8. STEEL STRUCTURES

8.1 HV connections for steel structures

„HV" is the marking of a screw assembly in steel construc-tions with high-strength screws in strength class 10.9. „H" stands here for high-strength, corresponding to the require-ments for strength class 10.9 and „V" for „preloaded", i.e. the possibility to bring the connection to a defined preload force with standardised methods.

While it is true that in over 90% of steel construction connections preloading is not necessary for technical reasons, because the connections are not designed with friction grip, in such cases it is often usual and practical to pre-stress the connections, in order to close gaps, to increase the resistance against dynamic loads on parts or to limit the deformation of the total construction.

HV connections are therefore suitable without restriction for implementing all the following standard connections in steel construction.

Shear bearing connections (SL) transfer the force applied from the outside transverse to the screw axis through direct force transmission from the inner wall of the drill hole to the shaft of the screw (Fig. 1) The components affect the screw shaft like the blades of scissors. This type of connection can be preloaded (SLV) or implemented with dowel screws (SLP) or both (SLVP). Preloading the connection is necessary in particular with dynamic loads in the screw's lengthways axis.
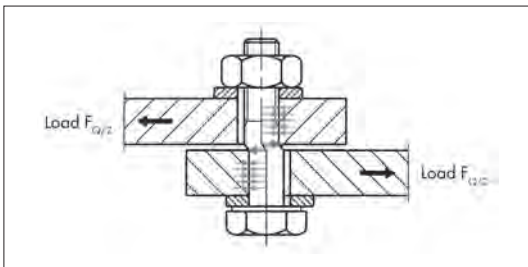

Fig. 1

The principle of operation of friction-grip preloaded con-nections (GV), which are used in individual cases, such as bridge building, including with screws with short threaded portions (GVP), is fundamentally different. Force transmis-

sion here takes place through friction between the contact surfaces of the preloaded components. For this purpose, the contact surfaces have to be made friction grip by blasting or by means of approved friction grip coatings. When the screw is tightened, the operating forces are transmitted vertically to the screw axis, as shown in Fig. 2.
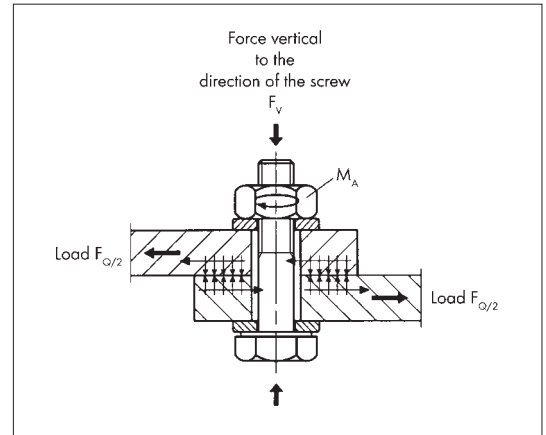

Fig. 2

Operating forces in the screw's lengthwise axis are of course permissible in all standard connections in steel construction and are accessible for verification of the strength by means of appropriate calculation formulae, for example, DIN 18800-1.

Würth HV sets have good, high-grade corrosion protec-tion through hot-dip galvanising with a zinc layer thickness of $60 - 80$ μm. In this way, long-term corrosion protection is achieved even in aggressive atmospheres. (Fig. 3).
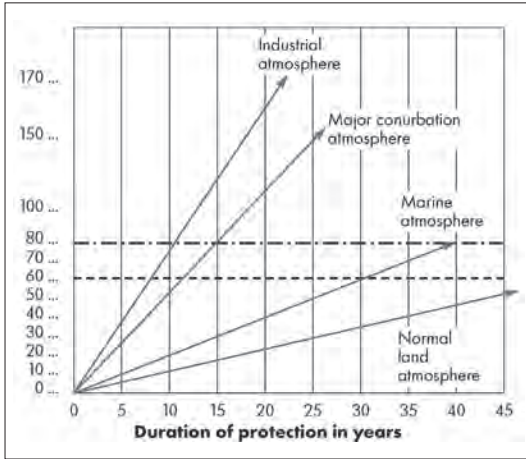
Fig. 3

The galvanising is carried out accordance with DIN EN ISO 10684, taking account of additional stipulations that conform to the state of the art on manufacturing hot-dip galvanised screws. The cutting of the nut thread and the lubrication of the nuts under process conditions are carried out after hot-dip galvanising, in order to ensure the thread's fit and to guarantee uniform tightening behaviour through special lubrication. The then unplated nut thread is corrosion protected after assembly by the zinc coating of the screw through cathodic corrosion protection. For this reason, only complete assemblies (screw, nut and washer) from **a single** manufacturer are to be used.

8.2 HV screws, nuts and washers
In the course of the changeover to the European Construction Products Directive, harmonised European standards were drawn up for fasteners in steel and metal construction that have replaced the previous German DIN standards to a great extent. The German standards have been retained only for ancillary products, such as HV square taper washers in accordance with DIN 6917 and DIN 6918. The procedure for verifying compliance in accordance with Building Rules List A continues to apply, i.e. the products are marketable with the so-called "Ü" sign (conformity sign). Table 1 provides an overview of the changeover of the standards.

	DIN	**DIN EN**
Calculation design	DIN 18 800-1	DIN EN 1993-1-8 DIN EN 1993-1-9
Execution	DIN 18 800-7	DIN EN 1090-2
Products	DIN 7968, DIN 7969 DIN 7990 DIN EN ISO 4014/4017 DIN 6914, DIN 6915, DIN 6916 DIN 7999	DIN EN 15048-1/-2 + tech. product specs. (DIN EN ISO 4014) DIN EN 14399-1/-2 DIN EN 14399-4 DIN EN 14399-6 DIN EN 14399-8

Tab. 1: Changeover to European standards

In future, DIN EN 1993-1-8 will apply to the calculation and design of joints, and DIN EN 1993-1-9 for the verification of fatigue, whereby the former DIN standards will continue to be applied during a transition period. DIN EN 1090-2 will apply in future to the execution, and there are transition periods here as well. The European standard DIN EN 15048 was created for non-preloaded, low-strength screwing assemblies and describes the procedure and the requirements for acquiring the CE mark. The appropriate technical descriptions for this may be, for example, the already existing standards for hexagon head screws such as DIN EN ISO 4014.

The harmonised standard DIN EN 14399 was drawn up for high-strength structural screwing assemblies. In Parts 1 and 2, this standard also describes the requirements and the procedure for acquiring the CE mark. In Europe, trade barriers may not exist or be established for products displaying the CE mark. The HV screws that are commonly used in Germany, and the appropriate nuts and washers, and HV fitting screws are found in Parts 4, 6, and 8 of this standard. The DIN pro-ducts were taken over to a great extent, so that there are only a few changes, and these will be discussed separately below.

• Under the European standard, HV nuts are always treated with a special lubricant, irrespective of the applied corrosion protection. Where the joints are preloaded in accordance with DIN 18800-7 with the help of the torque method, the same tightening torques are always applicable, which represents a simplification in comparison with the previous status.
• The screw grip lengths table contained in the standard defines the screw grip length **including the washers used** (Table 2a and 2b). In addition, the criteria

for calculating the screw grip length in accordance with the special requirements of DIN EN 1993-1-8 have been changed slightly, so that there are further minor differences. However, if a structure in accordance with DIN 18800 was planned, the planned DIN HV assemblies can be replaced by others with the same nominal length in accordance with the DIN EN standards without the necessity of a realignment of the screwed positions. The reason for this is the fact that DIN 18800 does not contain the above-mentioned special requirement in DIN EN 1993-1-8.

Nominal size	Sizes for HV and HVP screws[1]								
		M12	M16	M20	M22	M24	M27	M30	M36
P[1]		1.75	2	2.5	2.5	3	3	3.5	4
c	min.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	max.	0.6	0.6	0.8	0.8	0.8	0.8	0.8	0.8
d_a	max.	15.2	19.2	24	26	28	32	35	41
d_s	nom.	12	16	20	22	24	27	30	36
	min.	11.3	15.3	19.16	21.16	23.16	26.16	29.16	35
	max.	12.7	16.7	20.84	22.84	24.84	27.84	30	37
d_w [2]	min.	20.1	24.9	29.5	33.3	38.0	42.8	46.6	55.9
e	min.	23.91	29.56	35.03	39.55	45.20	50.85	55.37	66.44
k	nom.	8	10	13	14	15	17	19	23
	min.	7.55	9.25	12.1	13.1	14.1	16.1	17.95	21.95
	max.	8.45	10.75	13.9	14.9	15.9	17.9	20.05	24.05
k_w	min.	5.28	6.47	8.47	9.17	9.87	11.27	12.56	15.36
r	min.	1.2	1.2	1.5	1.5	1.5	2	2	2
s	max.	22	27	32	36	41	46	50	60
	min.	21.16	26.16	31	35	40	45	49	58.8
h	nom.	3	4	4	4	4	5	5	6
	min.	2.7	3.7	3.7	3.7	3.7	4.4	4.4	5.4
	max.	3.3	4.3	4.3	4.3	4.3	5.6	5.6	6.6
m	nom. = max.	10	13	16	18	20	22	24	29
	min.	9.64	12.3	14.9	16.9	18.7	20.7	22.7	27.7

Note: sizes before galvanising apply for hot-dip galvanised screws, washers and nuts
[1] P = thread pitch (standard thread)
[2] $d_{w,max.} = s_{ist}$

Tab. 2a

	Screw grip length $\Sigma t_{min.}$ and $\Sigma t_{max.}$ for HV and HVP screws[1]							
Nominal length l	**M12**	**M16**	**M20**	**M22**	**M24**	**M27**	**M30**	**M36**
30	11– 16							
35	16– 21	12– 17						
40	21– 26	17– 22						
45	26– 31	22– 27	18– 23					
50	31– 36	27– 32	23– 28	22– 27				
55	36– 41	32– 37	28– 33	27– 32				
60	41– 46	37– 42	33– 38	32– 37	29– 34			
65	46– 51	42– 47	38– 43	37– 42	34– 39			
70	51– 56	47– 52	43– 48	42– 47	39– 44	36– 41		
75	56– 61	52– 57	48– 53	47– 52	44– 49	41– 46	39– 44	
80	61– 66	57– 62	53– 58	52– 57	49– 54	46– 51	44– 49	
85	66– 71	62– 67	58– 63	57– 62	54– 59	51– 56	49– 54	43– 48
90	71– 76	67– 72	63– 68	62– 67	59– 64	56– 61	54– 59	48– 53
95	76– 81	72– 77	68– 73	67– 72	64– 69	61– 66	59– 64	53– 58
100	81– 86	77– 82	73– 78	72– 77	69– 74	66– 71	64– 69	58– 63
105	86– 91	82– 87	78– 83	77– 82	74– 79	71– 76	69– 74	63– 68
110	91– 96	87– 92	83– 88	82– 87	79– 84	76– 81	74– 79	68– 73
115	96–101	92– 97	88– 93	87– 92	84– 89	81– 86	79– 84	73– 78
120	101–106	97–102	93– 98	92– 97	89– 94	86– 91	84– 89	78– 83
125	106–111	102–107	98–103	97–102	94– 99	91– 96	89– 94	83– 88
130	111–116	107–112	103-108	102–107	99–104	96–101	94– 99	88– 93
135	116–121	112–117	108–113	107–112	104–109	101–106	99–104	93– 98
140	121–126	117–122	113–118	112–117	109–114	106–111	104–109	98–103
145	126–131	122–127	118–123	117–122	114–119	111–116	109–114	103-108
150	131–136	127–132	123–128	122–127	119–124	116–121	114–119	108–113
155	136–141	132–137	128–133	127–132	124–129	121–126	119–124	113–118
160	141–146	137–142	133–138	132–137	129–134	126–131	124–129	118–123
165	146–151	142–147	138–143	137–142	134–139	131–136	129–134	123–128
170	151–156	147–152	143–148	142–147	139–144	136–141	134–139	128–133
175	156–161	152–157	148–153	147–152	144–149	141–146	139–144	133–138
180	161–166	157–162	153–158	152–157	149–154	146–151	144–149	138–143
185			158–163	157–162	154–159	151–156	149–154	143–148
190			163–168	162–167	159–164	156–161	154–159	148–153
195			168–173	167–172	164–169	161–166	159–164	153–158
200			173–178	172–177	169–174	166–171	164–169	158–163
210			183–188	182–187	179–184	176–181	174–179	168–173
220			193–198	192–197	189–194	186–191	184–189	178–183
230			203–208	202–207	199–204	196–201	194–199	188–193
240			213–218	212–217	209–214	206–211	204–209	198–203
250			223–228	222–227	219–224	216–221	214–219	208–213
260			233–238	232–237	229–234	226–231	224–229	218–223

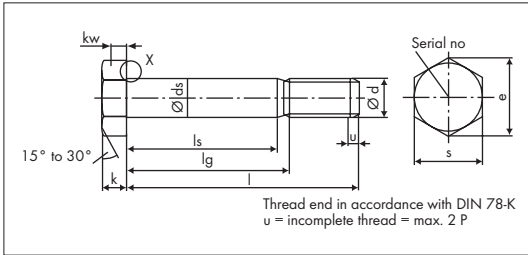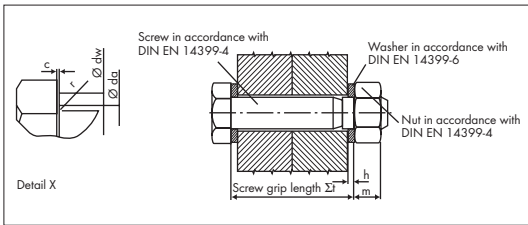[1] The screw grip length Σ_t comprises the two washers as well

Tab. 2b

Fig. 4

Fig. 5

8.3 Construction information and verifications for HV joints accordance with DIN 18800-1 and DIN EN 1993-1-8.

8.3.1 HV joints in accordance with DIN 18800-1 (2008)

The calculation values for the shearing stress V_a may not exceed the limit shear forces $V_{a,R,d}$ in accordance with DIN 18800-1:2008-11.

$$\frac{V_a}{V_{a,R,d}} \leq 1$$ The limit shear force $V_{a,R,d}$ is

$$V_{a,R,d} = A \cdot \tau_{a,R,d} = A \cdot \alpha_a \cdot \frac{f_{u,b,k}}{\gamma_M}$$

A   Shaft cross-section A_{sch}, when the smooth shaft is in the shear joint.
     Tension cross-section A_{Sp}, when the threaded part of the shaft is in the shear joint.

α_a 0.55 for HV screws in strength class 10.9, when the smooth shaft is in the shear joint.
     0.44 for HV screws in strength class 10.9, when the threaded part of the shaft is in the shear joint.

$f_{u,b,k}$ Characteristic tensile strength of the screw material, for HV screws:
     1000 N/mm²

γ_M = 1.1 part safety coefficient for the resistance

In accordance with DIN 18800-1:2008-11 the calculation values for the hole face loads V_l may not exceed the limit hole face forces $V_{l,R,d}$.

$$\frac{V_l}{V_{l,R,d}} \leq 1$$

The limit hole face force $V_{l,R,d}$ is

$$V_{l,R,d} = t \cdot d_{Sch} \cdot \sigma_{l,R,d}$$

$$= t \cdot d_{Sch} \cdot \alpha_l \cdot \frac{f_{z,k}}{\gamma_M}$$

With t thickness of the component
d_{Sch} Shaft diameter of the screw
α_l Factor for determining the hole face endurance, depending on the hole pattern
$f_{y,k}$ Characteristic yield point of the component material
γ_M = 1.1 part safety coefficient for the resistance

Factor α_l depends here on the geometry of the completed screwed connection, in particular on the distances of the screws from the edges of the components and from each other. Tables or appropriate software are usually available for calculation purposes.

DIN 18800-1 differentiates cases for the calculation of the limit tensile force under the pure tensile load on the screws. Because of the yield point ratios of strength class 10.9, the failure in the thread is decisive for HV screws. The limit tensile force is therefore calculated as:

$$N_{R,d} = \frac{A_{Sp} \cdot f_{u,b,k}}{1.25 \cdot \gamma_M}$$

A_{Sp} Tension cross-section
$f_{u,b,k}$ for FK 10.9 = 1,000 N/mm²
1.25 = Coefficient for the increased security against tensile strength
γ_M = 1.1

If a tensile force and a shear force affect a screw simultaneously, interaction verification has to be carried out in accordance with the requirements of DIN 18800-1.

With friction-grip connections (GV and GVP), the loads V_g may not exceed the boundary sliding forces $V_{g,R,d}$ in the boundary state of usability

$$\frac{V_g}{V_{g,R,d}} \leq 1$$

8.3.2 HV joints in accordance with DIN EN 1993-1-8

The European standard classifies the screw assemblies in accordance with Table 3 and makes a fundamental difference depending on the direction of the external force.

Shear/bearing resistant and friction-grip connections			
Category	**Remarks**	**Compared with DIN 18800-1**	
		GdG	**GdT**
A Shear/bearing connection	No preloading necessary, but in most cases an advantage, strength classes 4.6 to 10.9	SL or SLP	SL or SLP
B Friction-grip connection (GdG)	High-strength screws SC 8.8 or 10.9 preloaded	GV or GVP	SL or SLP
C Friction-grip connection (GdT)	High-strength screws SC 8.8 or 10.9 preloaded.	GV or GVP	GV or GVP (net)
Tensile loaded connections			
Category	**Remarks**	**Compared with DIN 18800-1**	
D Not preloaded	No preloading necessary, strength classes 4.6 to 10.9	Not classified, but verification criterion indicated	
E Preloaded	High-strength screws SC 8.8 or 10.9		

Tab. 3

The boundary sliding force $V_{g,R,d}$ is

$$V_{g,R,d} = \frac{\mu \cdot F_v}{(1.15 \cdot \gamma_M)}, \text{ if no external tensile force acts on the HV screw,}$$

$$V_{g,R,d} = \frac{\mu \cdot F_v \cdot (1 - \frac{N}{F_v})}{(1.15 \cdot \gamma_M)}, \text{ if an external tensile force acts on the HV screw,}$$

whereby:

μ is the coefficient of friction after pre-treatment of the friction surfaces in accordance with DIN 18800-7

F_v is the preload force in accordance with DIN 18800-7

N is the tensile force falling pro rate on the screw

γ_M = 1.0

In addition, interaction verification has to be carried out for GV and GVP connections in the same way as for SL and SLP connections.

The verification of bearing stress differs here in the approach from the procedure in accordance with DIN 18800-1 so that transmission of calculation results or table values is not possible. In this case, recalculation in accordance with the requirements of DIN EN 1993-1-8 is necessary. In many cases, the stress resistance in accordance with EN is greater than in accordance with DIN.

Verification of shearing off of the screws in accordance with EN differs only slightly and has a similar structure from the theoretical aspect. If the shaft is in the shear joint the stress resistances are approximately the same. If the thread is in the shear joint they are the same.

In the case of HV screws under tensile load in the screw's lengthwise axis the calculation approach hardly differs at all from that in the DIN standard and the results are approximately the same.

In the simple case of friction-grip connections without external tensile load the approaches in accordance with DIN and EN are also similar; however, a significant difference has to be mentioned at this point that also has effects on the applicable preloading method.

DIN EN 1993-1-8 stipulates a higher preload force level for friction-grip connections (and only for these) than is usual for preloaded HV joints in accordance with DIN 18800-7. The preload force should amount to 70% of the tensile strength of the screw:

$F_{p,C} = 0.7 \, f_{ub} \, A_S$

Because of friction distributions, this preload force level is no longer reliably achievable with the torque method, so that alternative methods have to be applied that reduce the influence of the friction.

However, a lower preload force level Fp,C* is permissible for all screw assemblies that are not friction-grip calculated and are to be preloaded for other reasons, for

8.4 Assembly
8.4.1 Assembly and test in accordance with DIN 18 800-7

The torque method is to be used preferably for preloading. The standard preload force in accordance with Table 4 corresponds to 70% of the screw yield point and is therefore generated by applying a tightening torque M_A.

The tightening torque is the same here for all surface conditions of the fasteners.

Screw assemblies that were preloaded with the help of the torque method are accessible very easily for a check by applying a test torque that is 10% greater than the tightening torque.

Dimensions		Standard preload force F_V [kN] (corresponds to $F_{p,c}$ * = 0.7 x f_{yb} · A_S)	Torque method
			Applicable tightening torque M_A for achieving the standard preload force F_V [Nm]
			Surface condition: hot-dip galvanised and lubricated[a] and as manufactured and lubricated[a]
1	M12	50	100
2	M16	100	250
3	M20	160	450
4	M22	190	650
5	M24	220	800
6	M27	290	1250
7	M30	350	1650
8	M36	510	2800
[a] Nuts treated in the delivery condition by the manufacturer with molybdenum sulphide or similar lubricant. In contrast to earlier rules, the tightening torque is always the same irrespective of the delivery condition.			

Tab. 4: Preloading through torque

example to increase the fatigue resistance. For example, this can be the preload force level in accordance with DIN 18800-7.

$F_{p,C}$ * = 0.7 f_{yb} A_S

That is, the preload force amounts to 70% of the screw yield point. This means that all preloaded screw assemblies in accordance with DIN EN 1993-1-8 that are not friction-grip preloaded may be preloaded with the standard torque method for screw assemblies. The assembly values may be taken from DIN 18800-7 and are shown in chapter 8.4.

Measures for checking are not required for connections that are not systematically preloaded. In the case of connections that are preloaded systematically at least 10% of the assemblies for the connection are tested in the case of connections that are not mainly loaded at rest, and at least 5% of the assemblies for the connection with connections that are mainly loaded at rest (with connections with less than 20 screws at least 2 connections, or 1 connection). The assembly is to be checked after the marking (situation of the nut relative to the screw shaft) from the side from which tightening took place.

The procedure in Table 5 that is used depends on the
further rotation angles that occur during the test. If an
unequivocal test is not possible (other methods used),
the operation must be monitored for at least 10% of the
connections. If deviations from the defaults specified in the
respective method test are found, following corrections
the complete execution of the whole connection must be
monitored.

Checking the preload force with standard preload forces

Further angle of rotation	Evaluation	Measure
< 30°	Preload force was sufficient	None
30° to 60°	Preload force was conditionally sufficient	Leave the assembly and test two adjoining connections in the same joint
> 60°	Preload force was not sufficient	Change the assembly[1] and test two adjoining connections in the same joint
[1] These checked fasteners may only be left in the construction with SLV or SLVP connections that are loaded mainly at rest without additional tensile loads.		

Tab. 5

Other methods referred to in the standard are the
momentum method, the angle of rotation method and
a combined method, which are only mentioned here
because they are seldom used. If necessary, the wording
of the standard is to be used.

8.4.2 Assembly in accordance with DIN EN 1090-2

With all preloaded connections that are not designed friction-proof the preload force is 70% of the screw yield point and thus the torque method in accordance with DIN 18800-7 is applicable in conformity with the EN without restriction. In the cases in which the connection is designed friction-proof, a preload force to:

$$F_{p,C} = 0.7 \, f_{ub} \, A_S$$

is stipulated in accordance with DIN EN 1993-1-8. This makes it necessary to apply other methods, whereby the combined method appears practicable here. The connections are tightened here with a pre-tightening torque that is recommended by the screw manufacturer or can be estimated with

$$M_{r,1} = 0.13 \, d \, F_{p,C}$$

if there is no recommendation from the manufacturer. After this the connections are then tightened by the further angle of rotation stipulated in the standard. Table 6 indicates the tightening parameters for the combined method in accordance with DIN EN 1090-2.

8.5 Special information for using HV assemblies

- When stored, HV screws, nuts and washers must be protected from corrosion and dirt.
- If preloading is carried out by turning the screw head, a suitable lubricant must be applied to the head and a method test carried out.
- If a preloaded assembly is unscrewed subsequently it must be dismantled and replaced with a new one.
- After tightening, the screw thread should usually project over the nut by a complete turn of a thread.
- Up to 3 washers with a total thickness of 12 mm are permissible on the side of the assembly that is not turned to compensate for the screw grip length.

Combined method									
Dimensions		M12	M16	M20	M22	M24	M27	M30	M36
Preload force $F_{p,C} = 0.7 \cdot f_{ub} \cdot A_S$ [kN]		59	110	172	212	247	321	393	572
Pretightening torque M_A [Nm][1]		75	190	340	490	600	940	1240	2100
	Further angle of rotation or revolution dimension for screw grip length Σt								
	Total nominal thickness "t" of the parts to be joined (including all lining plates and washers) d = screw diameter	Further angle of rotation			Further revolution dimension				
1	t < 2d	60			1/6				
2	2d ≤ t ≤ 6d	90			1/4				
3	6d ≤ t ≤ 10d	120			1/3				

Note: If the surface under the screw head or the nut (taking account of any square taper washers that are used as well) is not vertical to the screw axis, the necessary further angle of rotation should be determined in experiments.
[1] Example of manufacturer's recommendation

Tab. 6: Preloading with the combined method