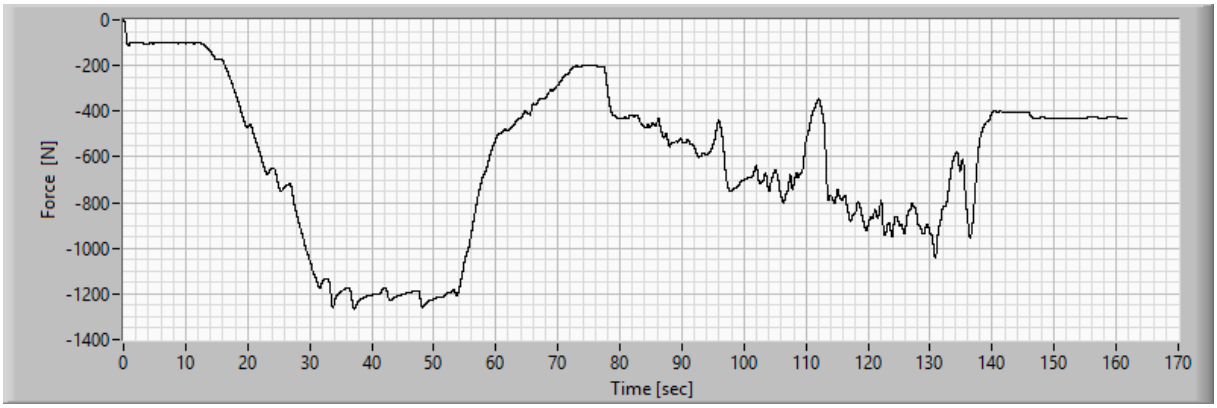
Date: 21.06.2017

Rope configuration	Remarks	Data File
	1-stage rope brakes on North log. Crane remains attached for safety. Picks up block during operation at 55 s, 112 s and 135 s $F_1 = 144$ N, $F_2 = 206$ N, $F_3 = 181$ N, $F_4 = 242$ N	20170621-093952



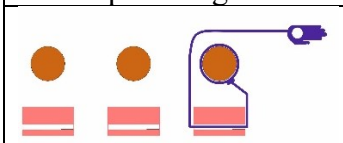
Total force ca. 600 N

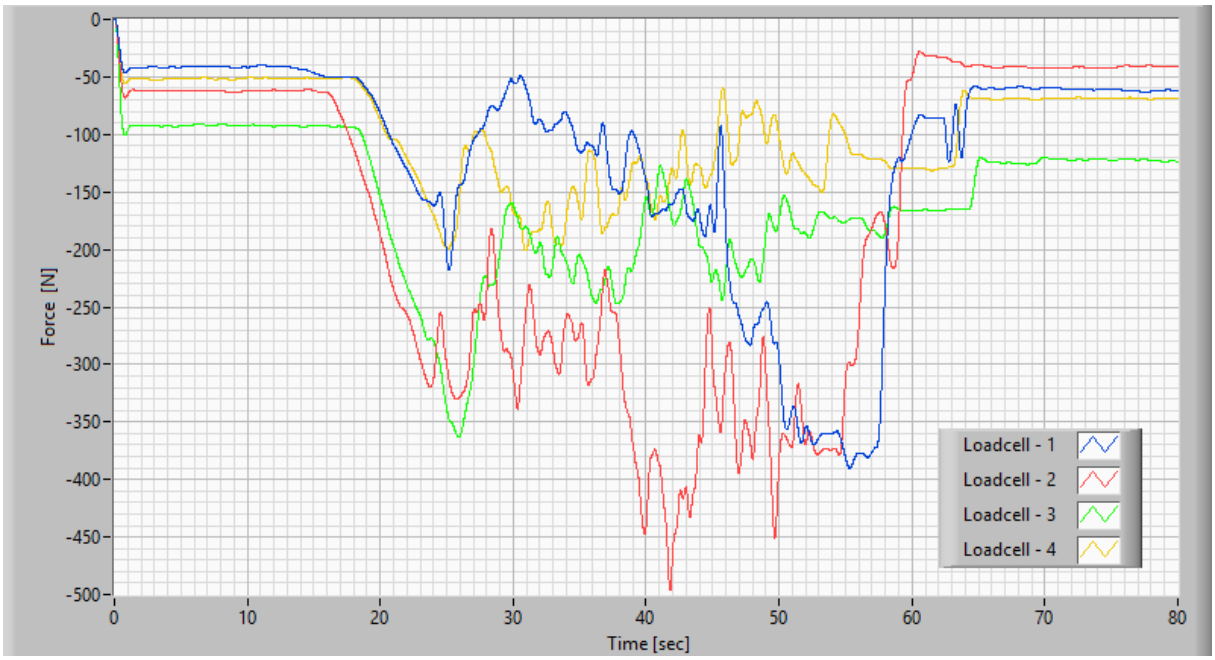
Rest from 200 N to 450 N



Test_3

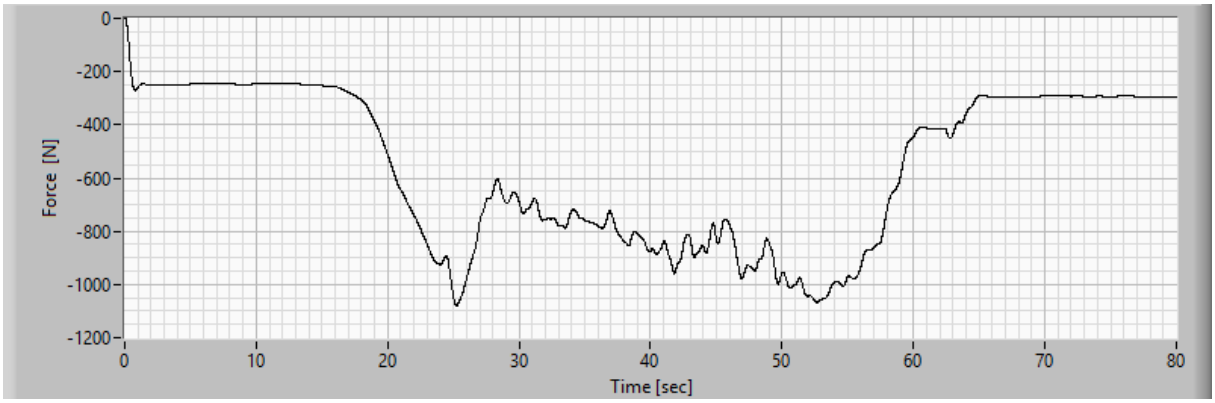
Date: 21.06.2017

Rope configuration	Remarks	Data File
	1-stage rope brake on North-log. Test 2 repeated without crane: Uneven rope handling tilts block sideways, picks up friction on sidewalls. $F_1 = 195$ N, $F_2 = 248$ N, $F_3 = 182$ N, $F_4 = 100$ N	20170621-104611



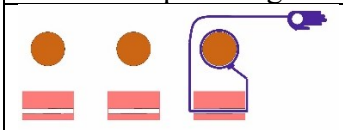
Total force ca. 450 N

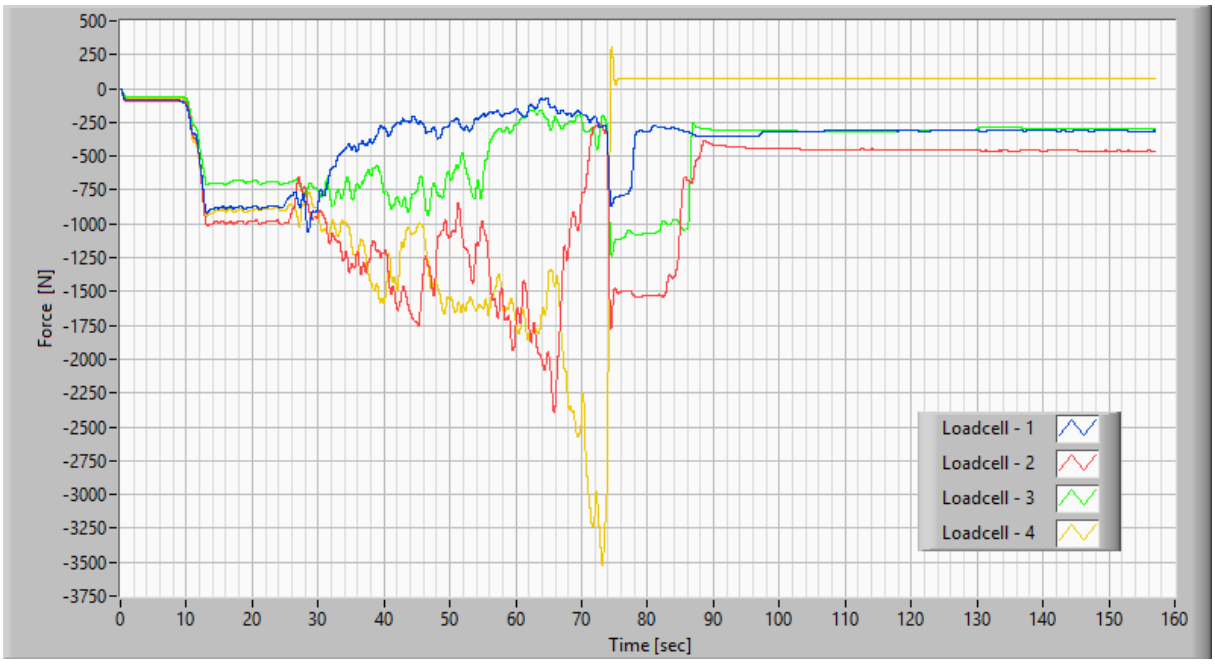
Rest 150 N



Test_4

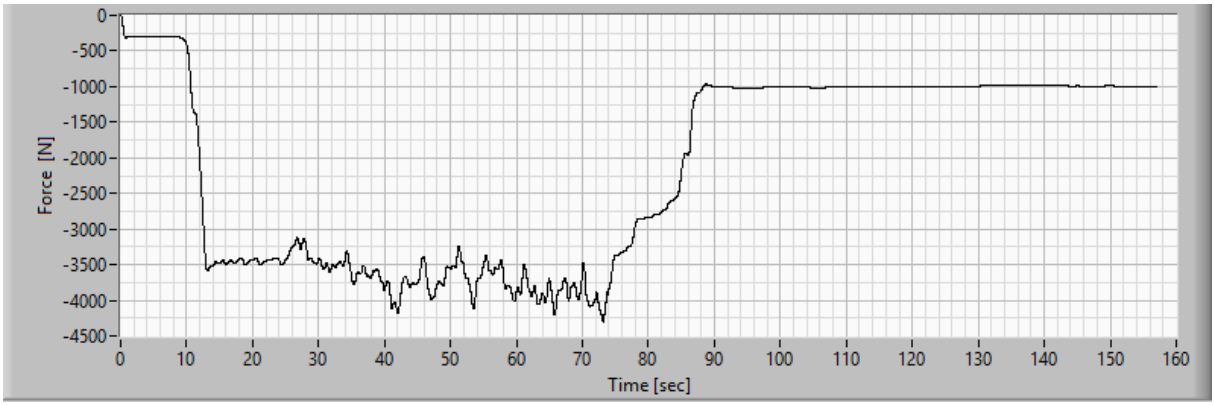
Date: 21.06.2017

Rope configuration	Remarks	Data File
	Friction causes force jitters. Rope 4 gets stuck in its red control hoop and ruptures. Small pieces break off block corners. $F_1 = 530$ N, $F_2 = 1198$ N, $F_3 = 621$ N, $F_4 = 1762$ N	20170621-115833



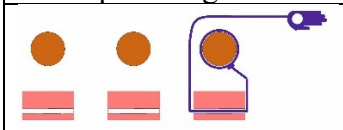
Total force ca. 1950 N

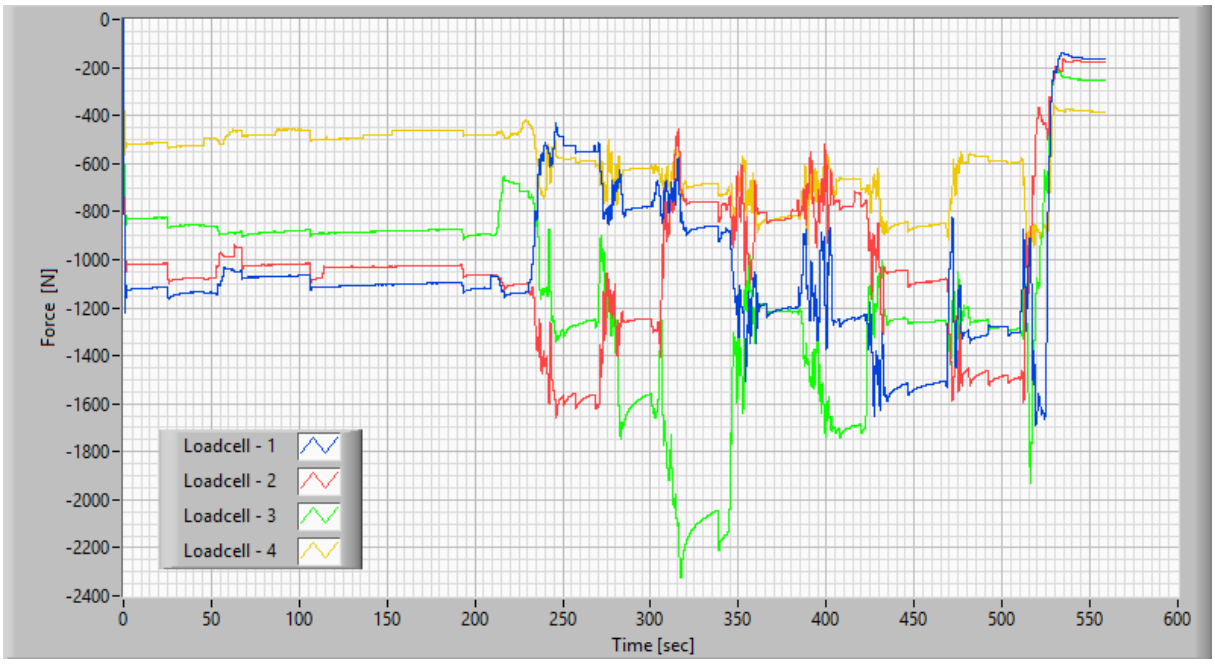
Rest 500 N



Test_5

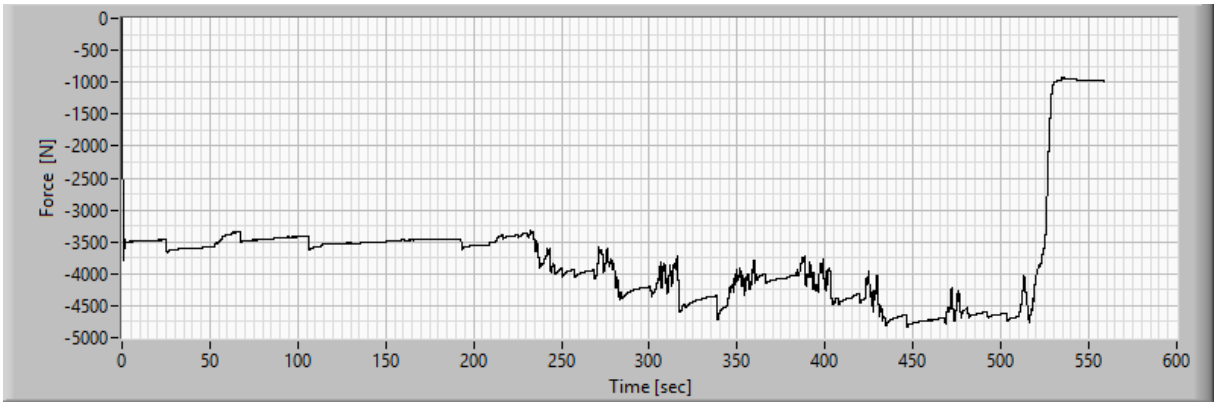
Date: 21.06.2017

Rope configuration	Remarks	Data File
	Test 4 repeated. Uneven rope handling causes serious force re-distribution. Forces about 4-times larger than with rope brake. $F_1 = 844$ N, $F_2 = 828$ N, $F_3 = 1163$ N, $F_4 = 493$ N	20170621-143634



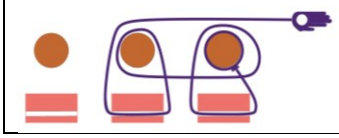
Total force from 1750 N to 2375 N

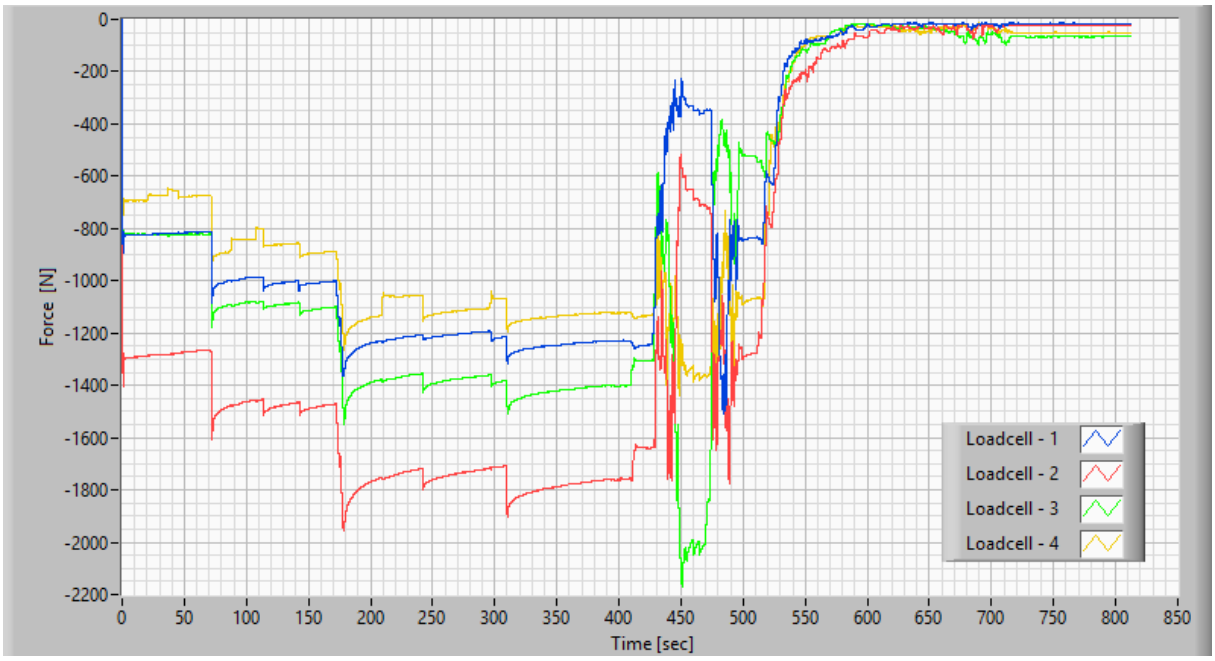
Rest 500 N



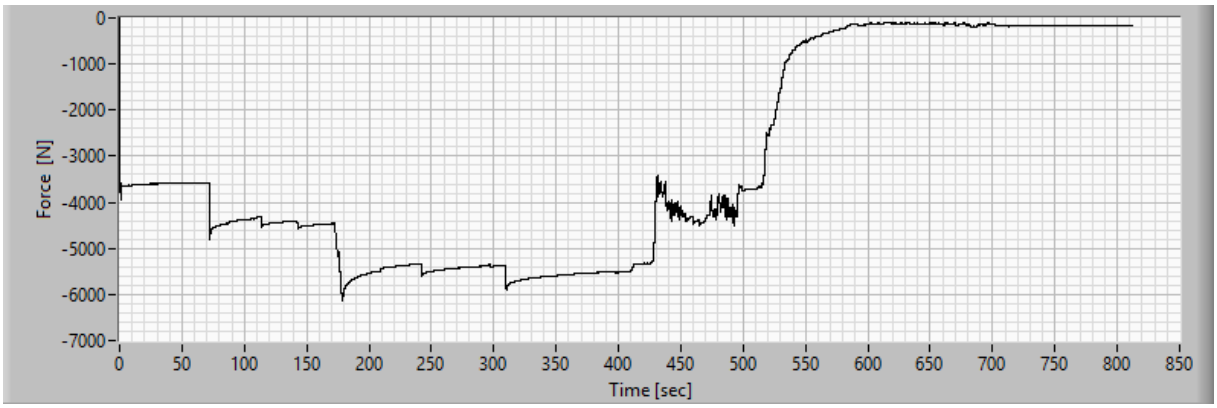
Test_6

Date: 21.06.2017

Rope configuration	Remarks	Data File
	Crane hangs M-block first, then N-block. N-block operation is difficult: forces are too small. $F_1 = 172$ N, $F_2 = 131$ N, $F_3 = 140$ N, $F_4 = 107$ N	20170621-171209

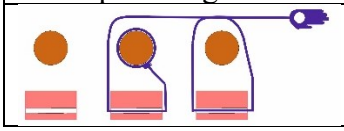


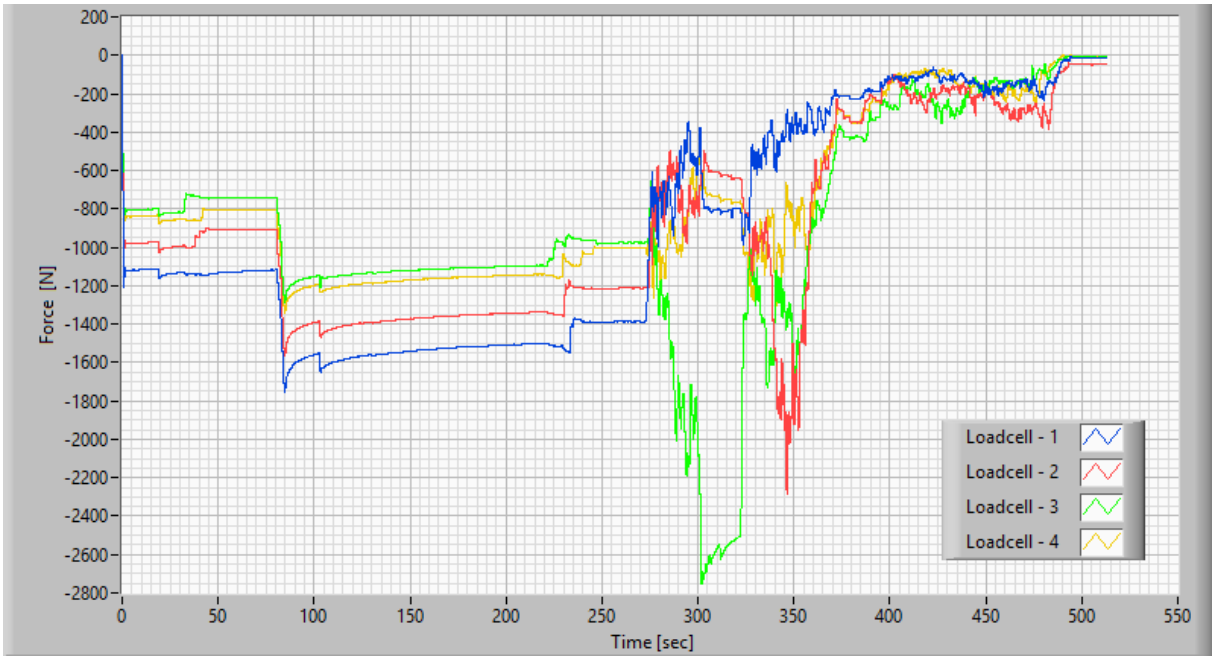
Total force Middle block ca. 2100 N, North block ca. 50 N



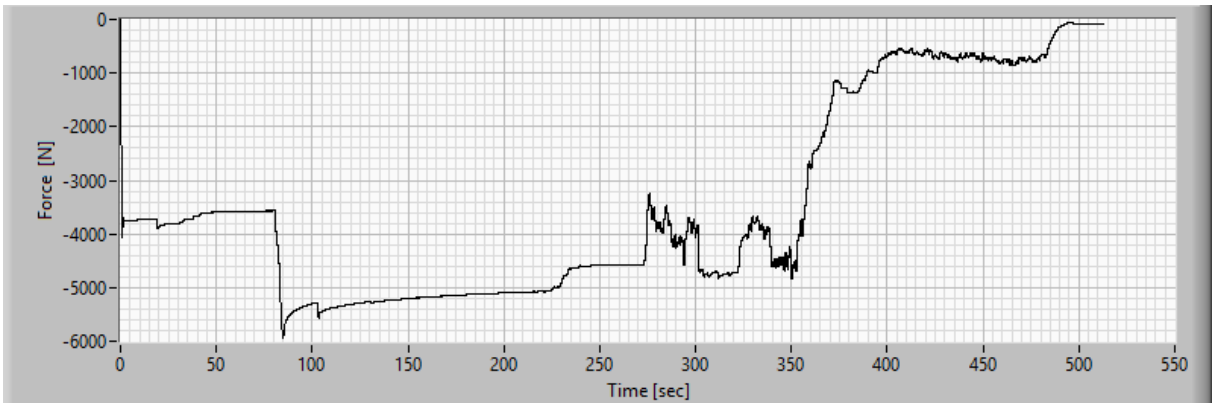
Test_7

Date: 22.06.2017

Rope configuration	Remarks	Data File
	Crane hangs N-block first, then M-block. Smooth operation of M-block. $F_1 = 497$ N, $F_2 = 1141$ N, $F_3 = 1376$ N, $F_4 = 655$ N	20170622-170046

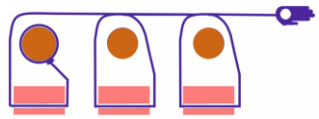


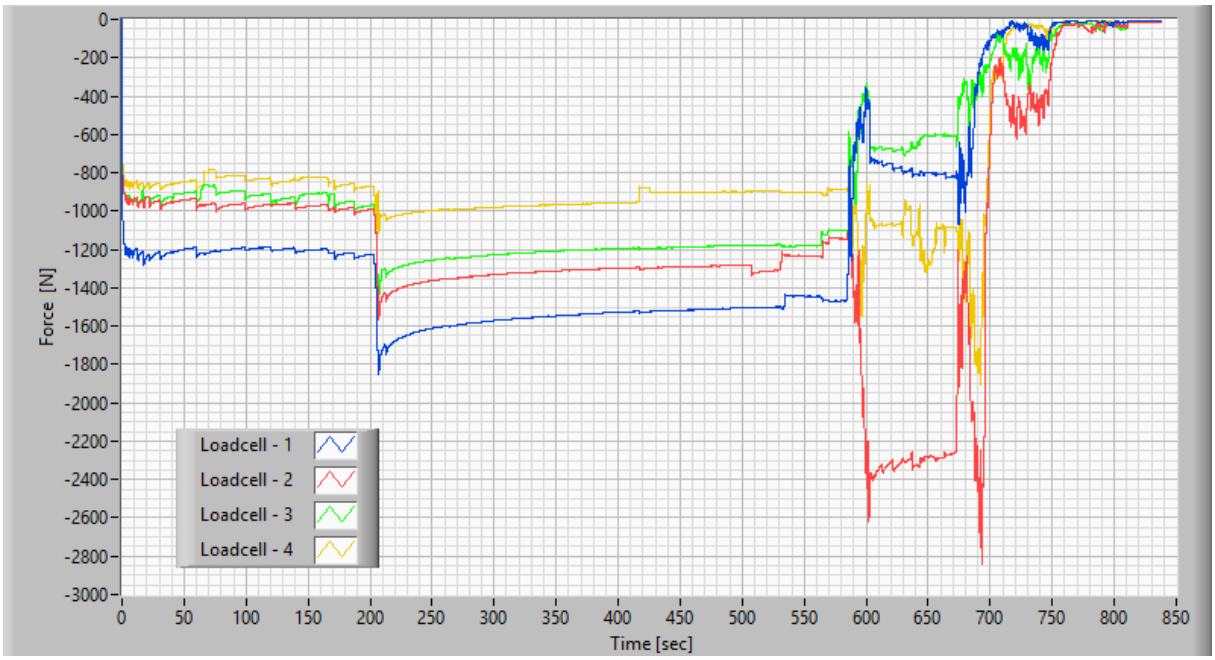
Total force North block ca. 2250 N, Middle block ca. 450 N



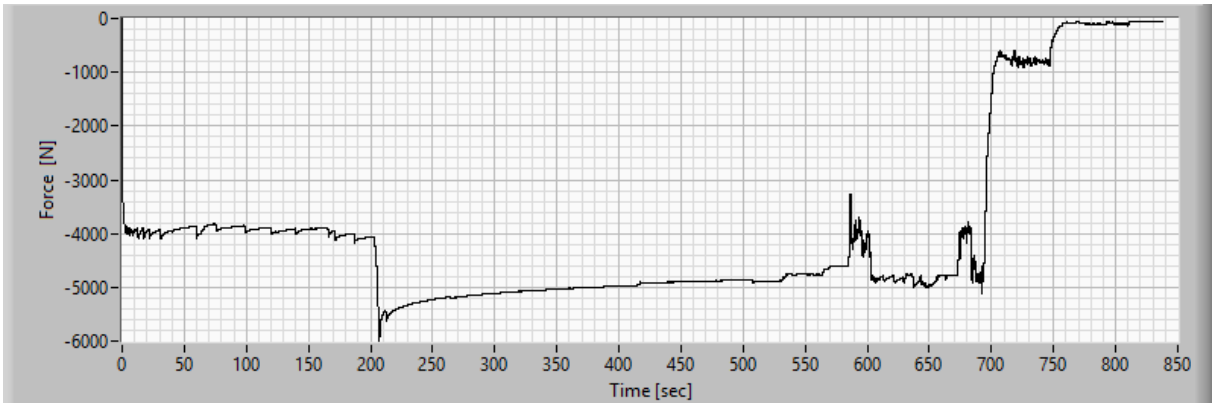
Test_8

Date: 22.06.2017

Rope configuration	Remarks	Data File
	Crane hangs N-, then M-, then S-block. Roller 2 blocks temporarily. S-block operation is difficult: forces are too small. $F_1 = 629$ N, $F_2 = 1420$ N, $F_3 = 485$ N, $F_4 = 952$ N	20170622-182523

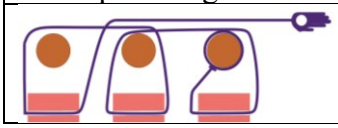


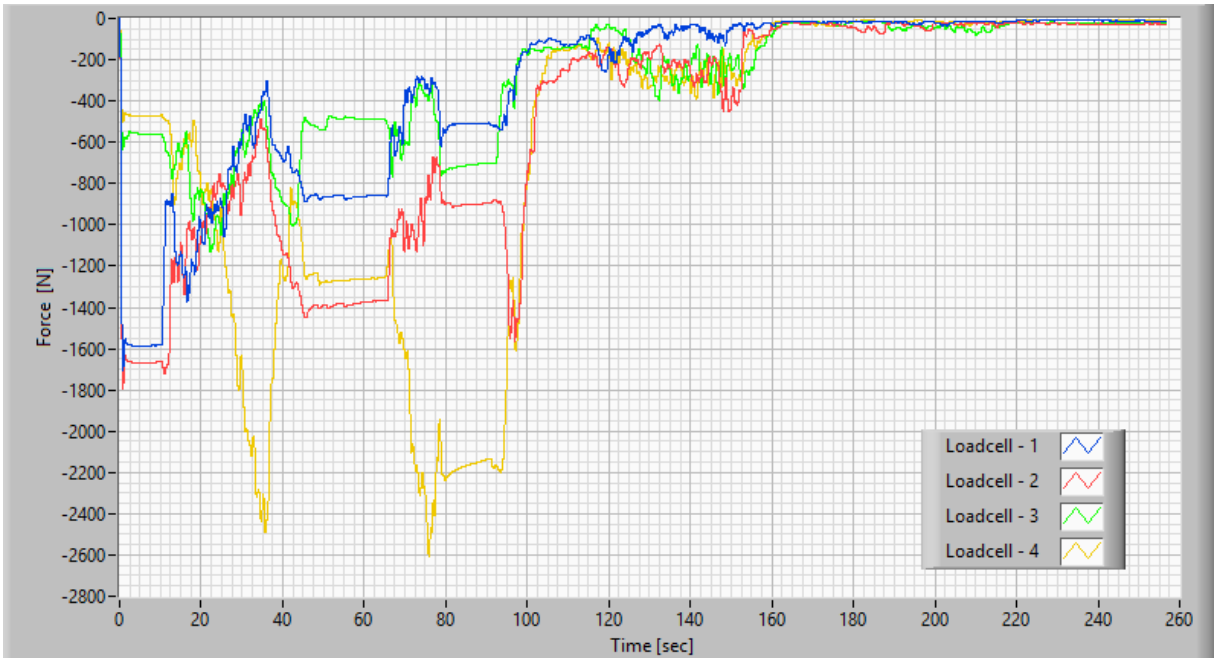
Total force North block ca. 2400 N, Middle block ca. 450 N, South block ca. 20 N



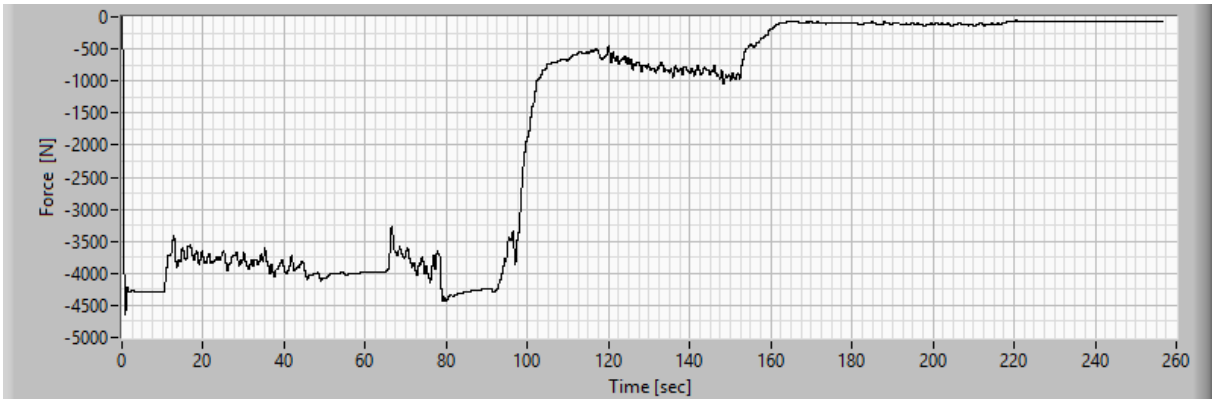
Test_9

Date: 05.07.2017

Rope configuration	Remarks	Data File
	Crane hangs N-, then M-, then S-block. M- and N-block operation difficult. $F_1 = 686$ N, $F_2 = 784$ N, $F_3 = 566$ N, $F_4 = 1304$ N	20170705-100239



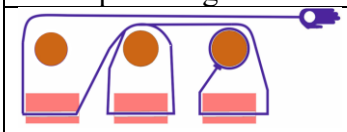
Total force South block ca. 2050 N, Middle block ca. 450 N, North block ca. 50 N

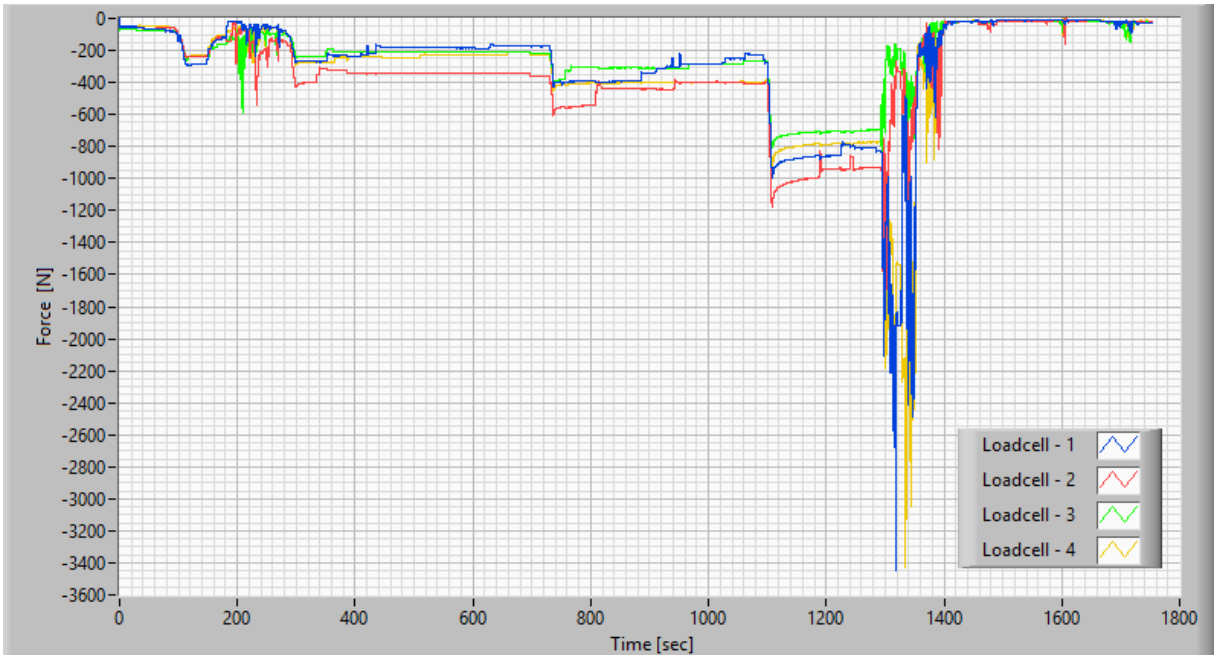


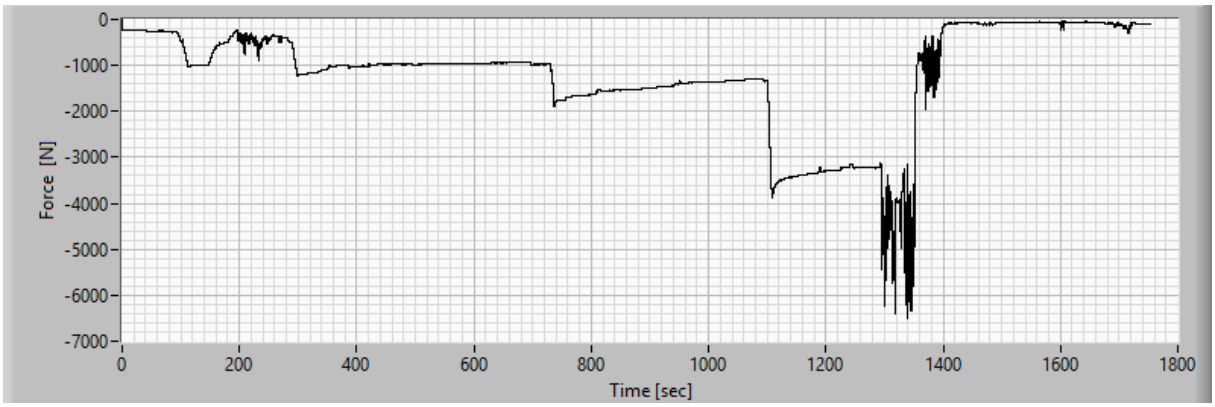
Test_24

Date: 30.01.2018

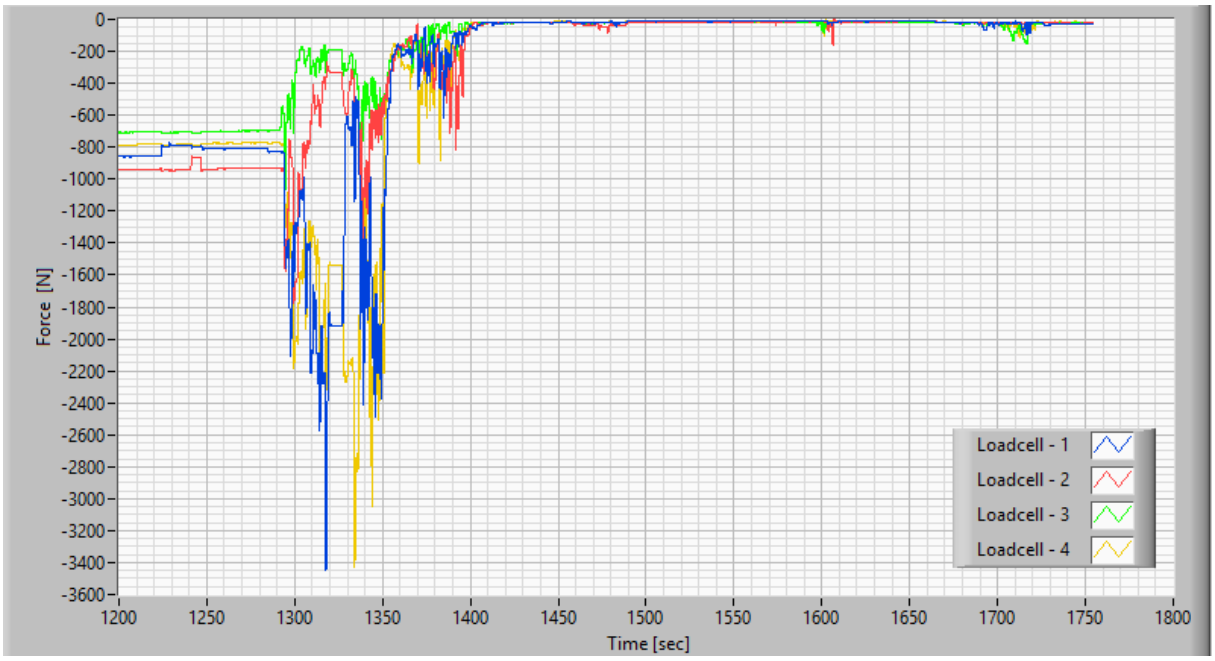
Lubricated

Rope configuration	Remarks	Data File
	1-stage brakes on South log. Crane hangs M-, then N-, then S-block: Sag: M: 22.5 cm, N: 0 cm, S: 5 cm F_1 = 1722 N, F_2 = 889 N, F_3 = 530 N, F_4 = 1715 N	20180130-121332

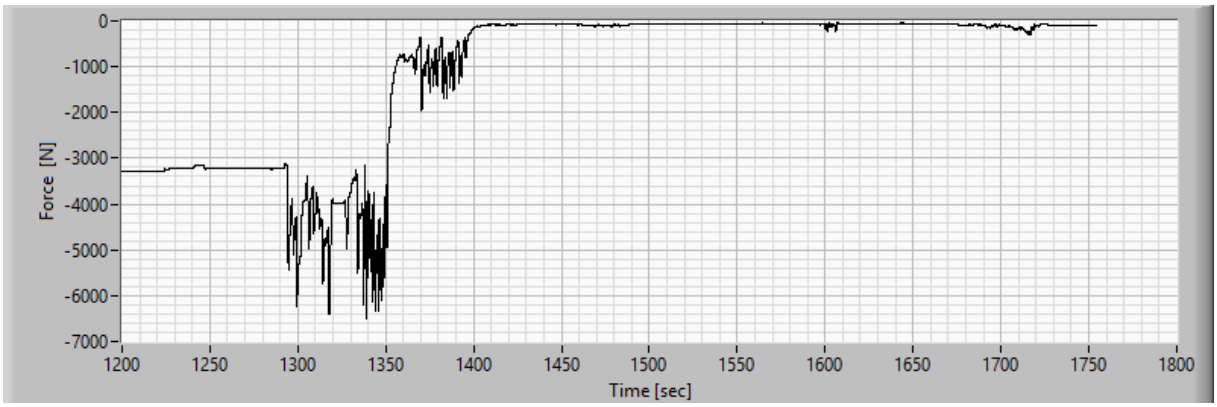




Release process



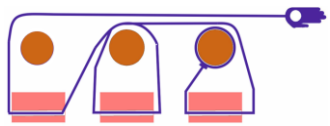
Total force South block ca. 2500 N, Middle block ca. 500 N, North block ca. 50 N

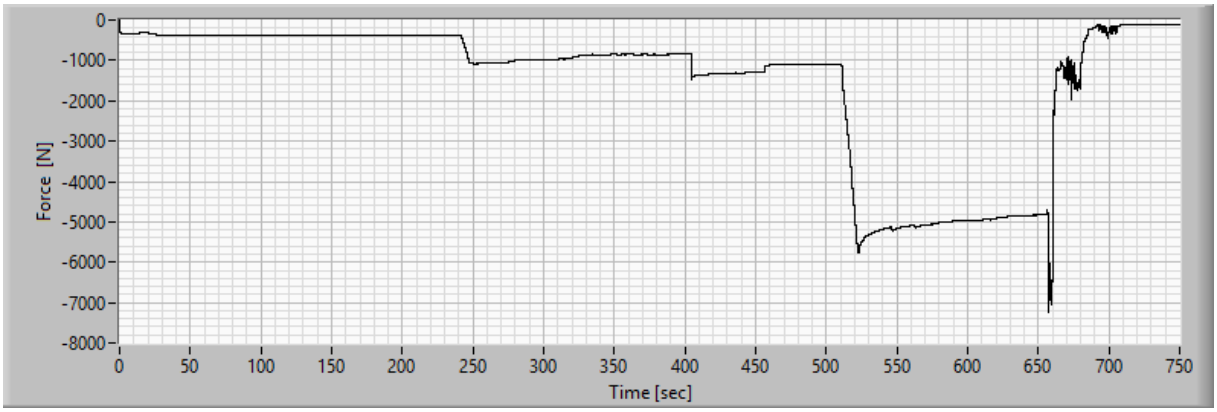


Test_25

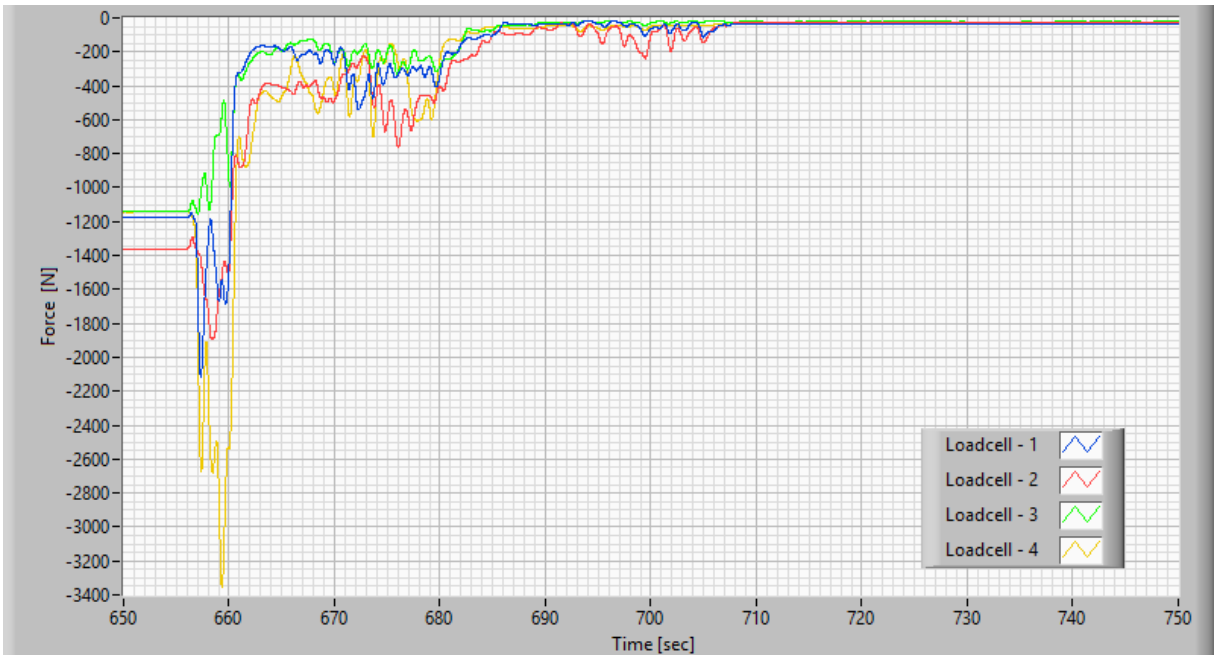
Date: 30.01.2018

Lubricated

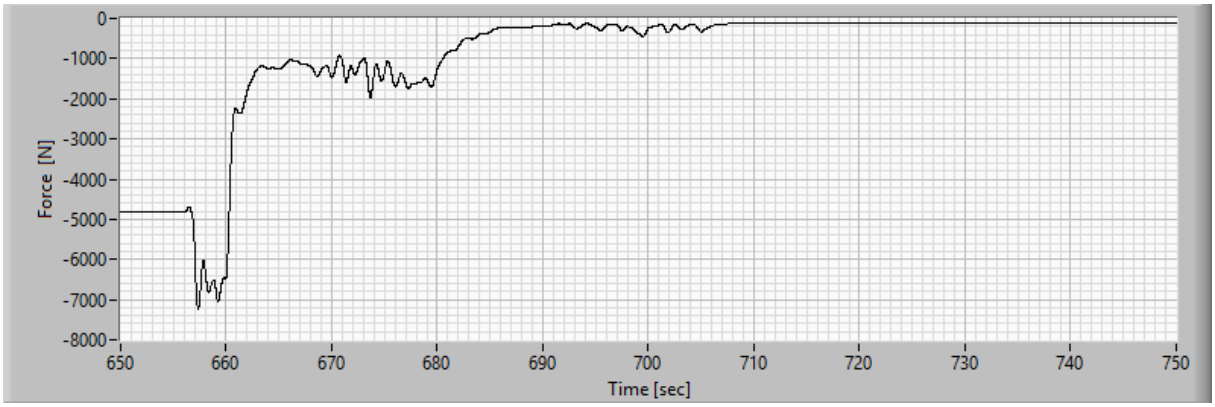
Rope configuration	Remarks	Data File
	Crane hangs N-, then M-, then S-block. M-block picked up again to equilibrate sag: N: 10 cm, M: 8 cm, S: 12 cm $F_1 = 1057$ N, $F_2 = 948$ N, $F_3 = 580$ N, $F_4 = 1677$ N	20180130-153835



Release process



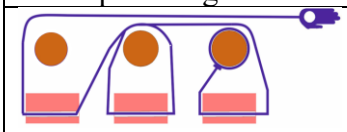
Total force South block ca. 3200 N, Middle block ca. 750 N, North block ca. 150 N

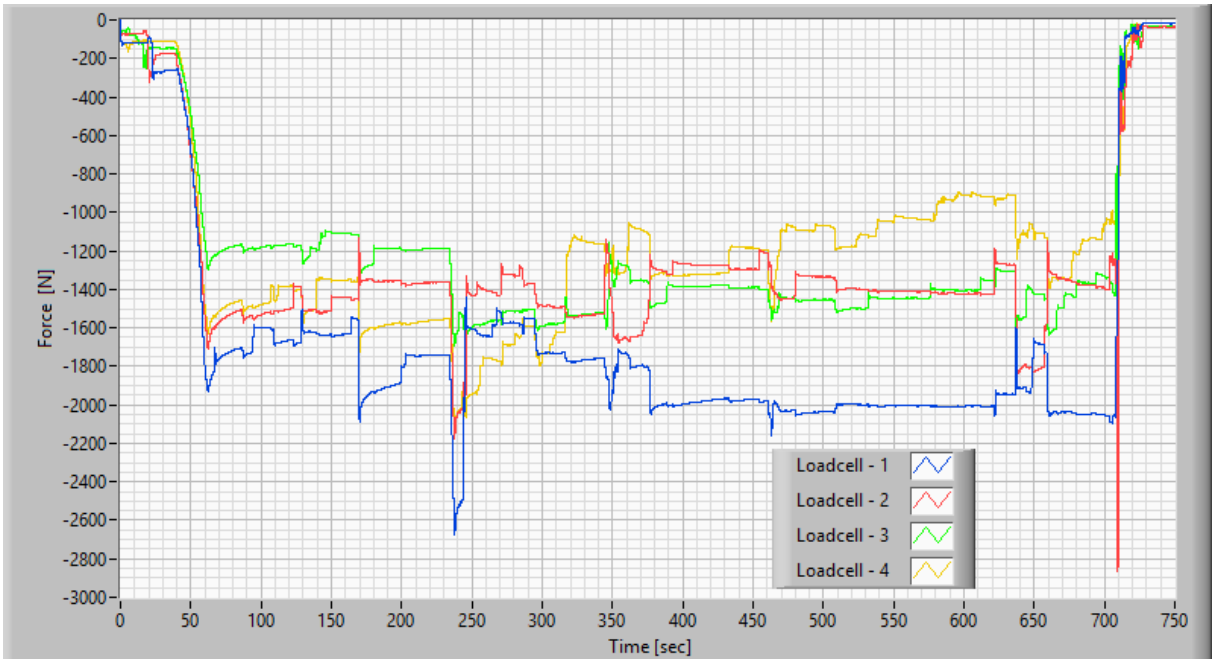


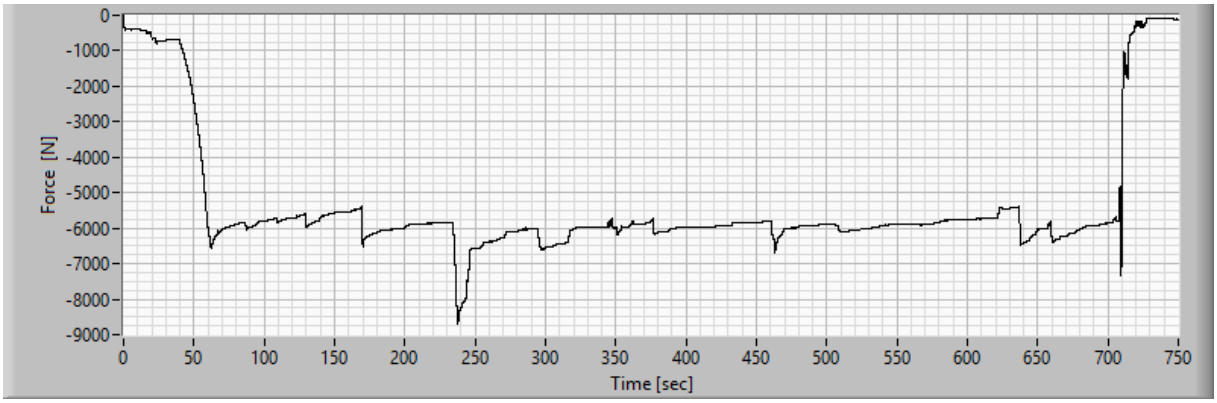
Test_26

Date: 30.01.2018

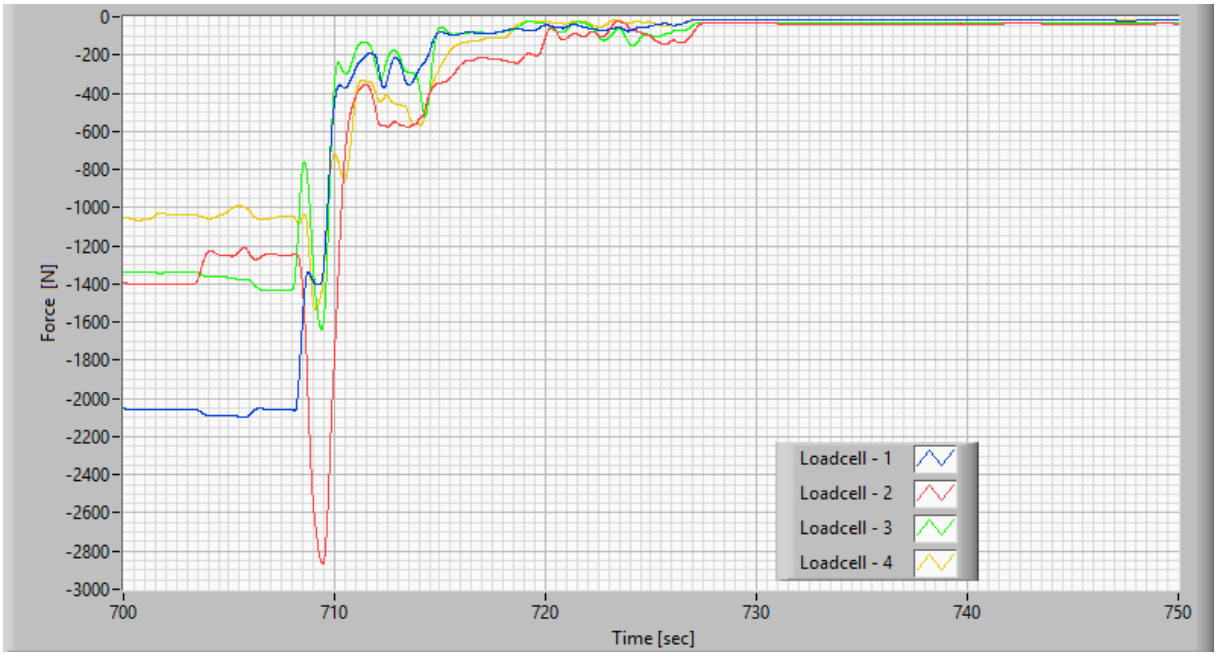
Lubricated

Rope configuration	Remarks	Data File
	Crane hangs S-, then M-, then N-block: Sag: S: 41.5 cm, M: 1 cm, N: 1 cm $F_1 = 1032$ N, $F_2 = 1432$ N, $F_3 = 818$ N, $F_4 = 769$ N	20180130-164454 #2

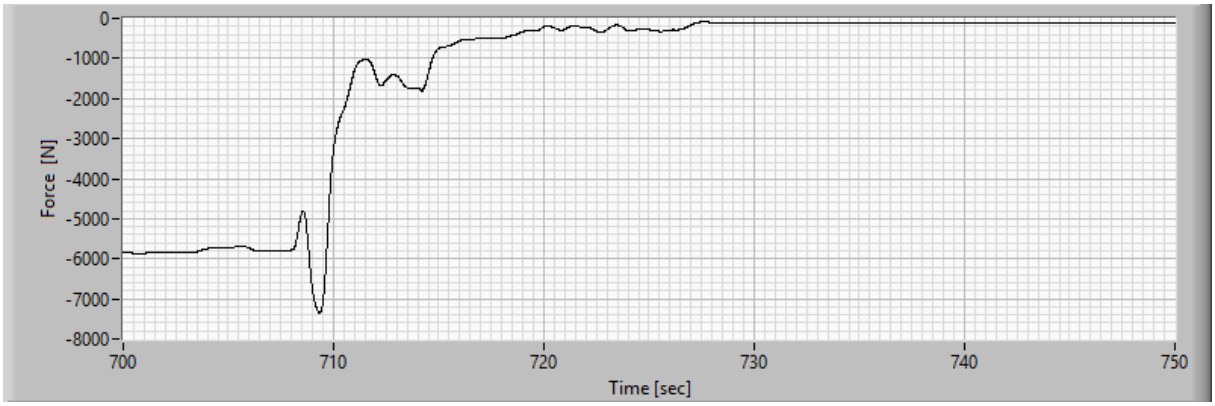




Release process



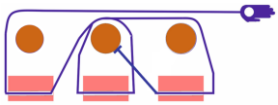
Total force South block ca. 3200 N, Middle block ca. 750 N,North block ca. 100 N

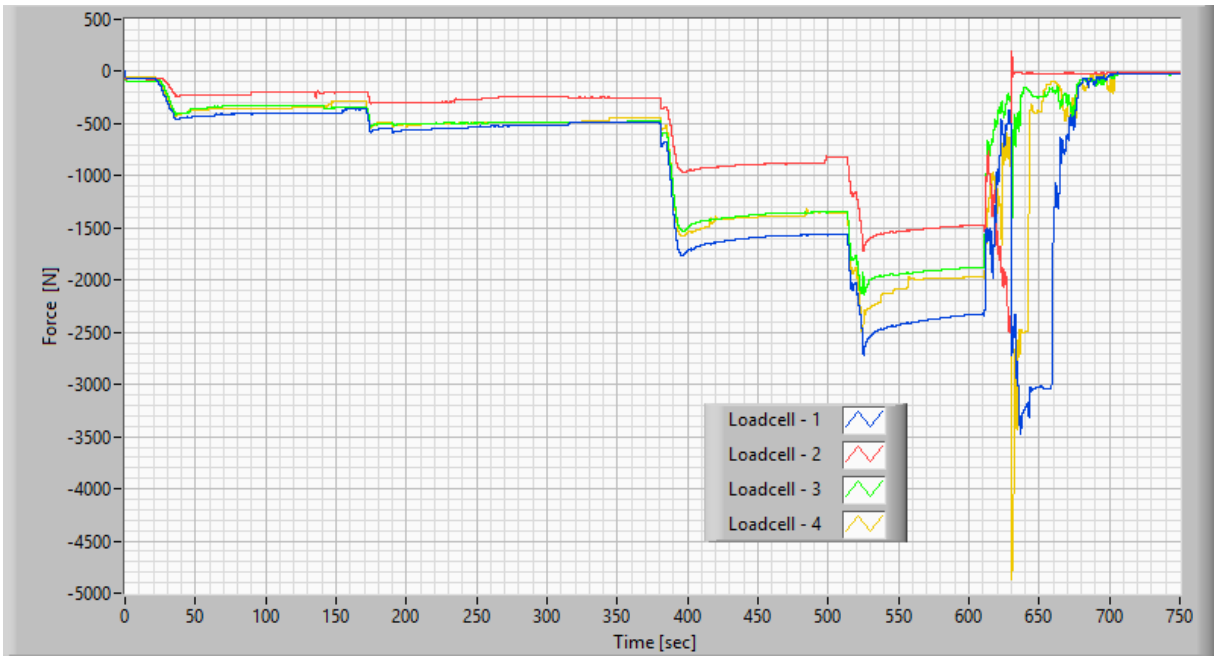


Test_40

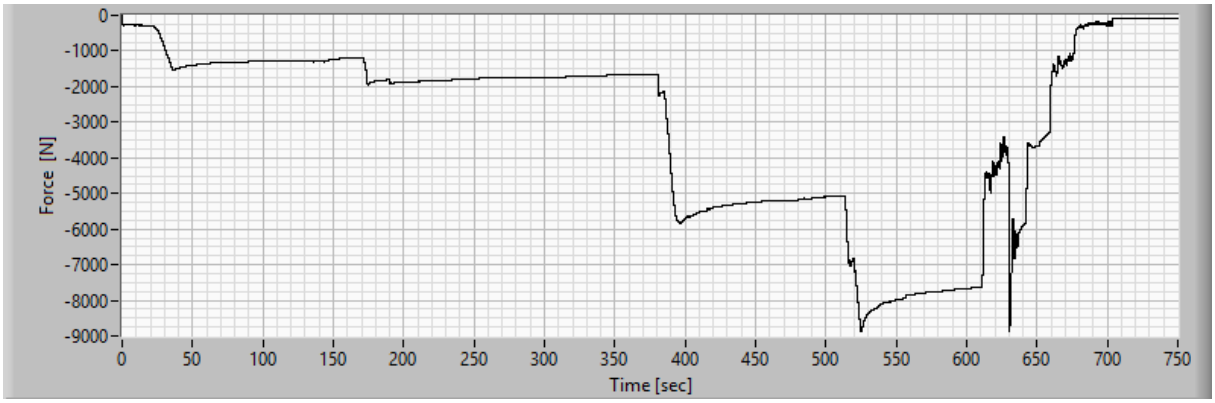
Date: 06.02.2018

Lubricated

Rope configuration	Remarks	Data File
	1-stage rope brakes only on ropes 2 and 3. Rope 2 ruptures. It was too worn out. $F_1 = 1735$ N, $F_2 = 1281$ N, $F_3 = 742$ N, $F_4 = 2432$ N	20180206-135315



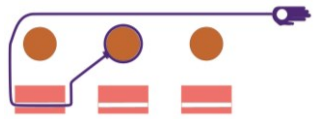
Total force South block ca. 2600 N, Middle block ca. 750 N, North block ca. 250 N

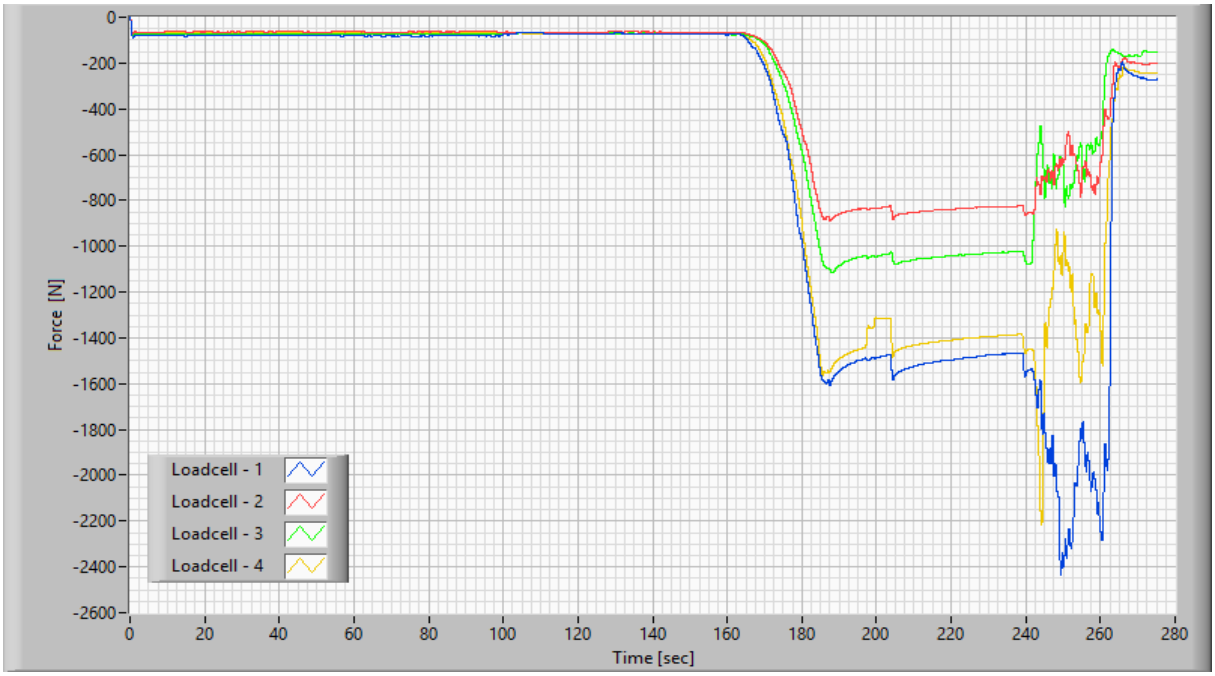


Test_41

Date: 09.02.2018

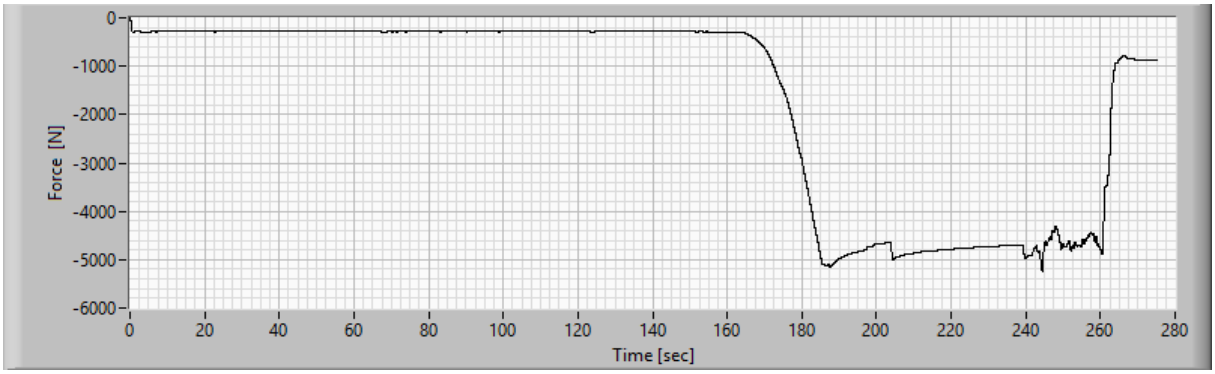
Lubricated

Rope configuration	Remarks	Data File
	During public presentation Feb. 9, 2018 $F_1 = 1225$ N, $F_2 = 430$ N, $F_3 = 538$ N, $F_4 = 1110$ N	20190209



Total force South block ca. 2400 N

Rest 450 N



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