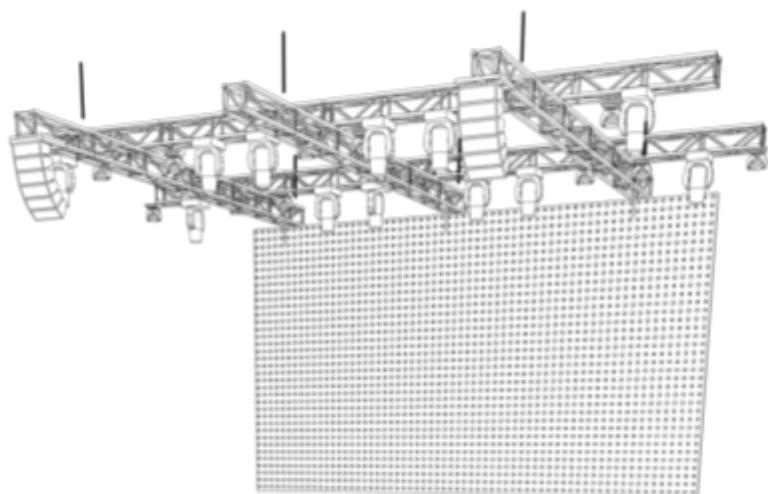


## Braceworks Calculation Comparison



## Introduction to Braceworks

The Braceworks™ structural analysis add-on module for Vectorworks® Spotlight provides design, production, and rigging professionals with an easy way to gauge the performance of temporary structures under load to ensure safety and compliance with engineering codes and standards. With Braceworks and Spotlight, entertainment professionals have, for the first time, a completely integrated modeling, analysis, and documentation process.

In this document, we will compare the results from two Braceworks projects with two other FEA programs: RSTAB from Dlubal and SCIA Engineer from SCIA.

For the first benchmark, we will use a small grid. We will compare reaction forces, deflection, bending moments and shear forces in detail. For the second benchmark, a larger grid structure will be used. For this second benchmark, only the reactions' force results are compared.

### Braceworks Calculation – What is happening?

Braceworks operates with the standard objects in Vectorworks Spotlight. It converts straight trusses, curved trusses, truss items, and lighting pipes created in Vectorworks into structural members. Structural members are modeled as 3D Bernoulli beams. When possible, the cross-section data from the manufacturers is used.

Hoists are used as supports. They are modeled as rope connections. The ropes are normally assumed rigid, but it is possible to use a rope cross section. The Braceworks FEA engine can check and highlight ropes that will fail. The chain shorten value can be used to model imperfections in the rope length and check resulting changes in the load distribution.

Vectorworks objects like speakers and lighting devices will attach loads to the structural members. Point loads and distributed loads are supported, and loads are automatically assigned to the structural members.

After modeling and loading, an FEA calculation is performed. The results, like reaction forces and influence lines, are stored inside the Vectorworks drawing.

### Comparison with Dlubal RSTAB and SCIA Engineer

To validate Braceworks results against results in other FEA programs, we compared the calculations from Braceworks to calculations performed in Dlubal RSTAB and SCIA Engineer.

To perform the benchmark, we exported two Spotlight projects as DSTV files. The DSTV files were imported into RSTAB 8.06 and SCIA Engineer 16.1.1031.

## Benchmark I

For Benchmark I, the rig shown in Figure 1 was used. The rig contains two 12-meter truss lines laying on three 9-meter truss lines. At various points, lighting devices and two speaker arrays are attached. At the back of the grid there is an LED screen. The six hoists are connected to the 9-meter trusses. The total structure weights 2693,4 kg; this includes a cable flat rate of 103,63 kg.

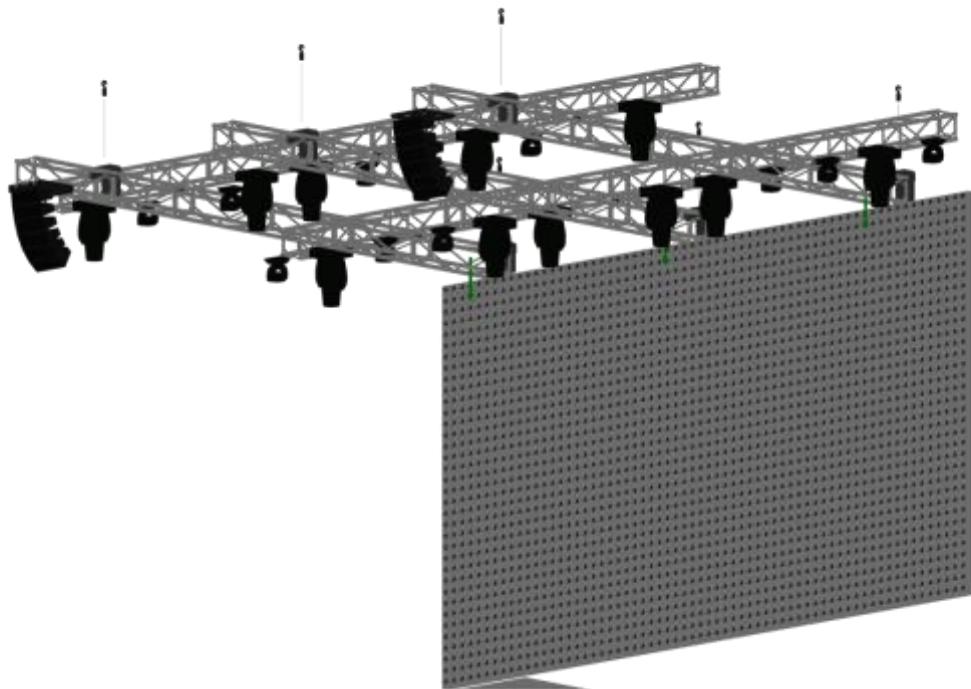


Figure 1

The following loads were used in the calculation (see Figure 2):

Count	Name	Load Type	Single Weight	Distributed Weight	Total Weight	Single Force	Distributed Force	Total Force
1	Cable flat-rate - Truss	Distributed Load		2,00 kg/m	103,63 kg		0,03 kN/m	1,37 kN
2	H40V 12m	Distributed Load	97,54 kg	8,00 kg/m	195,07 kg	1,29 kN	0,11 kN/m	2,58 kN
3	H40V 9m	Distributed Load	73,15 kg	8,00 kg/m	219,46 kg	0,97 kN	0,11 kN/m	2,91 kN
12	Moving Light	Point Load	50,00 kg		600,00 kg	0,74 kN		8,83 kN
12	Light Fixture	Point Load	12,00 kg		144,00 kg	0,18 kN		2,12 kN
2	Audio Array	Point Load	250,00 kg		500,00 kg	3,68 kN		7,36 kN
6	Hoist	Point Load	80,20 kg		481,20 kg	1,06 kN		6,37 kN
3	LED Wall	Point Load	150,00 kg		450,00 kg	2,21 kN		6,62 kN

Figure 2

From the Spotlight model, Braceworks creates the resulting FEA grid shown in Figure 3. It consists of 32 nodes and 33 members. To simplify the graphical output, the distributed load from the dead load of trusses and cable load is not shown.

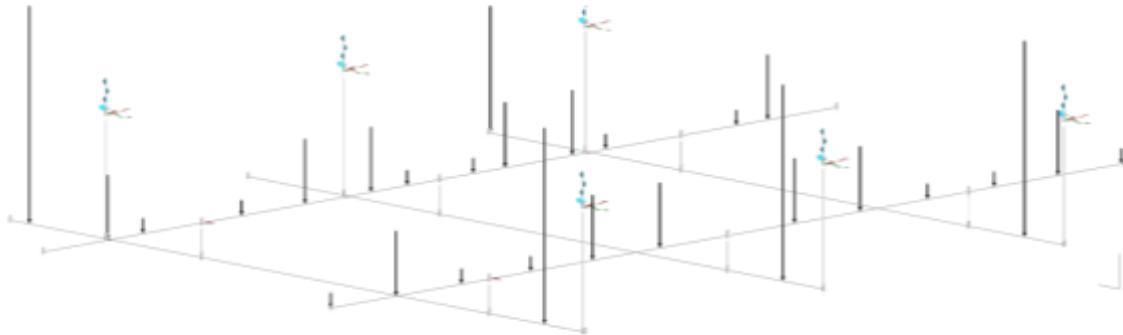


Figure 3

In the appendix of this document, you'll find the tables that list the information on the FEA objects used for this calculation.

#### Support Reaction

Figure 4 shows the result for the support reaction.

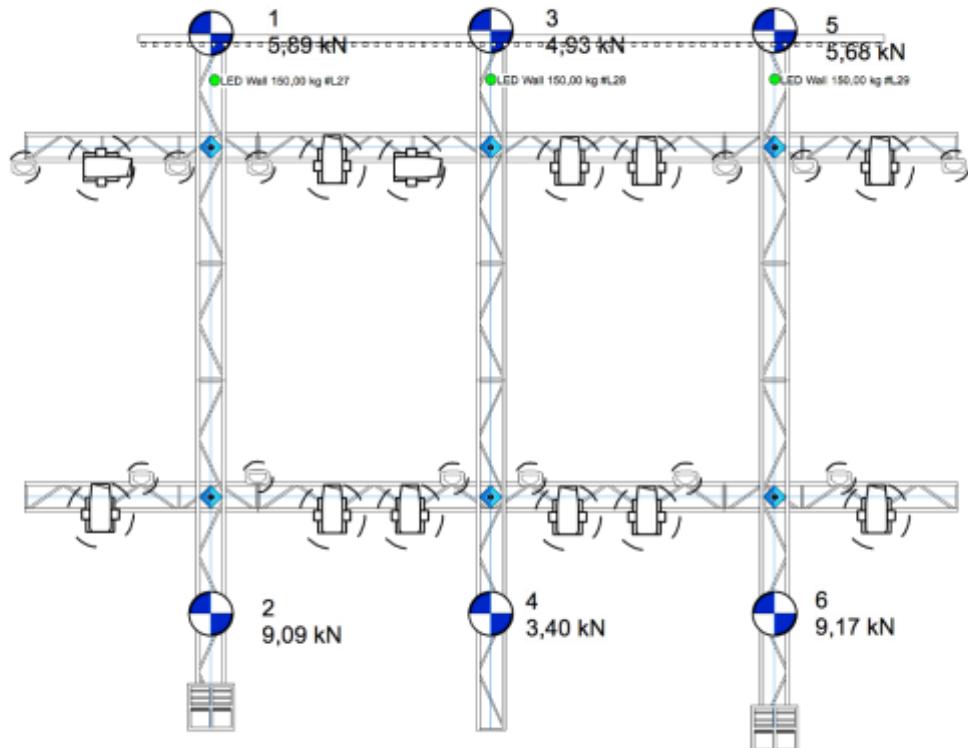


Figure 4

The total sum of the load is 38,16kN.

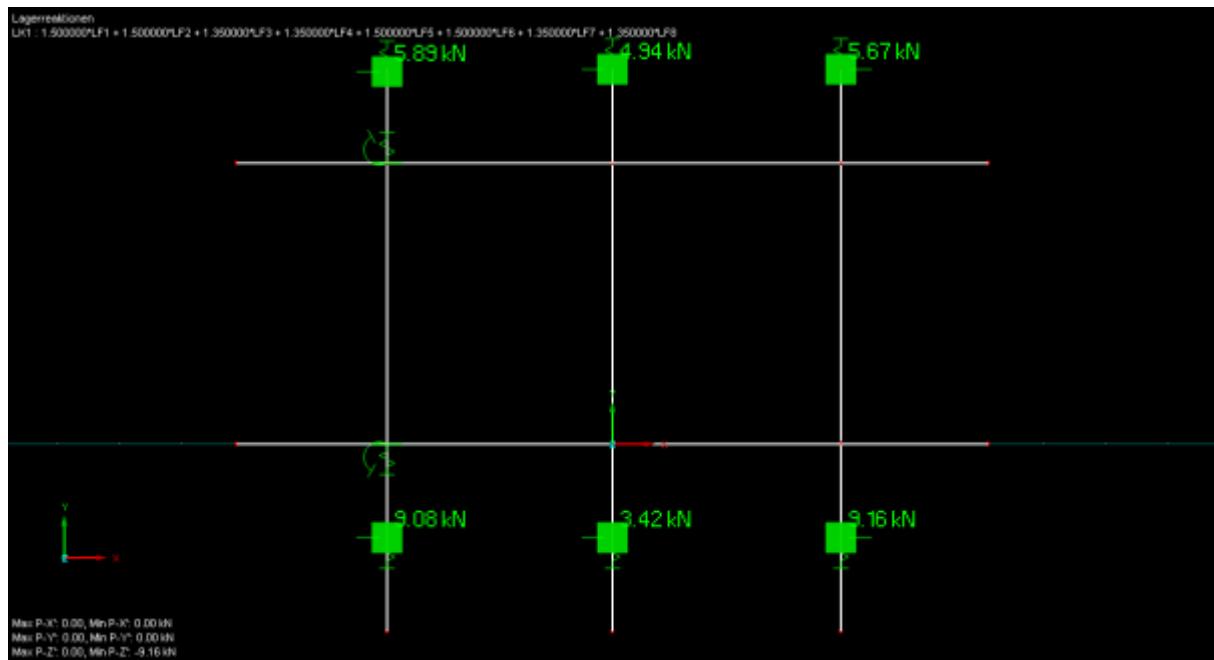


Figure 5

Figure 5 shows the result of the calculations performed in RSTAB. The total load sum is also 38,16 kN and the support reactions match the Braceworks results.

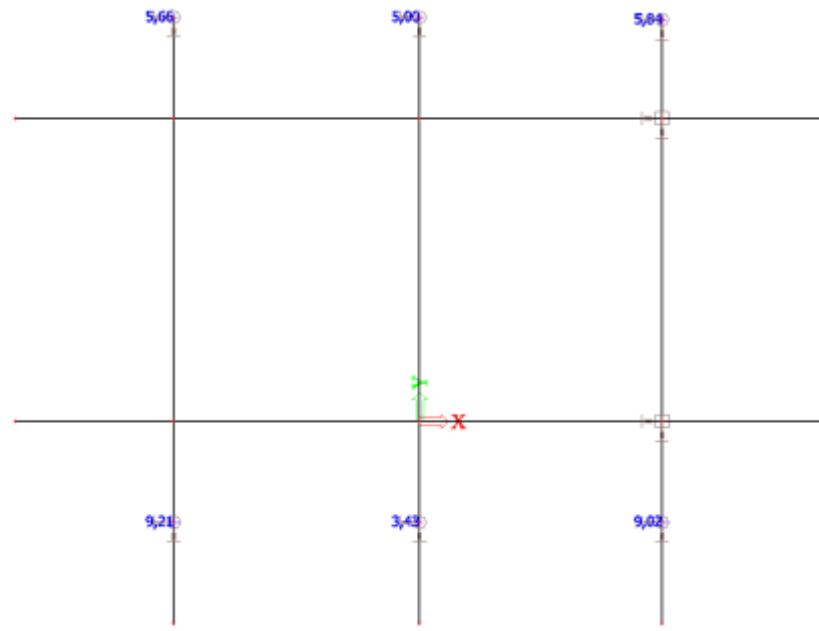


Figure 6

Figure 6 shows the result in SCIA Engineer. The total load sum is also 38,16 kN and the support reactions match the Braceworks results.

## Deflection

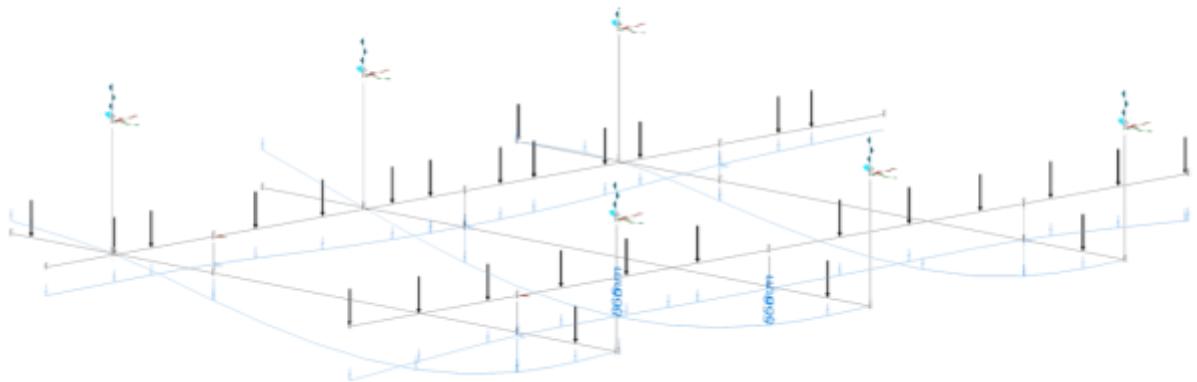


Figure 7

Figure 7 shows the Braceworks deflections for the structure above. The cross section used is Prolyte H40V. The maximum deflection is 8,65 mm and is highlighted in the figure. The assumption for the deflection on the hoist position is 0 mm.

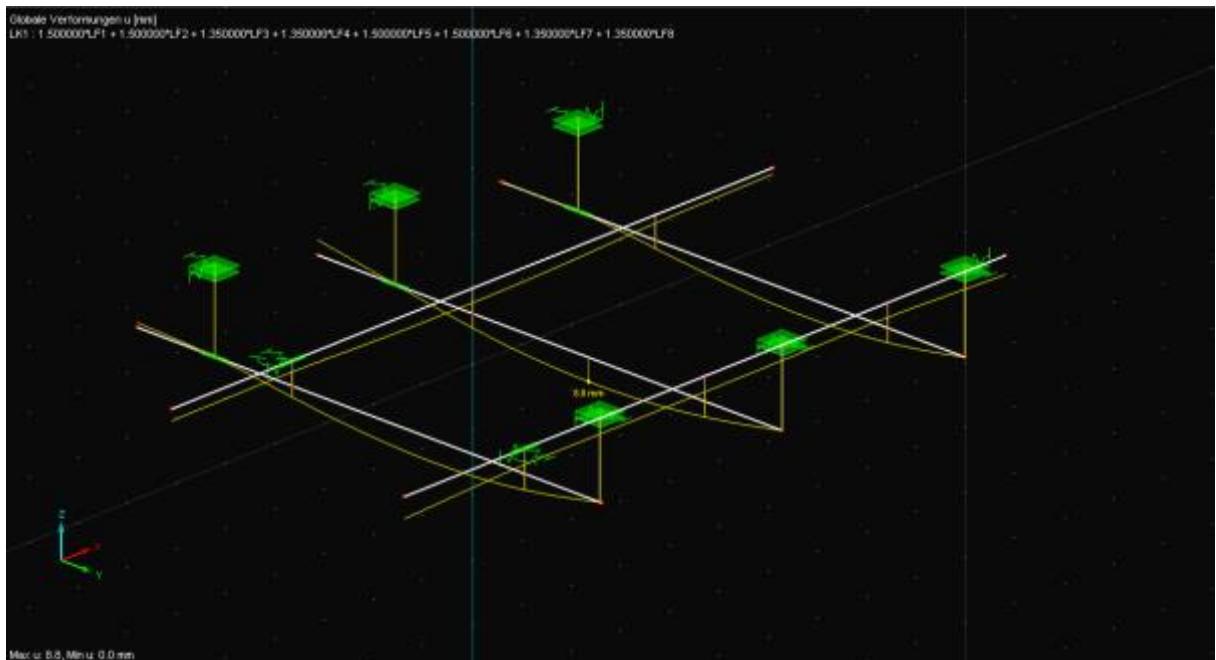


Figure 8

Figure 8 shows the deflection results in RSTAB. The maximum deflection is 8,8 mm and occurs at the same location as in the Braceworks calculation. In all other points, the deformed shape is similar to the Braceworks results.

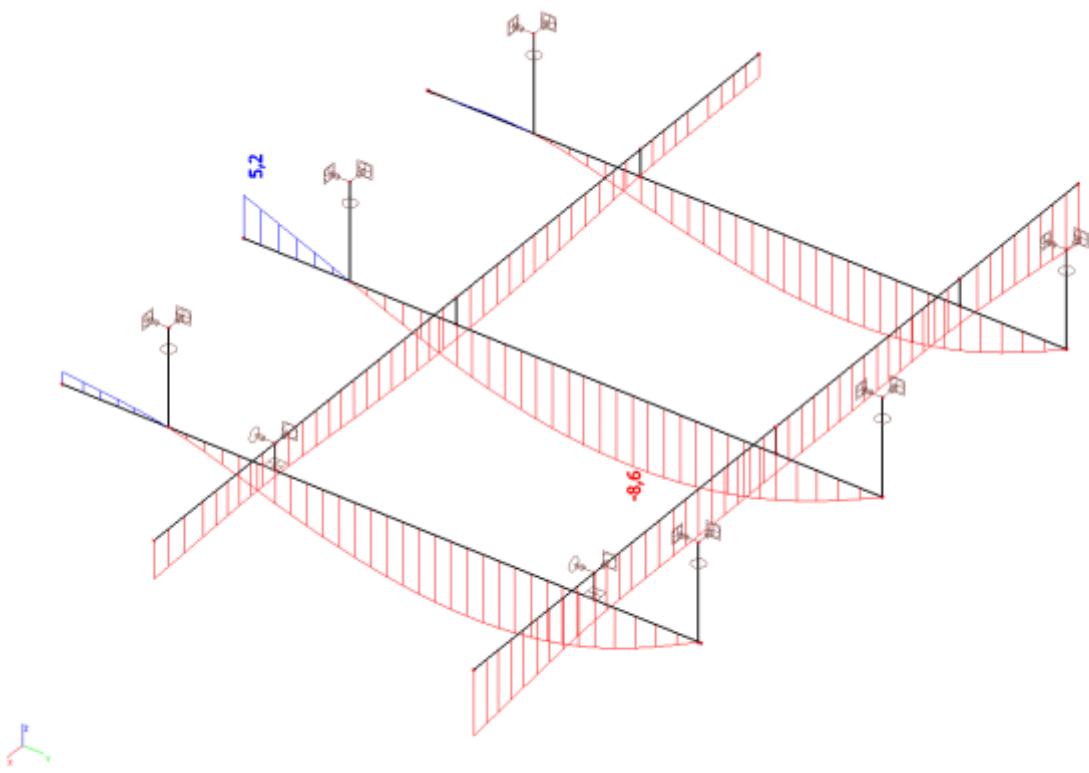


Figure 9

Figure 9 shows the deflection results in SCIA Engineer. The maximum deflection is 8,6 mm and occurs at the same location as in the Braceworks calculation. In all other points, the deformed shape is similar to the Braceworks results.

#### *Bending moment*

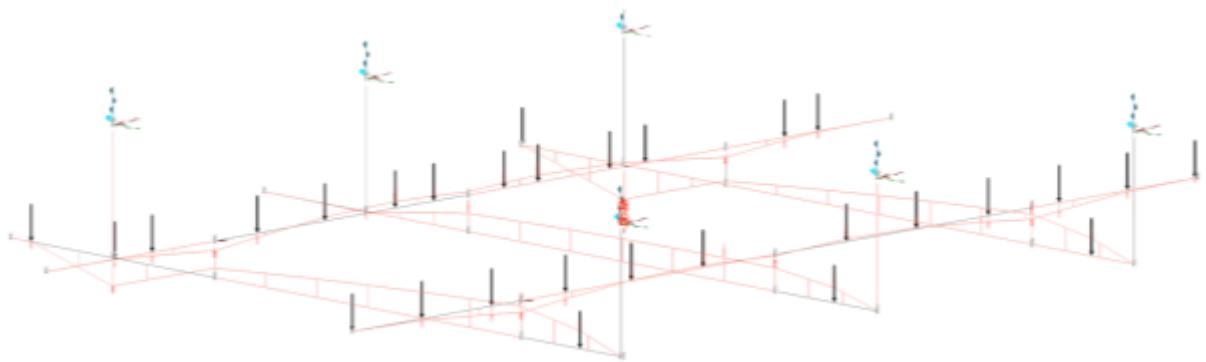


Figure 10

Figure 10 shows the bending moment for the structure as calculated in Braceworks. The maximum bending moment is -5,69 kNm, occurring at the connection point of hoist six and is highlighted in the figure.

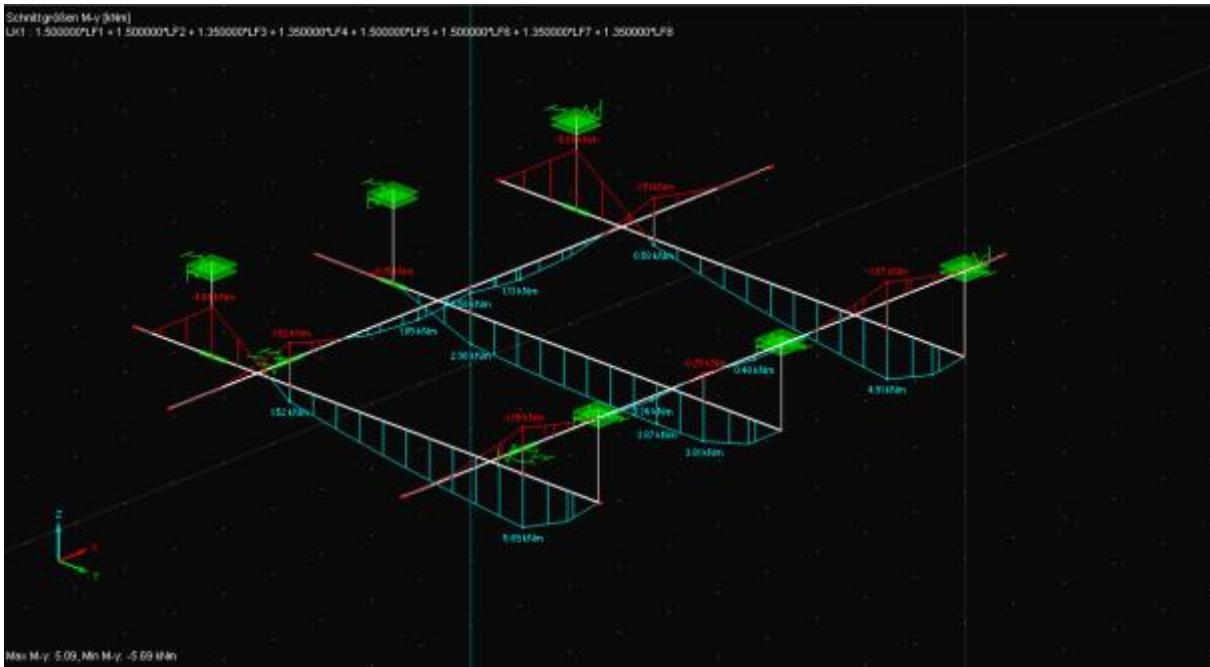


Figure 11

Figure 11 shows the result in RSTAB. The maximum bending moment is -5,69 kNm and occurs at the same location as in the Braceworks calculation.

The bending-moment trend matches the Braceworks results. Note that RSTAB shows positive bending moments in negative Z direction, and Braceworks shows positive bending moments in the positive Z direction.

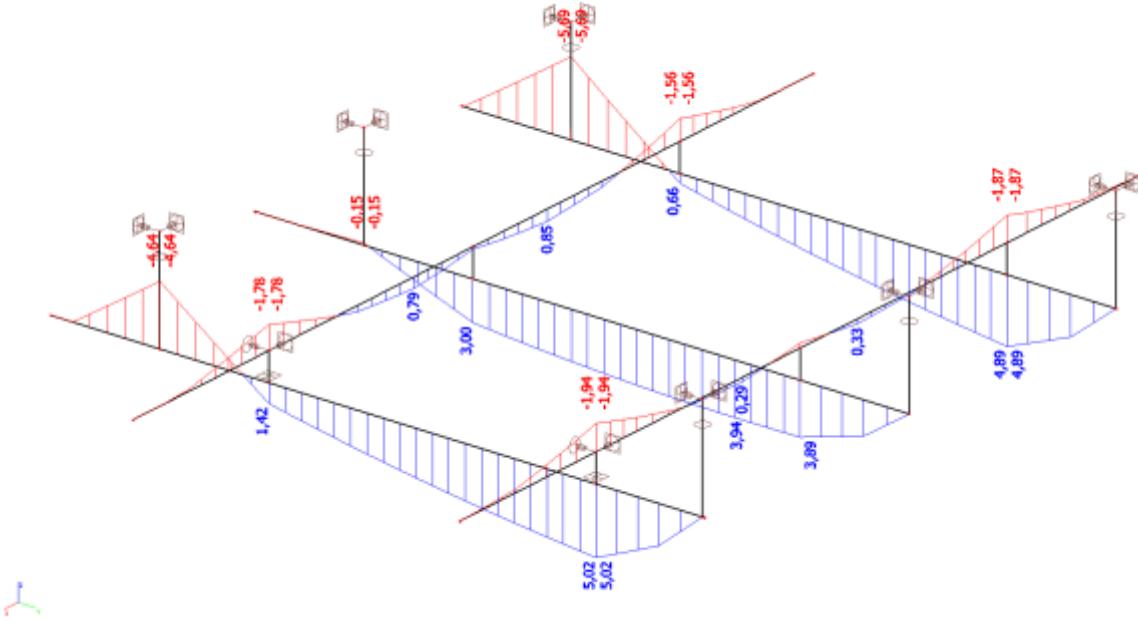


Figure 12

Figure 12 shows the result in SCIA Engineer. The maximum bending moment is -5,69 kNm and occurs at the same location as in the Braceworks calculation.

The bending moment trend matches the Braceworks results. Note that SCIA Engineer shows positive bending moments in the negative Z direction and Braceworks shows positive bending moments in the positive Z direction.

### *Shear force*

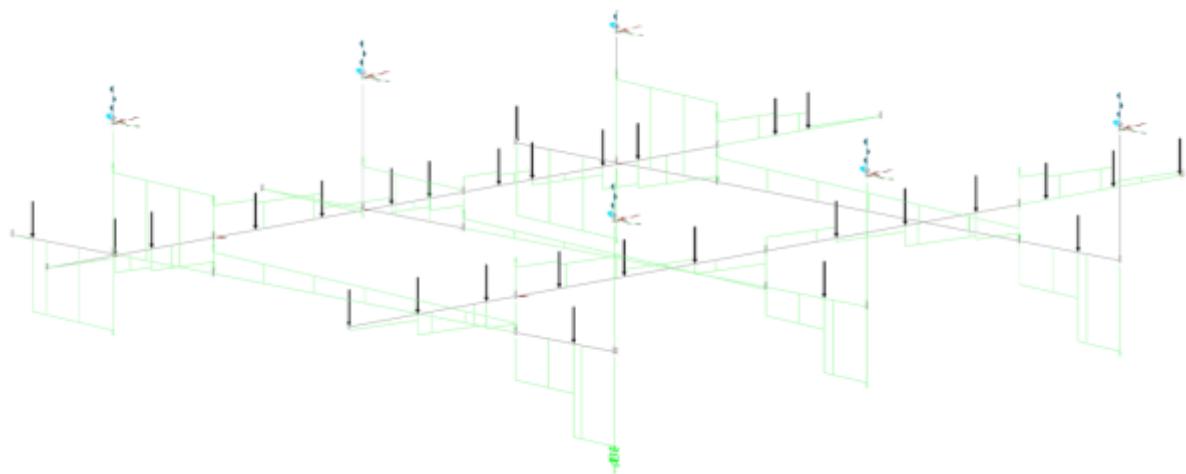


Figure 13

Figure 13 shows the shear force for the structure in Braceworks. The shear force moment is -4,83 kN, occurring at the connection point of hoist 1 and is highlighted in the figure.

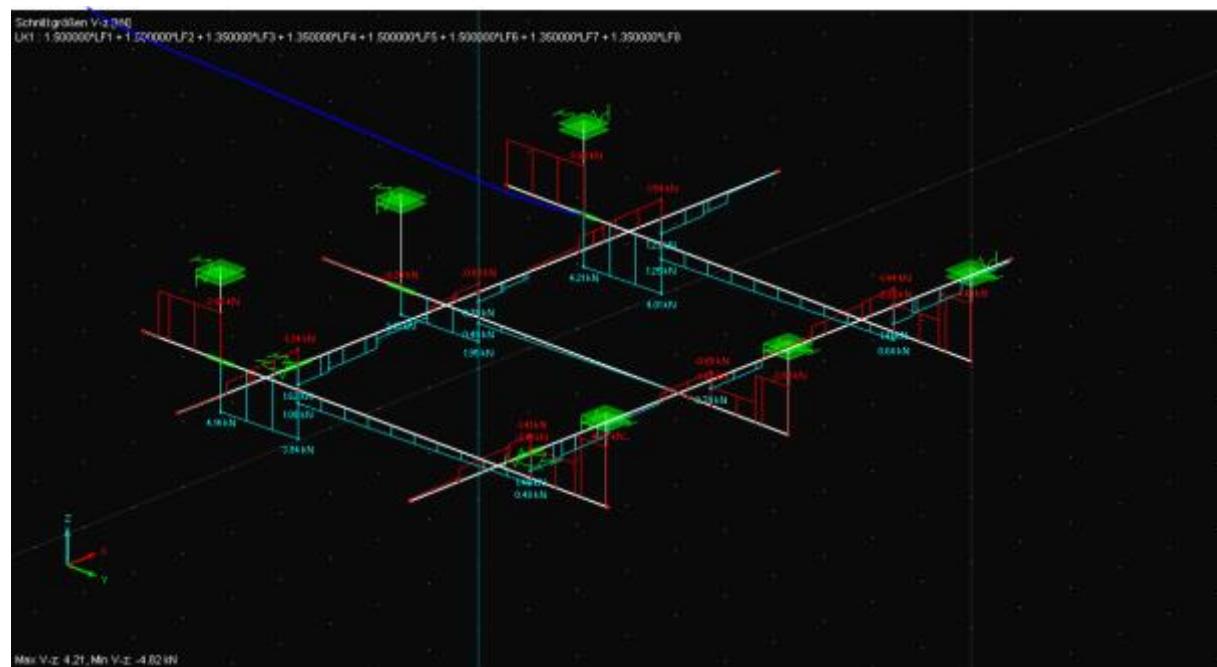


Figure 14

Figure 14 shows the result in RSTAB. The maximum shear force is -4,82 kN and occurs at the same location as in the Braceworks calculation.

The shear force trend matches the Braceworks results. Note that RSTAB shows positive shear forces in the negative Z direction, and Braceworks shows positive bending moments in the positive Z direction.

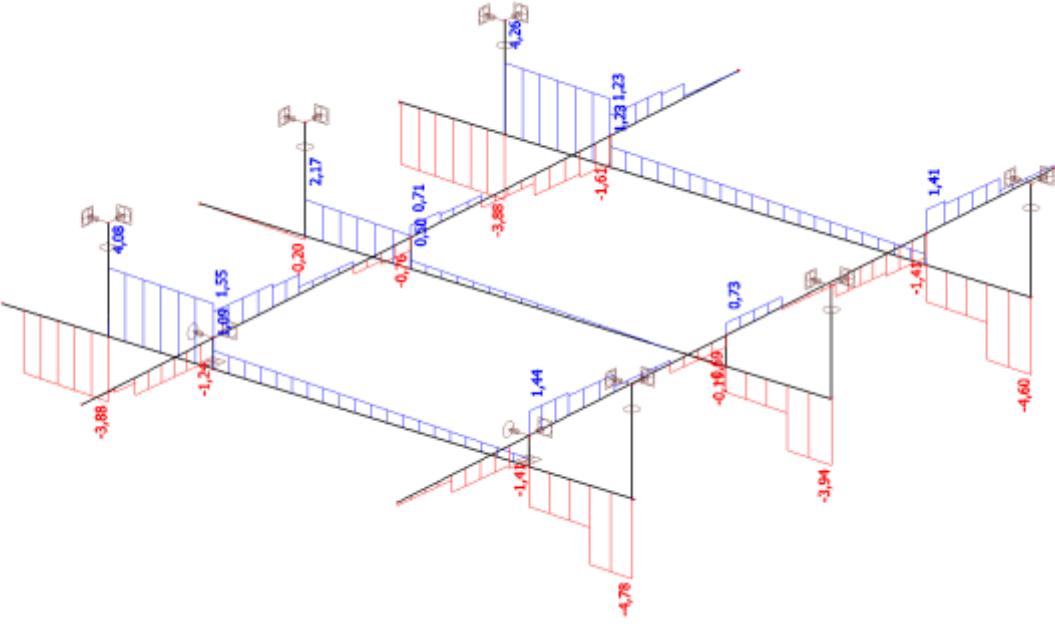


Figure 15

Figure 15 shows the result in SCIA Engineer. The maximum shear force is -4,82 kN and occurs at the same location as in the Braceworks calculation. The shear force trend matches the Braceworks results.

## Comparison and Conclusion for Benchmark I

The calculation in Braceworks matches the calculation in RSTAB and SCIA Engineer. Only small differences in the results occur, and they are linked mostly to rounding during the calculations.

The maximum difference between the calculation results is under 1% for RSTAB and around 1% for SCIA Engineer. These variances are normal and expected for FEA calculations.

### Support Reaction

Number	Braceworks	RSTAB	SCIA
1	5,89 kN	5,89 kN (0,0%)	5,84 kN (0,9%)
2	9,09 kN	9,08 kN (0,1%)	9,02 kN (0,7%)
3	4,93 kN	4,94 kN (0,2%)	5,00 kN (-1,2%)
4	3,40 kN	3,42 kN (0,6%)	3,43 kN (-0,3%)
5	5,68 kN	5,67 kN (0,2%)	5,66 kN (-0,2%)
6	9,17 kN	9,16 kN (0,1%)	9,21 kN (-0,6%)
<b>Sum</b>	<b>38,16 kN</b>	<b>38,16 kN (0,0%)</b>	<b>38,16 kN (-0,0%)</b>

Figure 16

### Forces

Number	Braceworks	RSTAB	SCIA
<b>Max Vz</b>	-4,83 kN	-4,82 kN (0,2%)	-4,78 kN
<b>Max Mby</b>	-5,69 kNm	-5,69 kNm (0,0%)	-5,69 kNm
<b>Max du</b>	8,65 mm	8,8 mm (1,7%)	8,6 mm (2,3%)

Figure 17

## Benchmark II

In Benchmark II, we used a much larger grid and compared the calculations between Braceworks, RSTAB, and SCIA Engineer. This benchmark only contains trusses and hoists.

The following loads were used in the calculation:

Count	Name	Load Type	Single Weight	Distributed Weight	Total Weight	Single Force	Distributed Force	Total Force
1	Cable flat-rate - Truss	Distributed Load		2,00 kg/m	2061,16 kg		0,03 kN/m	27,30 kN
178	FD34-500	Distributed Load	30,00 kg	6,00 kg/m	5340,00 kg	0,40 kN	0,08 kN/m	70,72 kN
99	FD34-X1	Point Load	7,08 kg		700,92 kg	0,09 kN		9,28 kN
96	Hoist	Point Load	80,20 kg		7698,73 kg	1,06 kN		101,96 kN

Figure 18

The figure below displays the top view of the system, with the hoist results generated from Braceworks.

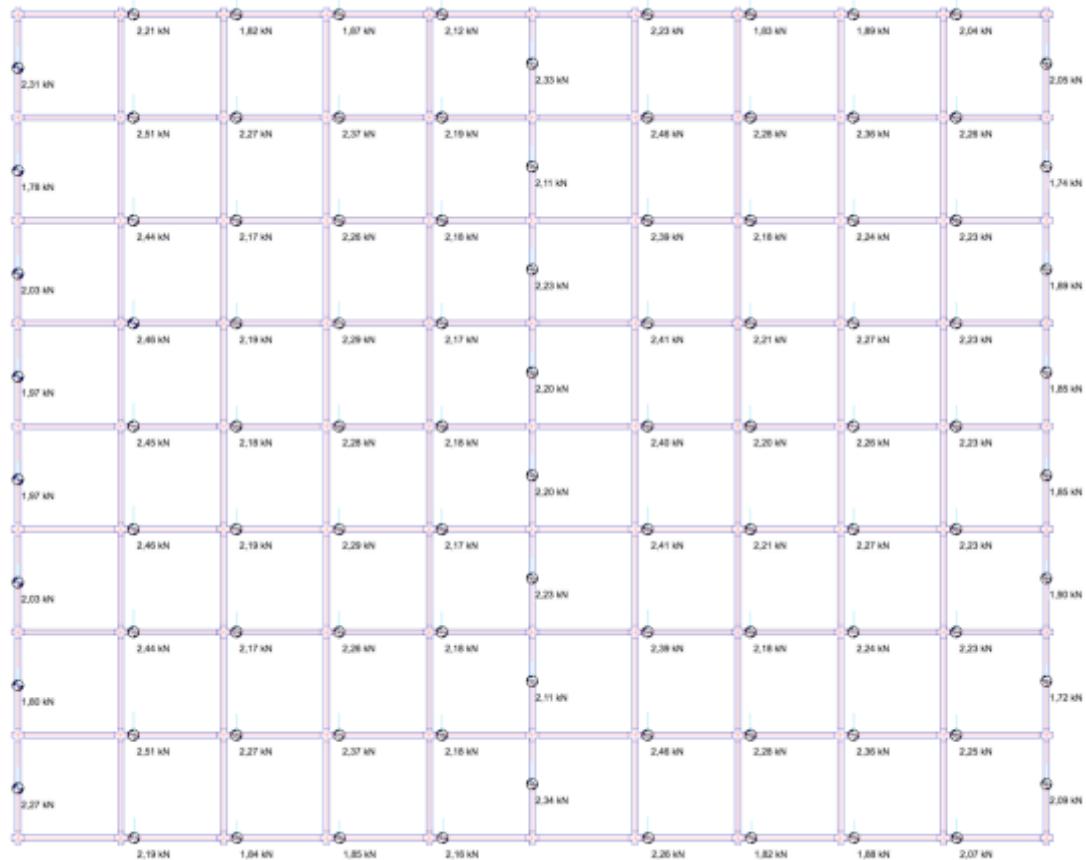


Figure 19

The corresponding RSTAB calculation is shown in the next figure.

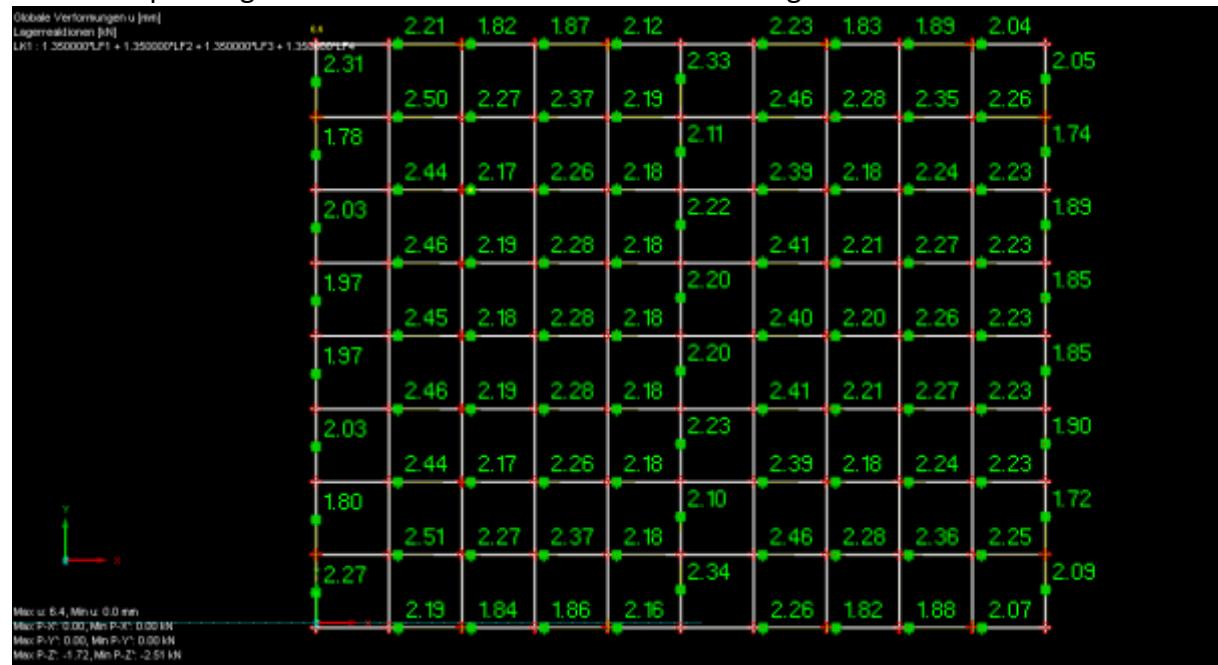


Figure 20

The corresponding SCIA Engineer calculation is shown in the Figure 21.

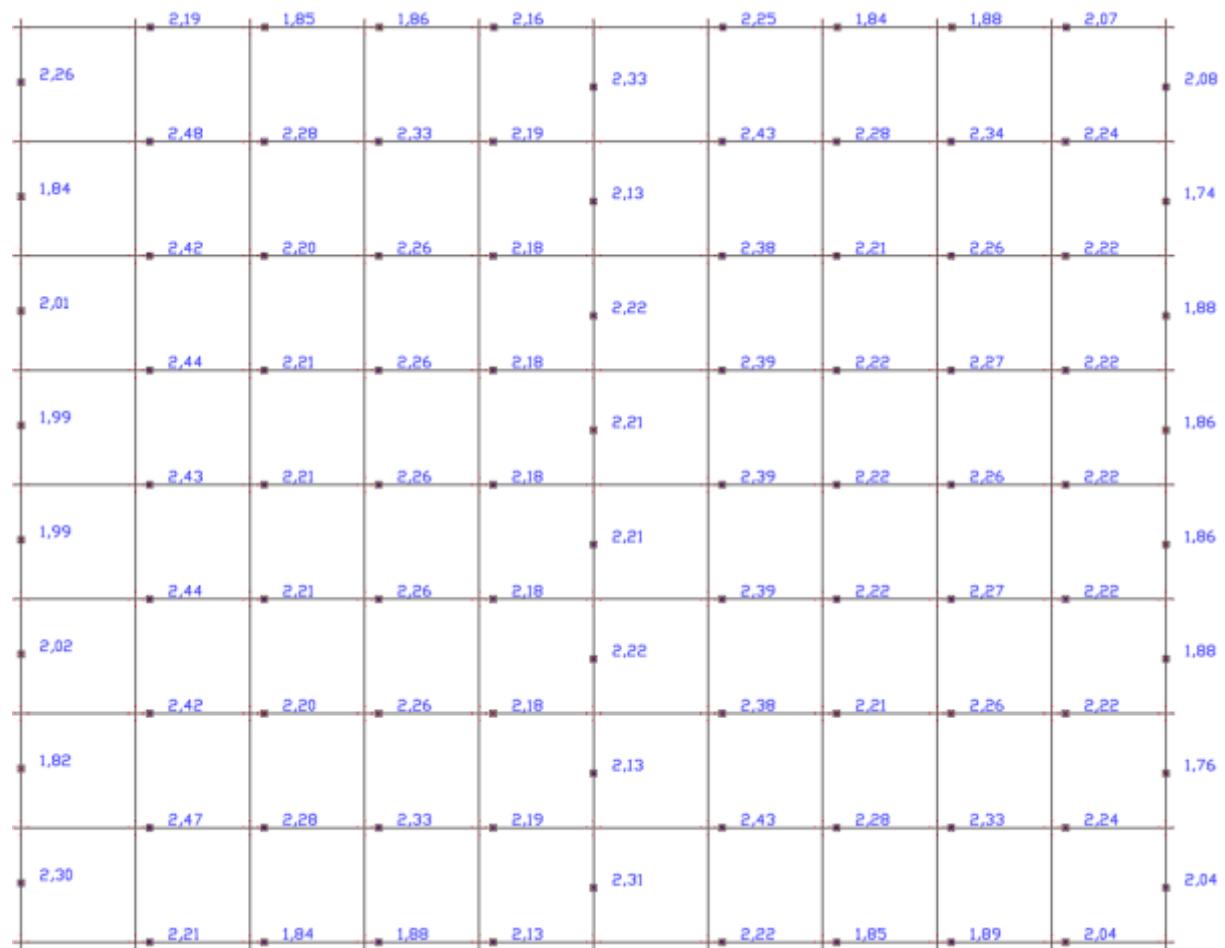


Figure 21

Figure 22 lists the results from Braceworks, RSTAB, and SCIA Engineer.

The maximum difference between the Braceworks and RSTAB is 0,5% and the standard deviation is 0,1%. For Scia and Braceworks the maximum difference is 2,6% and the standard deviation is 0,8%.

In both cases, the calculation results from the other FEA program matches the Braceworks results.

<b>Number</b>	<b>Braceworks</b>	<b>RSTAB</b>	<b>SCIA</b>	<b>% RSTAB</b>	<b>% SCIA</b>
1	2,27	2,27	2,29	0,0%	-0,9%
2	1,8	1,80	1,81	0,0%	-0,6%
3	2,03	2,03	2,03	0,0%	0,0%
4	1,97	1,97	1,98	0,0%	-0,5%
5	1,97	1,97	1,98	0,0%	-0,5%
6	2,03	2,03	2,02	0,0%	0,5%
7	1,78	1,78	1,83	0,0%	-2,8%
8	2,31	2,31	2,25	0,0%	2,6%
9	2,46	2,46	2,45	0,0%	0,4%
10	2,46	2,46	2,45	0,0%	0,4%
11	2,44	2,44	2,43	0,0%	0,4%
12	2,44	2,44	2,43	0,0%	0,4%
13	2,51	2,50	2,50	0,4%	0,4%
14	2,45	2,45	2,44	0,0%	0,4%
15	2,21	2,21	2,19	0,0%	0,9%
16	2,51	2,51	2,50	0,0%	0,4%
17	2,19	2,19	2,20	0,0%	-0,5%
18	2,17	2,17	2,18	0,0%	-0,5%
19	2,19	2,19	2,20	0,0%	-0,5%
20	2,27	2,27	2,27	0,0%	0,0%
21	2,27	2,27	2,27	0,0%	0,0%
22	2,19	2,19	2,20	0,0%	-0,5%
23	2,17	2,17	2,18	0,0%	-0,5%
24	1,82	1,82	1,85	0,0%	-1,6%
25	2,18	2,18	2,19	0,0%	-0,5%
26	1,84	1,84	1,84	0,0%	0,0%
27	2,29	2,28	2,28	0,4%	0,4%
28	2,28	2,28	2,27	0,0%	0,4%
29	2,37	2,37	2,36	0,0%	0,4%
30	2,26	2,26	2,26	0,0%	0,0%
31	2,37	2,37	2,35	0,0%	0,8%
32	2,26	2,26	2,26	0,0%	0,0%

33	1,87	1,87	1,86	0,0%	0,5%
34	2,29	2,28	2,28	0,4%	0,4%
35	1,85	1,86	1,88	-0,5%	-1,6%
36	2,18	2,18	2,20	0,0%	-0,9%
37	2,19	2,19	2,19	0,0%	0,0%
38	2,18	2,18	2,18	0,0%	0,0%
39	2,18	2,18	2,18	0,0%	0,0%
40	2,17	2,18	2,18	-0,5%	-0,5%
41	2,18	2,18	2,18	0,0%	0,0%
42	2,12	2,12	2,16	0,0%	-1,9%
43	2,17	2,18	2,18	-0,5%	-0,5%
44	2,16	2,16	2,12	0,0%	1,9%
45	2,11	2,11	2,11	0,0%	0,0%
46	2,23	2,22	2,22	0,4%	0,4%
47	2,11	2,10	2,11	0,5%	0,0%
48	2,34	2,34	2,31	0,0%	1,3%
49	2,2	2,20	2,20	0,0%	0,0%
50	2,23	2,23	2,22	0,0%	0,4%
51	2,33	2,33	2,33	0,0%	0,0%
52	2,2	2,20	2,20	0,0%	0,0%
53	2,46	2,46	2,45	0,0%	0,4%
54	2,39	2,39	2,39	0,0%	0,0%
55	2,41	2,41	2,41	0,0%	0,0%
56	2,4	2,40	2,40	0,0%	0,0%
57	2,41	2,41	2,41	0,0%	0,0%
58	2,39	2,39	2,39	0,0%	0,0%
59	2,46	2,46	2,45	0,0%	0,4%
60	2,23	2,23	2,25	0,0%	-0,9%
61	2,26	2,26	2,22	0,0%	1,8%
62	2,28	2,28	2,28	0,0%	0,0%
63	2,21	2,21	2,21	0,0%	0,0%
64	2,21	2,21	2,21	0,0%	0,0%
65	2,18	2,18	2,19	0,0%	-0,5%
66	2,18	2,18	2,19	0,0%	-0,5%
67	2,28	2,28	2,28	0,0%	0,0%
68	2,2	2,20	2,20	0,0%	0,0%
69	1,83	1,83	1,83	0,0%	0,0%
70	1,82	1,82	1,84	0,0%	-1,1%
71	2,26	2,26	2,26	0,0%	0,0%
72	2,24	2,24	2,24	0,0%	0,0%
73	2,27	2,27	2,27	0,0%	0,0%
74	2,36	2,36	2,34	0,0%	0,8%
75	2,36	2,35	2,35	0,4%	0,4%

76	2,27	2,27	2,27	0,0%	0,0%
77	2,24	2,24	2,25	0,0%	-0,4%
78	1,89	1,89	1,89	0,0%	0,0%
79	1,88	1,88	1,90	0,0%	-1,1%
80	2,23	2,23	2,23	0,0%	0,0%
81	2,23	2,23	2,23	0,0%	0,0%
82	2,23	2,23	2,23	0,0%	0,0%
83	2,26	2,26	2,26	0,0%	0,0%
84	2,23	2,23	2,23	0,0%	0,0%
85	2,25	2,25	2,26	0,0%	-0,4%
86	2,23	2,23	2,23	0,0%	0,0%
87	2,04	2,04	2,06	0,0%	-1,0%
88	2,07	2,07	2,04	0,0%	1,4%
89	1,9	1,90	1,89	0,0%	0,5%
90	2,09	2,09	2,04	0,0%	2,4%
91	1,74	1,74	1,73	0,0%	0,6%
92	1,85	1,85	1,85	0,0%	0,0%
93	1,89	1,89	1,89	0,0%	0,0%
94	1,85	1,85	1,85	0,0%	0,0%
95	1,72	1,72	1,75	0,0%	-1,7%
96	2,05	2,05	2,07	0,0%	-1,0%
<b>SUM</b>	<b>209,28</b>	<b>209,25</b>	<b>209,24</b>	<b>SD = 0,1%</b>	<b>SD = 0,8%</b>

Figure 22