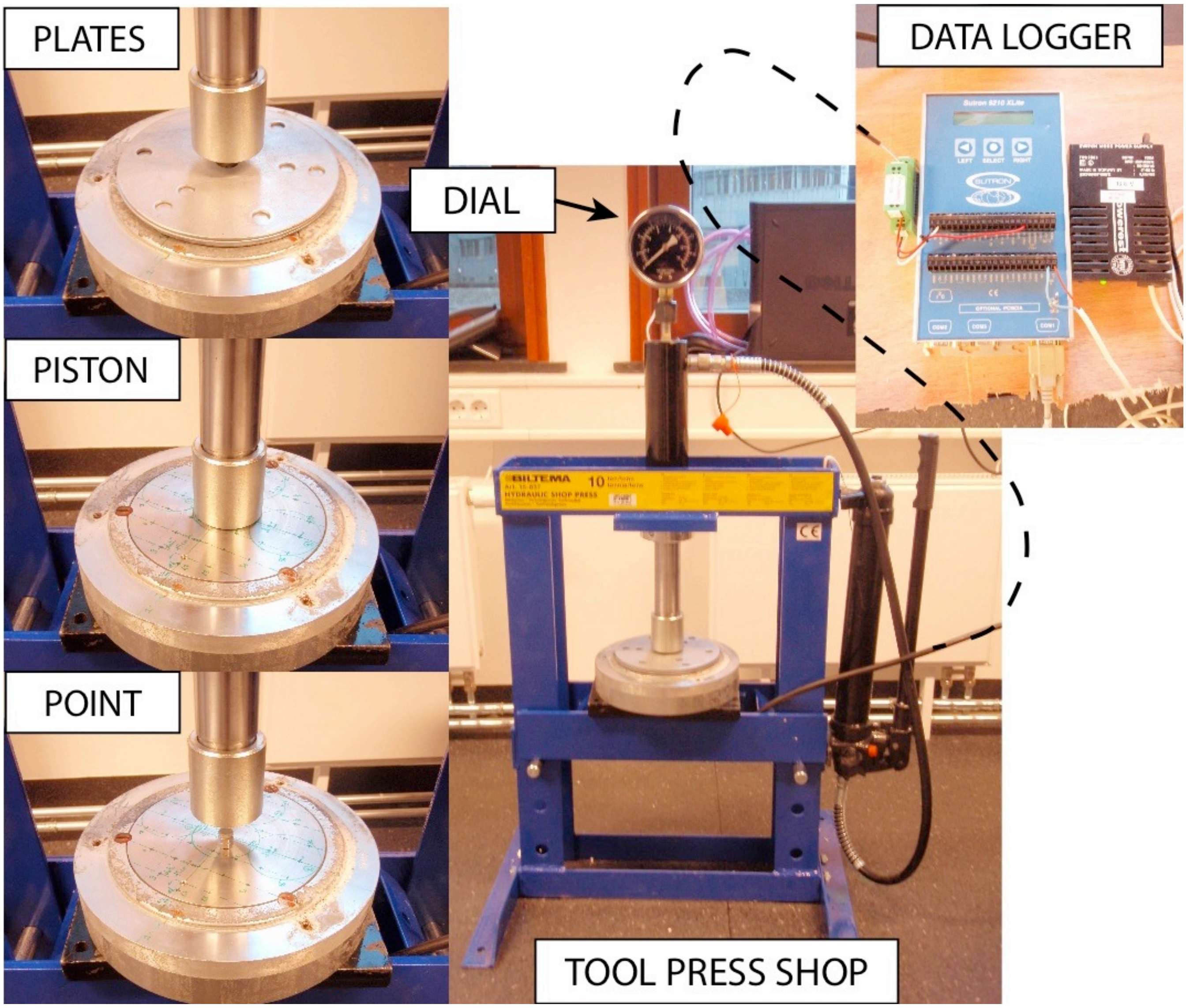
PRELIMINARY RESULTS OF THE LOAD CELL TEST



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Location: NVE
Helped by the NVE Technical Service, Miriam, Knut and finally Coline (during the test).

Reminder:

A Force ***F*** "is that which can cause an object with mass to accelerate" (Wiki). This is calculated by multiplying the mass *m* of a body by the acceleration due to gravity ***g***, which on Earth is equal to 9.81 m s^{-1}. The unit of the Force is the Newton [N], which in S.I. is equal to [kg m s^{-2}]. The Pressure *P* is defined as a force exerted on an object surface or area *A* and is measured in [Pa] or [bar] or in S.I. [kg m^{-1} s^{-2}]. For conversion, 1 bar equals 10^5 Pa.

$$P = \mathbf{F}/A = (m*\mathbf{g})/A$$

Methods:

This test consisted in applying a mass to the load cell plate and in varying the area of contact between the piston of the tool press shop and the load cell (see the first page picture). The used apparatus was composed of a hydraulic pump and a piston. A handle served to increase the pressure in the pump. The load was spread over the whole plate ("plate test"), then over a 5 cm diameter disc ("piston test") and finally over a 0.25 cm diameter point ("point stress test"). During that test, the load was fixed to 500 kg, in order to not overpass the maximum pressure of the sensor and for easier reading.

For the point stress analysis, a grid of 37 points with 7 rows and 7 columns was created to test the sensitivity of the load cell plate. The space between two points was about 2 cm, except for the point 16 and 22, which were 2.6 cm away from their neighbouring point on the horizontal axis (see Figure 1). A screw of 25 mm diameter with some screw nuts (to keep it steady) was placed at one point of the grid between the piston and the load cell (see Figure 1). The data logger recorded at 1 min interval the Frequency [Hz] of the load cell wire, which was then converted in Pressure [bar] using a calibration curve specific to the load cell (Figure 5). First, the data logger recorded the pressure of the exerted mass, and then the load was removed to get the zero value of the load cell. We did that three times per point and then we moved the screw to the following one.

For the piston test, only 5 points were defined and their centres were located at the points 6, 17, 19, 21 and 32, which were called point C, E, A, D and B, respectively (see Figure 1). The piston (5 cm of diameter) was directly in contact with the plate. During that test, we followed the same procedure than previously.

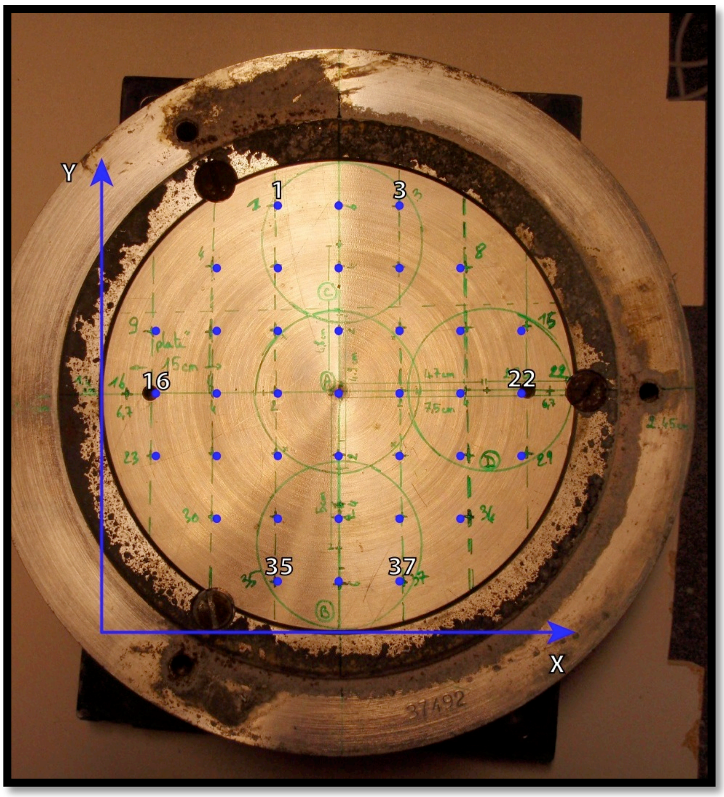

Figure 1: Map view of the load cell with in blue the grid used for the point stress test. 4 of the 5 positions tested with the piston are also drawn in green (A, B, C, D). Note that point 16 and 22 are shifted. They should be seven millimetres away toward the outer part of the load cell.

Issues:

The first tests over passed the pressure range accepted by the load cell. According to the fabricant, the sensor can measure from 0 to 50 bars. The maximum load applied using the piston was about 4 tons, for which the load cell recorded a pressure of about 80 bars. Considering that the load was spread over an area of 19.6 cm^2 (5 cm of diameter), the pressure must have been equal to 200 bars at the location of the piston. However, this stress was transferred over the whole plate increasing the surface area to 177 cm^2, which should then give a computed pressure of 22 bars. Those differences indicate either a complex stress transfer from the piston to the load cell or a bias in the load cell when the pressure is not homogeneously distributed. The 80 bars value was repeatedly reached the first week of the experiment, which could have damaged the load cell. Nevertheless, the consistency of the measurements obtained during the point stress test and piston test (low standard deviation) convinced us that the load cell functioned correctly.

We also noticed that the tool press shop was quickly losing pressure and unfortunately this leak couldn't be fixed. Therefore to keep the pressure constant, the users had to manually pump and check on the dial that it does not vary. To account for that effect, three measurements were taken at each point and then averaged. The standard deviation might reflect the difficulties in maintaining the pressure at the same level.

Bolts were put between the bar where was placed the load cell and the main structure of the apparatus to stop it to move. Despite this precaution, slight motion of the load cell were observed and were of the order of the millimetre or sub-millimetre, notably when the piston was localised on its edges. Those displacement being small, it is supposed to not have influenced the results.

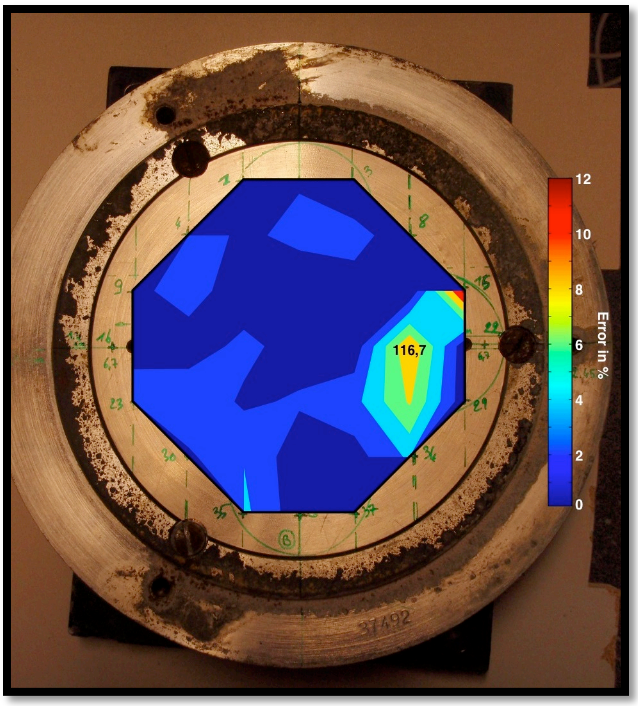

Figure 2: This contour plot displays the error estimate of measurements in %. For one point, its value was reduced to 10% for better plotting, its real error estimate being 116,7%.

To assess the error in the measurements, the standard deviation of the measurements can be divided by the computed pressure and then multiplied by 100 to get an error estimate in percentage. Figure 2 shows that the error is generally below 12% except for one point, which has an error of 116,7% (reduced to 10% in the plot for better visualisation). Thus, that point should not be taken into account during interpretations, but it has been kept in the others contour maps to better show the spatial fluctuation of the computed pressure.

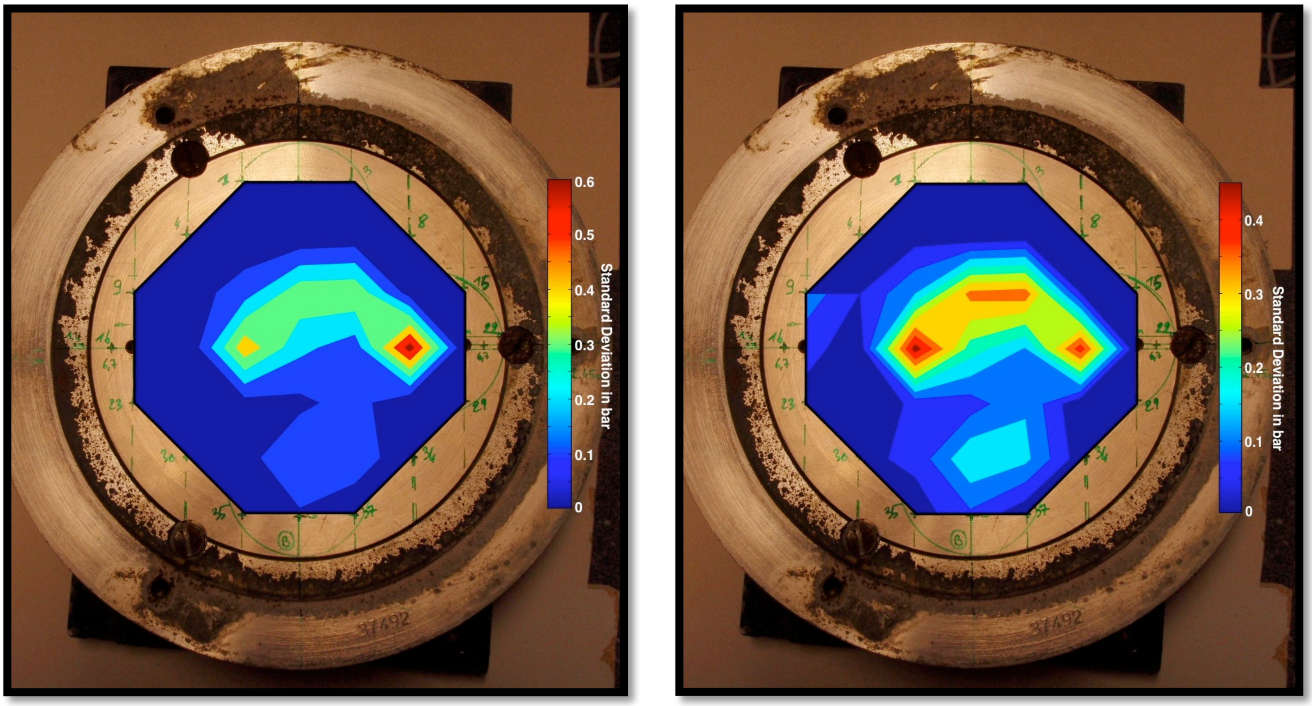

Figure 3: Contour plot of the standard deviation (obtained during the point stress test) before and after the zero correction. The difference between the two graphs is mainly due to a change in scale between the two figures. The point with the highest standard deviation on the first graph is the point that has the highest error in Figure 2.

After each obtained pressure value, the zero was measured. The latter was drifting between -0.056 and 0.082 bars. Thereafter, knowing its variation, a correction was applied to the computed pressure (see Table on the last page of this report). Although the pressure contour map did not vary much, the standard deviation map showed a slightly different picture as shown on Figure 3.

Results:

For the point stress test, the computed pressure ranged from -5 to 23.6 bars. The averaged pressure is equal to 4.5 bars and the measurements have a standard deviation of 7.2 bars. The sum of the whole recorded pressure reaches 166.8 bars and the same calculus for the standard deviation gives 0.098 bars.

For the piston test, the computed pressure ranged from about -1 to 20.6 bars. The averaged pressure is of 5.7 bars and the standard deviation is about 9 bars. The sum of the whole pressure values is about 28.5 bars and the same calculus for the standard deviation gives 0.156 bars.

For the plate test, the load cell recorded a pressure of 17.9 bars with a standard deviation of 1.113 bars.

The Load Cell responds differently when the load is exerted at different point on the plate. In contrary, the area on which is applied the load does not seem to be an important factor as the results of the point stress, piston and plate tests are very similar (see Figure 4).

Negative values of pressure (while the measured frequency was lower than the frequency zero) were recorded on the edges of the x-axis, whereas it was not seen along the centreline of the y-axis.

Looking at the standard deviation (Figure 3), the measurements along the horizontal axis seems firstly more irregular than the vertical axis and secondly at least two points along the x-axis show much higher variation than the other point of the load cell.

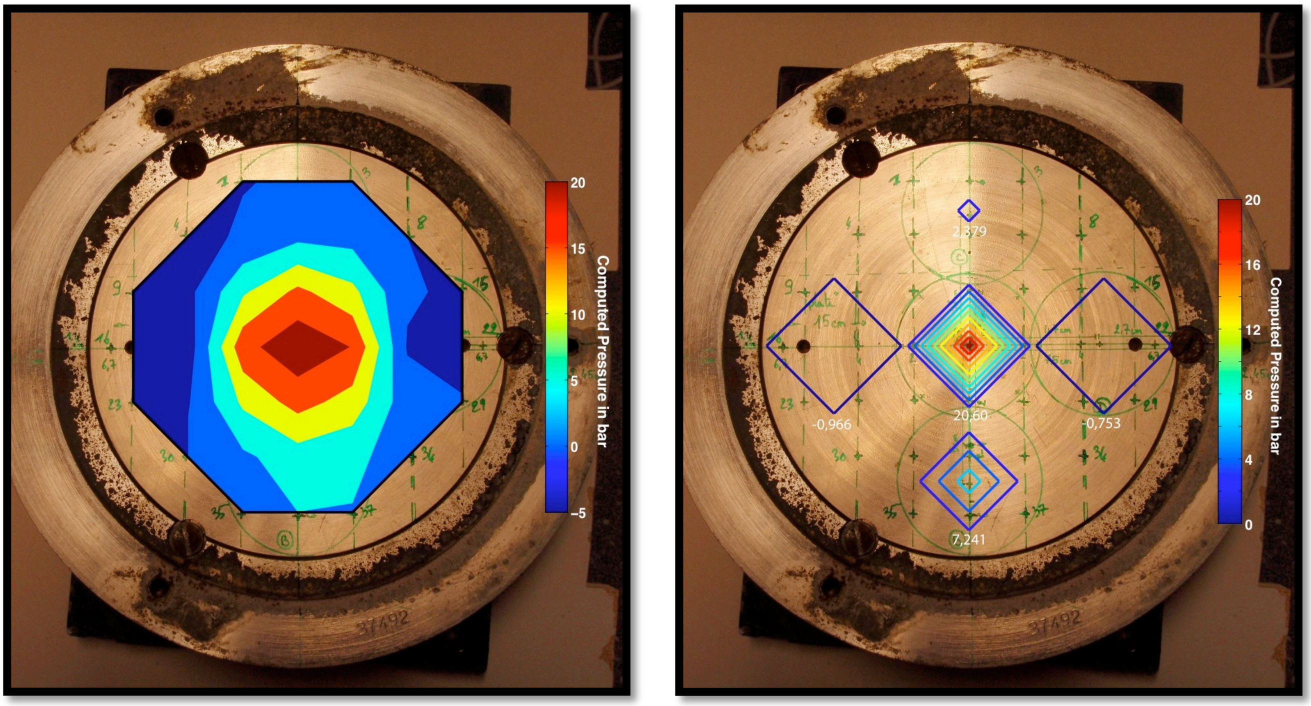

Figure 4: The graph on the left hand side presents the results of the point stress test and the graph on the right hand side displays the results of the piston test. Just for comparison the plate test yielded a pressure of 17.9 bar with 6% error.

Discussion/Conclusion:

The technique used to develop the load cell is indeed very suited for homogeneously distributed stress. The plate bends inward, increasing the distance between the two extremities of the wire, thereby increasing the frequency at which vibrates the wire. However, in our case, if the load is concentrated on the edges of the x-axis, the plate will bend outward decreasing the frequency and giving negative values of pressure.

As expected the fact that the load cell has an uniaxial vibrating wire create an anisotropy in the recorded frequency and so in the computed pressure. The given description of the load cell P-105 being not very explicit, it is awkward to define the axis of the wire by just looking at the outer part of the load cell. Nevertheless, one can notice that the values on the x-axis are firstly varying much more than the y-axis and then they show the steepest gradient along the former [-5, 20] than along the latter [0, 20]. In addition, two holes are drilled on the plate and their direction is parallel to the horizontal axis. From those observations, one can assume that it indicates the emplacement of the wire. Nonetheless, one would expect the wire to be centred underneath the plate, and actually the peaks are not situated around the plate centre but slightly shifted eastward (Figure 3). Thus, the question is does the standard deviation show the location of the wire or something else? This anisotropy in the load cell is primordial to understand the subglacial pressure time series, especially since some negative values have been recorded in the past. It is recommended that the orientation of the wire on each load cell is measured and put in relation with the ice flow direction. Surveying the bedrock topography will be instrumental for assessing that parameter.

The low sensitivity of the load cell plate to a change in area, on which is exerted the force, means that the sensor will record the same pressure for the same centre point whether it is a pebble or a cobble or ice. In the case of a rock passing over the load cell along the x-axis, the records should show negative values followed by high positive values and once more time negative values. This will be investigated, but a quick look at the time series suggests that such variations are very rare.

The standard deviation is very interesting as it is the results of a combination of factors:

- Errors in controlling the exerted load when looking at the dial,
- Errors when the wire vibrates at higher frequency (more difficult to get a stable value),
- Errors in the calibration curve more likely at higher frequency because the slope is steeper as shown on Figure 5.

However, the second one seems to be the most important element owing to the fact that the largest errors are located around the highest pressure values. This could also reveal a problem of fabrication of load cell linked to a high sensitivity of the two pins where is attached the wire. Without definitive confirmation of the location of the wire, this idea cannot be pushed forward.

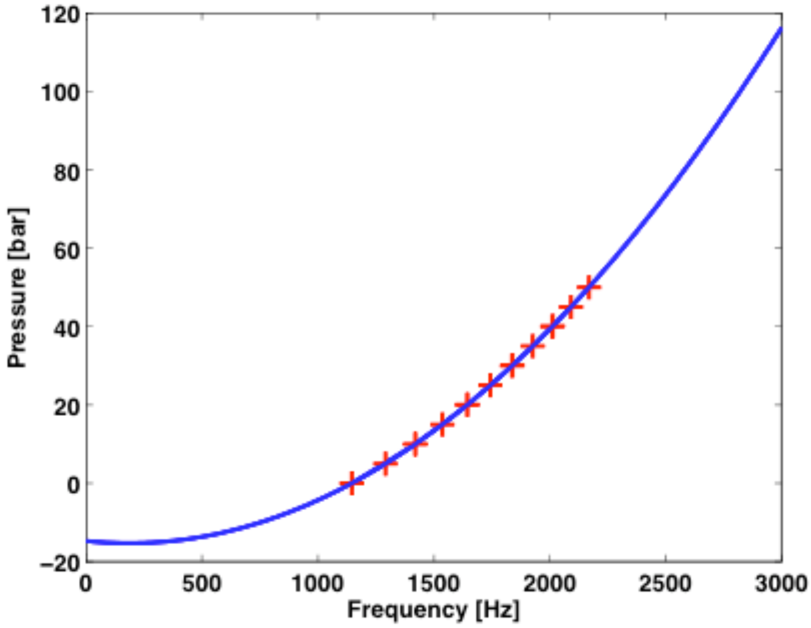

Figure 5: Calibration curve (blue) to calculate the pressure from the frequency at which vibrates the wire. The red crosses were used to calibrate the calibration curve. One can notice that the higher the pressure, the steeper the slope. This could partially explain why the standard deviation is larger when the frequency is higher.

ID	Time	Freq	Load	Zero(+1Min)	Load corr.	Time	Freq	Load	Zero(+1Min)	Load corr.	Time	Freq	Load	Zero(+1Min)	Load corr.	Mean	Std dev	Mean corr.	Std dev corr.	Error %
1	14:01	1139.7	-0.200	0.082	-0.282	14:04	1139.3	-0.211	0.070	-0.281	14:07	1138.4	-0.240	0.064	-0.304	-0.217	0.0207	-0.289	0.0130	4.5
2	14:10	1173.5	0.888	0.064	0.824	14:13	1173.3	0.882	0.064	0.818	14:17	1173.5	0.888	0.058	0.830	0.886	0.0035	0.824	0.0060	0.7
3	14:21	1182.0	1.170	-0.010	1.180	14:27	1181.5	1.153	-0.014	1.167	14:32	1181.9	1.167	-0.020	1.187	1.163	0.0091	1.178	0.0101	0.9
4	14:36	1072.3	-2.258	-0.020	-2.238	14:39	1072.0	-2.268	-0.021	-2.247	14:42	1071.3	-2.290	-0.025	-2.265	-2.272	0.0164	-2.250	0.0137	0.6
5	14:55	1171.2	0.815	-0.020	0.835	14:58	1171.0	0.809	-0.020	0.829	15:01	1172.5	0.858	-0.031	0.889	0.827	0.0267	0.851	0.0330	3.9
6	15:04	1256.7	3.732	-0.018	3.750	15:08	1255.3	3.682	-0.020	3.702	15:11	1255.5	3.689	-0.025	3.714	3.701	0.0271	3.722	0.0250	0.7
7	15:15	1241.1	3.183	-0.015	3.198	15:18	1240.7	3.169	-0.021	3.190	15:21	1238.9	3.105	-0.025	3.130	3.152	0.0416	3.173	0.0372	1.2
8	15:26	1162.4	0.528	-0.020	0.548	15:29	1162.2	0.522	-0.020	0.542	15:32	1161.1	0.485	-0.020	0.505	0.512	0.0233	0.532	0.0233	4.4
9	15:35	990.7	-4.549	-0.027	-4.522	15:38	988.1	-4.619	-0.031	-4.588	15:41	983.4	-4.746	0.031	-4.777	-4.638	0.0999	-4.629	0.1324	2.9
10	15:45	1100.8	-1.406	-0.033	-1.373	15:49	1104.2	-1.305	-0.031	-1.274	15:52	1102.6	-1.352	-0.033	-1.319	-1.354	0.0505	-1.322	0.0496	3.7
11	15:55	1398.8	9.121	-0.031	9.152	15:58	1404.9	9.369	-0.031	9.400	16:01	1398.1	9.091	-0.037	9.128	9.194	0.1526	9.227	0.1506	1.6
12	16:04	1565.9	16.315	-0.037	16.352	16:08	1553.6	15.756	-0.045	15.801	16:11	1568.9	16.452	-0.049	16.501	16.174	0.3687	16.218	0.3687	2.3
13	16:14	1440.3	10.822	-0.045	10.867	16:17	1454.7	11.423	-0.043	11.466	16:20	1457.2	11.531	-0.043	11.574	11.259	0.3820	11.302	0.3809	3.4
14	16:23	1162.2	0.522	-0.039	0.561	16:26	1163.7	0.570	-0.039	0.609	16:29	1165.2	0.619	-0.043	0.662	0.570	0.0485	0.611	0.0505	8.3
15	16:32	1113.3	-1.026	-0.039	-0.987	16:35	1113.1	-1.031	-0.043	-0.988	16:38	1112.9	-1.037	-0.039	-0.998	-1.031	0.0055	-0.991	0.0061	0.6
16	16:41	973.3	-5.010	-0.045	-4.965	16:44	973.0	-5.018	-0.051	-4.967	16:47	968.7	-5.131	-0.045	-5.086	-5.053	0.0677	-5.006	0.0693	1.4
17	16:50	1059.2	-2.641	-0.045	-2.596	16:53	1057.6	-2.688	-0.051	-2.637	16:56	1058.7	-2.656	-0.039	-2.617	-2.662	0.0240	-2.617	0.0205	0.8
18	16:59	1605.1	18.137	-0.051	18.188	17:02	1599.6	17.879	-0.033	17.912	17:06	1619.0	18.794	-0.051	18.845	18.270	0.4718	18.315	0.4793	2.6
19	17:09	1712.3	23.384	-0.051	23.435	17:12	1720.8	23.811	-0.051	23.862	17:15	1713.9	23.461	-0.056	23.517	23.552	0.2276	23.605	0.2266	1.0
20	14:46	1636.8	19.650	-0.049	19.699	14:48	1638.4	19.726	-0.043	19.769	14:50	1642.6	19.928	-0.051	19.979	19.768	0.1437	19.816	0.1457	0.7
21	14:56	1141.2	-0.151	-0.031	-0.120	14:58	1141.4	-0.146	-0.025	-0.121	15:00	117.7	-0.888	-0.020	-0.868	-0.395	0.6515	-0.370	0.4316	116.7
22	15:03	1108.9	-1.161	-0.024	-1.137	15:05	1109.2	-1.150	-0.025	-1.125	15:07	1109.2	-1.150	-0.025	-1.125	-1.154	0.0064	-1.129	0.0069	0.6
23	15:09	1072.3	-2.258	-0.025	-2.233	15:11	1071.9	-2.270	-0.031	-2.239	15:13	1070.6	-2.310	-0.021	-2.289	-2.279	0.0272	-2.254	0.0307	1.4
24	15:15	1133.4	-0.400	-0.021	-0.379	15:17	1133.0	-0.411	-0.021	-0.390	15:19	1132.6	-0.423	-0.020	-0.403	-0.411	0.0115	-0.391	0.0120	3.1
25	15:21	1442.2	10.899	-0.015	10.914	15:23	1445.0	11.019	-0.015	11.034	15:25	1443.4	10.951	-0.027	10.978	10.956	0.0602	10.975	0.0600	0.5
26	15:27	1581.5	17.034	-0.014	17.048	15:29	1578.3	16.885	-0.017	16.902	15:31	1580.1	16.971	-0.014	16.985	16.963	0.0748	16.978	0.0732	0.4
27	15:33	1493.0	13.064	-0.008	13.072	15:35	1486.8	12.796	-0.010	12.806	15:37	1492.1	13.023	-0.015	13.038	12.961	0.1444	12.972	0.1448	1.1
28	15:39	1208.5	2.057	-0.014	2.071	15:41	1208.6	2.060	-0.014	2.074	15:43	1208.5	2.057	-0.020	2.077	2.058	0.0017	2.074	0.0030	0.1
29	15:45	1152.5	0.207	-0.015	0.222	15:47	1152.1	0.196	-0.020	0.216	15:49	1151.0	0.160	-0.014	0.174	0.188	0.0246	0.204	0.0262	12.8
30	15:55	1180.0	1.104	-0.015	1.119	15:58	1180.6	1.123	-0.014	1.137	16:00	1178.5	1.055	-0.014	1.069	1.094	0.0351	1.108	0.0352	3.2
31	16:02	1263.9	3.991	-0.008	3.999	16:04	1267.2	4.107	-0.014	4.121	16:06	1264.5	4.013	-0.014	4.027	4.037	0.0616	4.049	0.0639	1.6
32	16:08	1355.7	7.417	-0.008	7.425	16:10	1365.6	7.800	-0.008	7.808	16:12	1362.5	7.681	-0.014	7.695	7.633	0.1960	7.643	0.1968	2.6
33	16:14	1313.8	5.816	-0.014	5.830	16:16	1322.5	6.144	-0.008	6.152	16:18	1319.4	6.029	-0.014	6.043	5.996	0.1664	6.008	0.1638	2.7
34	16:20	1234.3	2.945	-0.014	2.959	16:22	1234.6	2.957	-0.015	2.972	16:24	1233.5	2.915	-0.015	2.930	2.939	0.0216	2.954	0.0215	0.7
35	16:26	1261.3	3.897	-0.015	3.912	16:28	1262.1	3.926	-0.014	3.940	16:30	1262.5	3.941	-0.014	3.955	3.921	0.0224	3.936	0.0218	0.6
36	16:32	1288.9	4.896	-0.020	4.916	16:34	1293.6	5.068	-0.021	5.089	16:36	1290.0	4.936	-0.021	4.957	4.967	0.0900	4.987	0.0904	1.8
37	16:38	1285.5	4.772	-0.027	4.799	16:40	1285.3	4.764	-0.027	4.791	16:43	1286.5	4.808	-0.008	4.816	4.781	0.0234	4.802	0.0128	0.3
Apply homogeneous stress using three plates																				
Whole	16:59	1607.7	18.261	0.000	18.261	16:47	1609.8	18.358	-0.023	18.381	16:49	1616.7	18.684	-0.025	18.709	17.887	1.1102	17.910	1.1126	6.2
Apply homogeneous stress using the piston																				
A	16:51	1651.0	20.335	-0.029	20.364	16:53	1654.4	20.501	-0.037	20.538	16:55	1662.5	20.889	-0.008	20.897	20.575	0.2843	20.600	0.2718	1.3
B	17:37	1355.1	7.391	-0.033	7.424	17:39	1349.4	7.172	-0.039	7.211	17:41	1346.3	7.054	-0.033	7.087	7.206	0.1710	7.241	0.1704	2.4
C	17:31	1215.5	2.295	-0.031	2.326	17:33	1215.6	2.298	-0.025	2.323	17:35	1220.2	2.458	-0.031	2.489	2.350	0.0933	2.379	0.0950	4.0
D	17:24	1117.3	-0.902	-0.031	-0.871	17:26	1115.5	-0.957	-0.033	-0.924	17:29	1121.7	-0.765	-0.033	-0.732	-0.784	0.1643	-0.753	0.1615	21.5
E	17:43	1115.4	-0.961	-0.045	-0.916	17:45	1115.7	-0.950	-0.043	-0.907	17:47	1111.8	-1.070	-0.045	-1.025	-1.010	0.0849	-0.966	0.0834	8.6

Center of the piston	
A	19
B	32
C	6
D	21
E	17

Location of the points on the Load Cell

		1	2	3		
	4	5	6	7	8	
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
	30	31	32	33	34	
		35	36	37		

Pressure calculus

	Radius [m]	Area [m^2]	Mass [kg]	P [Pa]	P [bar]
point	2.50E-03	1.96E-05	500	2.50E+08	2498
piston	2.50E-02	1.96E-03	500	2.50E+06	25
plate	7.50E-02	1.77E-02	500	2.78E+05	3