Construction equipment and
building material machinery

Technical information

Safe fastening of core-drilling equipment

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Note:

The clauses contained in the present publication reflect only non-binding examples that have been shared by VDMA member companies. The fact that they have been included in this guide gives no indication as to whether they are customary in the industry or not. This is why the clauses cannot be used as boilerplate text. Especially with respect to warranty, liability and terms of payment, many other variants and alternatives could be possible. It is rather the individual contract and the facts of the individual case that have to be assessed in order to be able to make a sound decision on what clauses can be used at all and how they have to be amended.

1 Introduction

For the safe operation of machines and equipment on construction sites, the user of a machine is obliged to observe the legal prescriptions in force and the operating instructions of the respective manufacturers. The observance of all pertinent safety regulations lies within the responsibility of the company performing the work.

With regard to the use of machines on construction sites, the company performing the work must not only respect all pertinent regulations in conjunction with occupational health and safety, accident prevention and other safety aspects (laws, decrees, operating instructions, etc.) regarding

- the operation of the machine as such,

but also those concerning

- the use of the machine in the vicinity of the construction site as for instance:
  - nature and quality of the ground
  - nature and quality of the material to be cut
  - state of wear of the drill bit
  - training level and experience of the operating personnel
  - ambient conditions on site (outside / inside a building, lighting conditions, humidity, climatic conditions)

In the operator’s manual the manufacturer gives instructions concerning the intended use and thus the safe handling of the machine, but also with regard to foreseeable cases of abusive use of the machine.

As far as the use of core-drilling equipment is concerned, the special focus is on the safe fastening of the machine on its foundation. In order to fulfil this requirement, it is additionally necessary to consider also those influencing variables on the construction site that are of importance for the operational safety, but the extent and the nature of which are difficult to anticipate and to quantify. At this interface between manufacturer and company performing the work a precise definition and separation of the responsibilities is indispensable.

The present brochure is therefore intended to provide the contractor with all the essential information with which the manufacturer can – apart from the information already contained in the operating instructions – contribute to the safe operation of the core-drilling equipment on the construction site.

For the purpose of elaborating the present brochure, the section “light construction equipment” of VDMA Construction Equipment and Building Material Machinery has established the working group “core-drilling equipment”. The experience contributed by the machine manufacturers have shown that the relationship between the influencing variables “machine” and “site conditions” is a rather complex one. The implementation of the information contained in this brochure therefore requires a profound knowledge of the machines and the respective fastening technologies discussed in this context. For this reason, the companies working with this type of equipment are advised to make sure that all decisions regarding the method of fastening core-drilling rigs on constructions sites are taken by adequately trained and instructed personnel only.

The present brochure has been elaborated and edited by Prof. Dr.-Ing. Detlev Borstell of the Koblenz University of Applied Sciences who also attended closely to the work of the working group.

2 Summary

The list below summarizes the essential contents of the following chapters in a generally understandable form by means of simple basic rules:

Summary

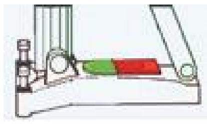
Setting up the machine	The nut should be located at the front end of the oblong hole in the baseplate (green) and not at the rear (red). 
Before drilling	It must be ensured that the dowel will not be loosened or extracted (by prestressing force Fv) already during tightening of the nut.
	The magnitude of the prestressing force Fv exerted on the dowel is essentially dependent on the tightening procedure and the tightening torque applied on the dowel nut.
	The greater the care and precision with which the nut is being tightened (tightening method, torque) the lower the probability that the dowel will be loosened already during tightening.
	The greater the precision with which the prestressing force F_v can be ascertained, the more precise and the safer the determination of the dowel force F.
During drilling	With new, sharp drill bits (low friction coefficient μ) the dowel force F will be greater than with older and already blunt drill bits (higher friction coefficient μ).
	With new, sharp drill bits, the dowel force F shows a considerably higher sensitivity to changes of drill bit diameter and rotational speed than in case of older and already blunt drill bits.
	The prestressing force F_v always acts in addition to the operation-induced forces during the drilling process.
	The magnitude of prestressing force F_v is independent of the operation-induced forces during the drilling process.
	Small drill bit diameters in combination with high rotational speeds result in higher dowel forces. The influence of friction coefficient μ (old drill bit / new drill bit) on dowel force F is, however, considerably greater than the influence exerted by rotational speed and drill bit diameter.
	Low friction coefficients μ (new sharp drill bits) AND a position of the threaded rod somewhere in the red zone of the oblong hole will result in an extremely sharp increase of dowel force F.

Table 2-1

The above-mentioned rules have been given without complex background information which has been deliberately omitted.

These facts will be discussed in greater detail in the following chapters.

Besides their own experience, contractors, executives or interested experts are equally bound to use their knowledge of the theoretical and technical details described in the following chapters in any decision taken in favour of a certain fastening system.

3 Construction and fastening of a core-drilling machine

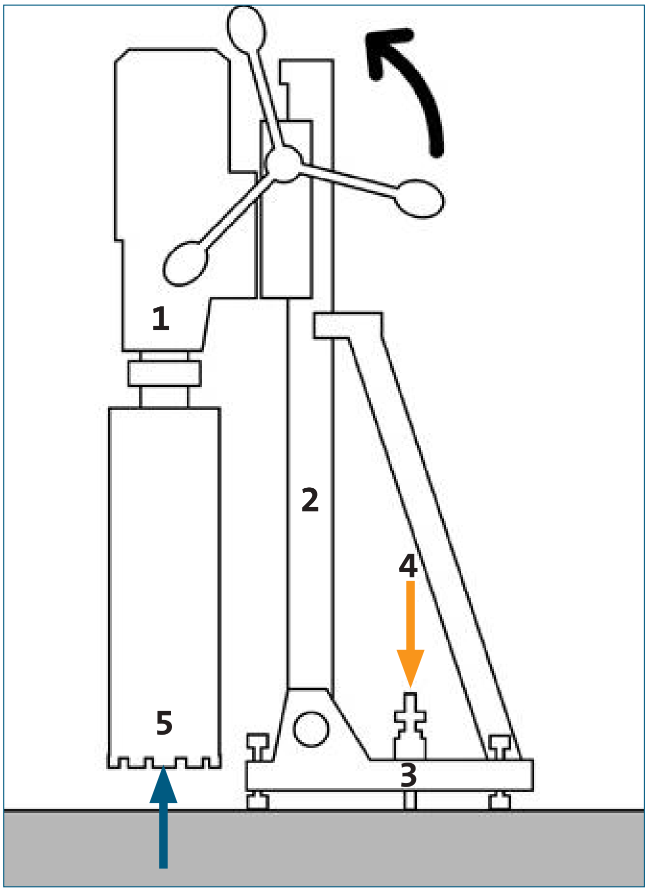


Figure 3-1
Construction of a core-drilling machine

A core-drilling machine basically consists of

1 drill bit with motor and feed unit

2 linear guide and support

3 baseplate

The core-drilling machine is anchored in the ground with its mounting or base plate mostly by means of a dowel (4) in order to cope with the feeding force at the drill bit (5) which is required for drilling. Safe anchoring of the machine in all working positions is therefore decisive (vertical on a floor, horizontal in a wall, overhead in a ceiling).

The machine is generally fastened with a system consisting of dowel + threaded rod + nut.

Figure 3-2 Source: Prof. Borstell
Dowel (drive-in anchor)

Figure 3-3 Source: Prof. Borstell
Threaded rod + nut

After drilling a hole into the ground, the dowel (drive-in anchor) is at first driven into the hole. Thereafter, the core-drilling machine is positioned with its baseplate over the hole and the threaded rod is screwed through the oblong hole in the baseplate into the drive-in anchor. For tightening of the rod, for instance, a screwdriver placed in the transverse hole of the rod can be used. The dowel is then tightened by means of the nut and thus gets jammed in the borehole.

The numerous influencing variables existing on the construction site play a decisive role in choosing the components of the fastening system (dowel / drive-in anchor, threaded rod, nut) and the sizes of dowel and threaded rod. They must therefore all be taken into account in the decision for a certain fastening system and for the dimensions of the latter.

The most important parameter in this respect is the force acting on the dowel which is referred to in the following text as the dowel force.
The following chapters therefore focus on the description of the conditions influencing this force and of the effects of these influences on the magnitude of the dowel force.

4 Procedure of determining the maximum dowel force

The following sections describe the procedure of determining the maximum dowel force with the help of the basic notions of technical mechanics. This procedure includes

- assumptions,
- simplifications,
- limitations and
- boundaries

that must be observed.

For all subsequent calculations we shall basically assume the following geometry with the given designations for forces and lever arms:

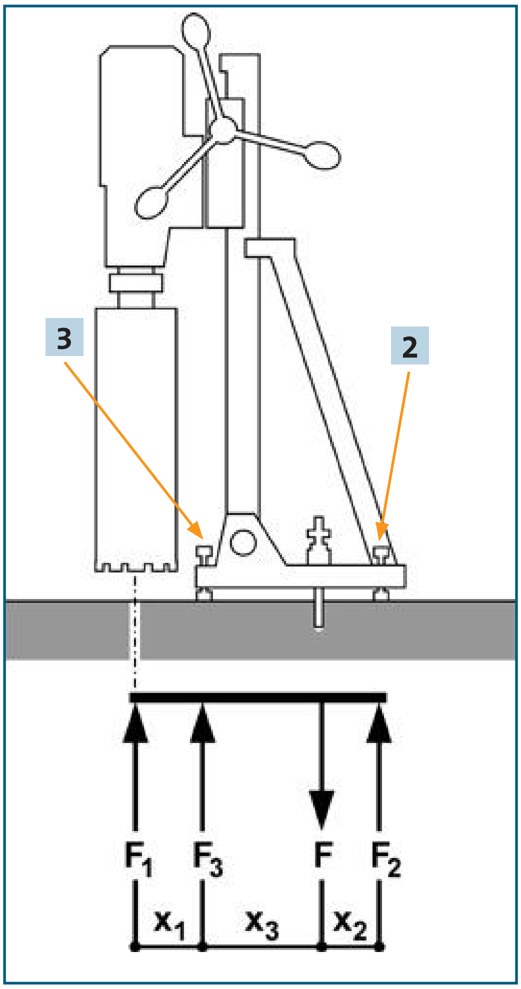


Figure 4-1

Designation	Description
F_1	Feeding force at the drill bit
F_3	Reaction force at the front baseplate support (item „3“)
F_2	Reaction force at the rear baseplate support (item „2“)
F	Force acting on the fastening dowel
x_1	Distance between centre of drill bit and front baseplate support
x_2	Distance between centre of dowel and rear baseplate support
x_3	Distance between front baseplate support and centre of dowel

Table 4-1

4.1 Mechanical fundamentals

The force F can basically be calculated – first without taking the prestress applied on the dowel by tightening the nut or the screw into account – from the equilibriums of forces and moments at the core-drilling machine in accordance with figure 4-1.

Equilibrium of forces:

Formula 4-1 $$F = F_1 + F_2 + F_3$$

Equilibrium of moments in “2” (cf. fig. 4-1):

Formula 4-2 $$F_1 \cdot (x_1 + x_2 + x_3) + F_3 \cdot (x_2 + x_3) - F \cdot x_2 = 0$$

In this case, we have three unknown forces, but only two equations for finding a solution. Since no further equation is at hand one of the unknown forces must be assumed with a value that makes sense and therefore be treated as a known force.

As an approach to the solution of this problem we shall focus exactly on the instant in which the drill stand lifts off in front (point “3”, cf. fig. 4-1), i.e. the instant when force F_3 equals 0.

Mechanical fundamentals

F	unknown and to be determined
F_2	unknown
F_3	unknown
F1	can be calculated by means of the friction coefficient between drill bit and material from the motor moment

Table 4-2

This approach represents, however, only one of the possible states of operation which may lead to the extraction of the dowel. In the order of increasing dowel force F, these states are the following:

State a)
The machine is not yet in operation. The dowel screw is just about to be tightened. It must be ensured that the dowel is not extracted already during the tightening process. In this case, the dowel force depends only on the boundary conditions existing during tightening of the screw.

State b)
The machine is in operation. F_1 is rising, F_3 is (still) > 0, i.e. the front baseplate support still rests firmly on the ground. When F_1 rises, F_3 will decrease, but F increases so that the force acting on the dowel can rise to such an extent that the dowel will be extracted. Due to the acting of F_1, dowel force F is now greater than in state a. As this condition is statically overdefined it cannot be calculated by means of simple analytical approaches.

State c)
The machine is in operation and F_1 has become so great that the front support has lifted off and that $F_3 = 0$. This state is undesired in practice and must therefore generally be avoided. However, the equations are simpler and F can be calculated by means of simple analytical approaches. Should $F_{state\ c}$ still be smaller than the permissible extraction force, it does make sense to use this simplified approach because if the dowel resists in state c it will also resist in state b ($F_{state\ c} > F_{state\ b}$). If, however, $F_{state\ c}$ exceeds the permissible dowel extraction force, it is worth considering whether to perform a further calculation for state b or to use this negative result without doing any further recalculation. With this decision one would be on the safe side.

Summary

State	Boundary conditions	Σ F	Σ M	Remarks	Conclusion
a	$F_1=0$	$F_{state\ a}=F_2+F_3$	$F_3=F_2\cdot(x_2/x_3)$	$F_{state\ a}$ is the prestressing force of the dowel screw resulting from the tightening torque	The company performing the work must ensure that the dowel will not be loosened or extracted already during the tightening process of the screw
b	$F_1>0$ and $F_3>0$	$F_{state\ a}=F_2+F_3$	not required	no solution by simple analytical means	The forces can be determined by means of the FEM[1]) method [1]
c	$F_1>0$ and $F_3=0$	$F_{state\ c}=F_1+F_2$	$F_2=F_1\cdot(x_1+x_3)/x_2$	solution by simple analytical means if either $F_{state\ c}$ or F_1 are known	Since the maximum value of F1 can be calculated from the motor moment, this approach can be used as the basis for a simplified calculation of F.

Table 4-3

The following chapters will therefore deal with the general principles for a simplified determination of the dowel force based on state c in order to identify the factors with a special influence on the magnitude of the dowel force.

[1]) The Finite Element Method (FEM) is a numerical procedure for solving partial differential equations. It is widely used as a modern computation procedure in the field of engineering science and the standard tool for the simulation of solid bodies.

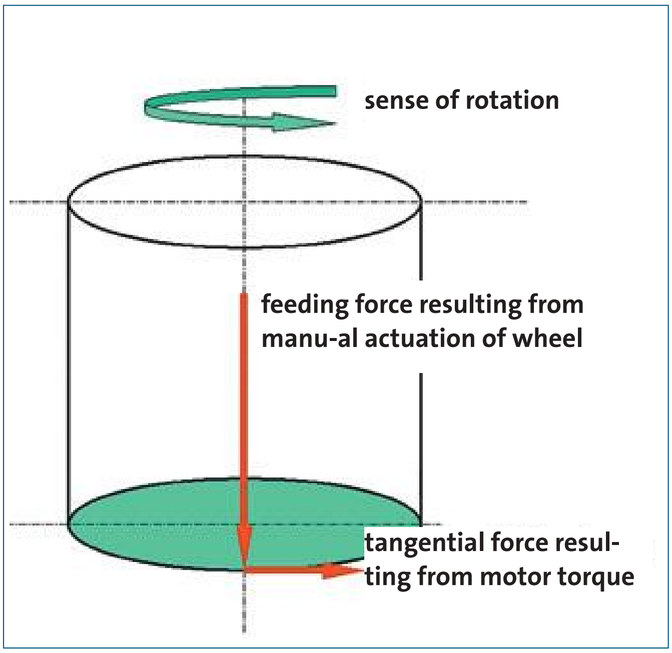


Figure 4-2 Source: Prof. Borstell

4.2 Simplified calculation of forces for state c

4.2.1 Forces and friction at the drill bit cutting edge

During the operation of a core-drilling machine, the vertical feeding force is generated manually by means of a handwheel and transferred via a pinion/toothed rack to the drill bit. At the same time, a horizontally acting tangential force resulting from the motor torque is present at the drill bit. Only the vertical feeding force as force F_1 is part of the forces and moments equilibrium for the determination of the forces acting on the dowel.

In the process of cutting the concrete and in consideration of the friction in the cut and the corresponding available motor torque, the vertical feeding force and the horizontal tangential force will be present in a certain proportion. For the determination of the maximum dowel force one can assume

- that the motor torque is at its maximum because
- the feeding force is only so great that the motor is not yet stalled.

The maximum motor moment of drill motor T is known. It can be calculated from the maximum power P delivered by the motor and by rotational speed n:

Formula 4-3

$$T = \frac{P}{2 \cdot \pi \cdot n}$$

According to the friction law, the existing feeding force F_1 is thus dependent only on friction coefficient μ between drill bit and the material being cut, on drill bit diameter d and on the momentary torque T.

Formula 4-4

$$F_1 \cdot \mu = F_t = \frac{2T}{d}$$

so that

Formula 4-5

$$F_1 = \frac{2 \cdot T}{d \cdot \mu}$$

4.2.2 Calculation of dowel force F

In acc. with table 4-3 state c) and with formulas 4-3 and 4-5, the dowel force can now (and still without prestressing force) be calculated as follows:

Formula 4-6

$$F_{state\,c} = F_1 + F_2 = F_1 \cdot \left(1 + \frac{x_1 + x_3}{x_2}\right) = \frac{P}{\pi \cdot n \cdot d \cdot \mu} \cdot \left(1 + \frac{x_1 + x_3}{x_2}\right)$$

Tightening of the dowel screw / dowel nut now generates a prestressing force F_v which must still be added to the dowel force as determined above.

Formula 4-7

$$F_{state\,c} = F_V + \frac{P}{\pi \cdot n \cdot d \cdot \mu} \cdot \left(1 + \frac{x_1 + x_3}{x_2}\right)$$

This formula now includes all essential influencing variables:

- friction coefficient μ
- prestressing force F_v
- delivered power P (which can also be described with the help of torque T and rotational speed n)
- diameter of drill bit d
- lengths x_1, x_2 and x_3

The importance of these influencing variables for the dowel force will be discussed in detail on the following pages. For this purpose, we shall use fictitious but realistic figures as an example in the calculations.

Fictitious exemplary values:

	Exemplary values	
max. power delivered P	2250	W
rotational speed under full load n	220 / 420 / 650	min^{-1}
core drill diameter d	350 / 160 / 100	mm
length $x_1 = d_{max}/2$ (approximation)	175	mm
length $x_2 + x_3$	500	mm
$q = x_2 / x_3$	0.11 to 9	
friction coefficient µ	0.14 to 0.94	
screw /dowel diameter	M12	

Table 4-4

4.2.2.1 Influencing variables prestressing force F_v and friction coefficient µ

Friction coefficient

No reference regarding friction coefficients for the diamond drill bit / concrete pair has been found in the literature. It has been attempted, however, to determine a generally valid friction coefficient K_v between the drill bit and the concrete from force measurements performed by manufacturers in 2009 [2] [4]. For this purpose, several measurement series resulting in 92 measured values altogether were performed. The large spread between the measured values indicated, however, that the adoption of a generally valid friction coefficient was not possible. The evaluation by the Koblenz University of Applied Sciences led to the conclusion that:

" ... in clearly more than 16 out of 100 cases, an assumed value of K_v = 0.4 will result in too low dowel extraction forces. Material parameters are generally determined with a failure probability of 2.5%. This is so far away from the Kv values determined in 2009 that these values cannot be used and that a measurement of the friction coefficients at the drill bits will be required." [3]

From the above mentioned conclusion it becomes clear that the assumption of a generally valid friction coefficient is impossible and that it cannot be provided by the machine manufacturers either. For this reason, the present information brochure will resort to a parameter variation for the friction coefficient μ in order to show the effects of very small (μ = 0.05) to large friction coefficients (μ = 0.95).

The influence of friction coefficient μ can be seen immediately from formula 4-7 (and also from 4-11): the greater the friction coefficient the smaller the dowel force. The relationship between F and μ is, however, not linear (see fig. 4-3).

If the procedure described is applied, it is up to the company performing the work to take the influence of friction coefficient μ properly into account.

Prestressing force

The amount of prestressing force F_v depends to a large extent on the tightening method and on the tightening torque applied to the dowel nut.

For current standard screws acc. to DIN the prestressing forces are specified as a function of tightening torques, thread friction and strength class of the screw in compliance with VDI Standard 2230 [5]. These values may serve in this case as a point of reference for the prestressing force. As a rule, the dowel screws used will be screws of size M12 or M16. For these screws, VDI Standard 2230 specifies the following possible prestressing forces that should be reached when the indicated tightening torque is applied:

Assembly prestressing forces [kN] and the respective tightening torques [Nm] in acc. with VDI 2230

Size	Strength class	Total friction in the thread							
		0,08	0,10	0,12	0,14	0,16	0,20	0,24	
M12	8.8	45,2 63	44,1 73	43 84	41,9 93	40,7 102	38,3 117	35,9 130	kN at Nm
	10.9	66,3 92	64,8 108	63,2 123	61,5 137	59,8 149	56,3 172	52,8 191	kN at Nm
	12.9	77,6 108	75,9 126	74,0 144	72,0 160	70,0 175	65,8 201	61,8 223	kN at Nm
M16	8.8	84,7 153	82,9 180	80,9 206	78,8 230	76,6 252	72,2 291	67,8 325	kN at Nm
	10.9	124,4 224	121,7 264	118,8 302	115,7 338	112,6 370	106,1 428	99,6 477	kN at Nm
	12.9	145,5 262	142,4 309	139,0 354	135,4 395	131,7 433	124,1 501	116,6 558	kN at Nm

Table 4-5

The prerequisite for the assumption of a force for Fv is not so much the process of tightening the screws with the tightening torque in acc. with VDI 2230, but rather the fact that the tightening torque and thus the magnitude of Fv must be known at all. This requirement must be ensured by the company performing the work.

As an example, the following calculations will be based on a thread friction of μ_{total} = 0.14 and a screw (dowel) of size M12 and strength class 8.8. This will then lead to the following prestressing force to be taken into consideration:
M12 : F_v = 41.9 kN.

Figure 4-3 shows the influence of friction coefficient μ and prestressing force Fv on the dowel force F:

Figure 4-3 allows the following statements:

- Dowel force F is increased by F_v independent of all other influencing variables. F_v thus has a decisive and direct influence on the magnitude of dowel force F.
- The correlation between F and μ is not linear!
- Small friction coefficients always correlate with higher dowel forces than large friction coefficients.
- The response of the dowel force to changes in the case of small friction coefficients is considerably more pronounced than in the case of large friction coefficients.

Influence of friction coefficient μ and prestressing force Fv on dowel force F

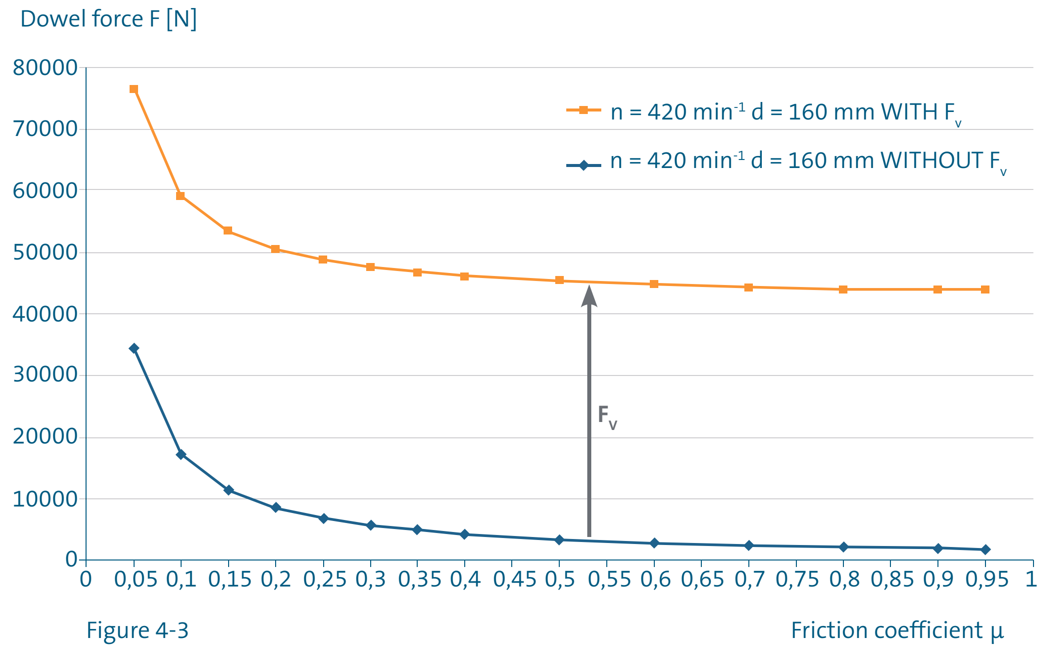


Figure 4-3

4.2.2.2 Influencing variables rotational speed and core drill diameter

The influence of rotational speed n and core drill bit diameter d is shown in figure 4-4:

Influence of rotational speed n and core drill bit diameter d on dowel force F

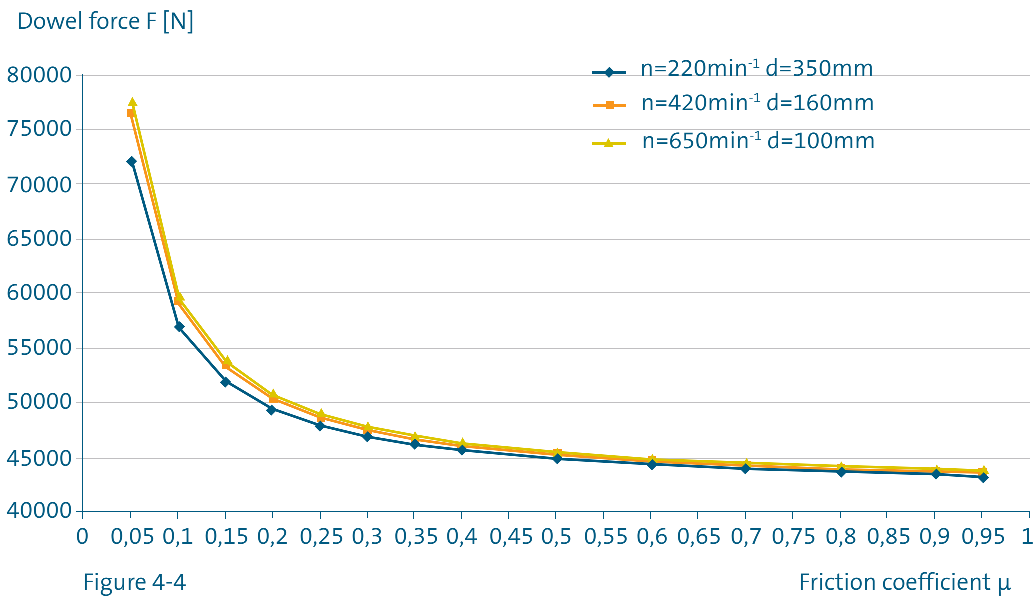


Figure 4-4

This diagram allows the following statements:

- Small drill bit diameters together with high rotational speeds result in higher dowel forces.
- The response of the dowel force to changes in rotational speed and drill bit diameter in the case of small friction coefficients is considerably more pronounced than in the case of large friction coefficients.

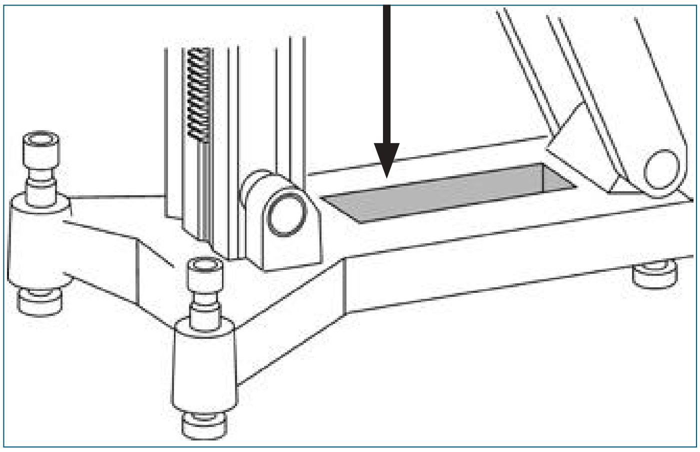


Figure 4-5

4.2.2.3 Geometric influencing variables x_1, x_2 and x_3

Influencing variable x_1

Depending on the construction of the baseplate, length x_1 can have different values. For the calculation example, x_1 is to be assumed with half the maximum possible drill bit diameter. For any specific application, x_1 can be precisely determined.

Influencing variable $q = x_2 / x_3$

The baseplates of core-drilling equipment are often equipped with oblong holes to ensure precise positioning of the drill even after the installation of the dowel and before tightening of the nut. The distance of the dowel from the front baseplate support also has an influence on the magnitude of the dowel force. This distance can be described with the ratio of x_2 to x_3.

If $q = x_2 / x_3 = 1$ then $x_2 = x_3$ and the dowel is located exactly in the middle between front and rear baseplate support.

If the dowel is shifted in the direction of the front baseplate support (blue arrow) we have

$x_2 > x_3$ and $q = x_2 / x_3 > 1$.

If the dowel is shifted in the direction of the rear baseplate support (yellow arrow) we have

$x_2 < x_3$ and $q = x_2 / x_3 < 1$.

Length L of the baseplate is mostly known from the manufacturer's specifications so that the spacing $x_2 + x_3$ between the supports approximates to this value.

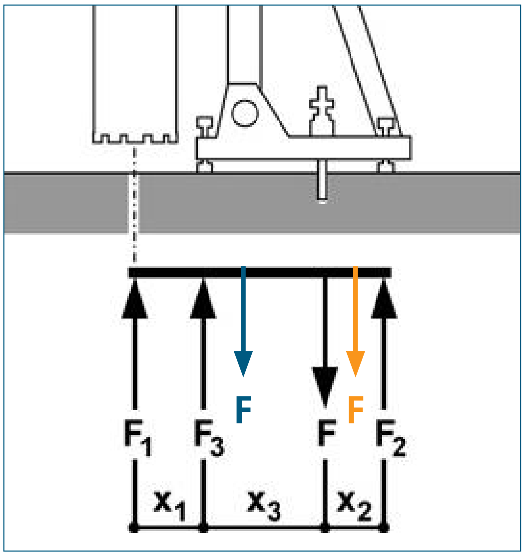


Figure 4-6

Formula 4-8

$$L = x_2 + x_3$$

With formula 4-8 and q, values x_2 and x_3 can now be replaced:

Formula 4-9

$$x_2 = L \cdot \frac{q}{q+1}$$

Formula 4-10

$$x_3 = L \cdot \frac{1}{q+1}$$

The formula for the calculation of the dowel force then becomes:

Formula 4-11

$$F_{static} = F_V + \frac{P}{\pi \cdot n \cdot d \cdot \mu} \cdot \left(1 + \frac{x_1 + L \cdot \frac{1}{q+1}}{L \cdot \frac{q}{q+1}}\right)$$

The calculation example shows the effect of different dowel positions between q = 9 and q = 0.11 for n = 420 min^{-1} and a drill bit diameter d = 160 mm as a function of friction coefficient μ.

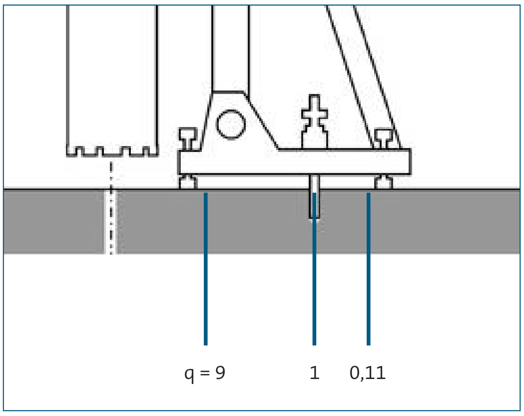


Figure 4-7

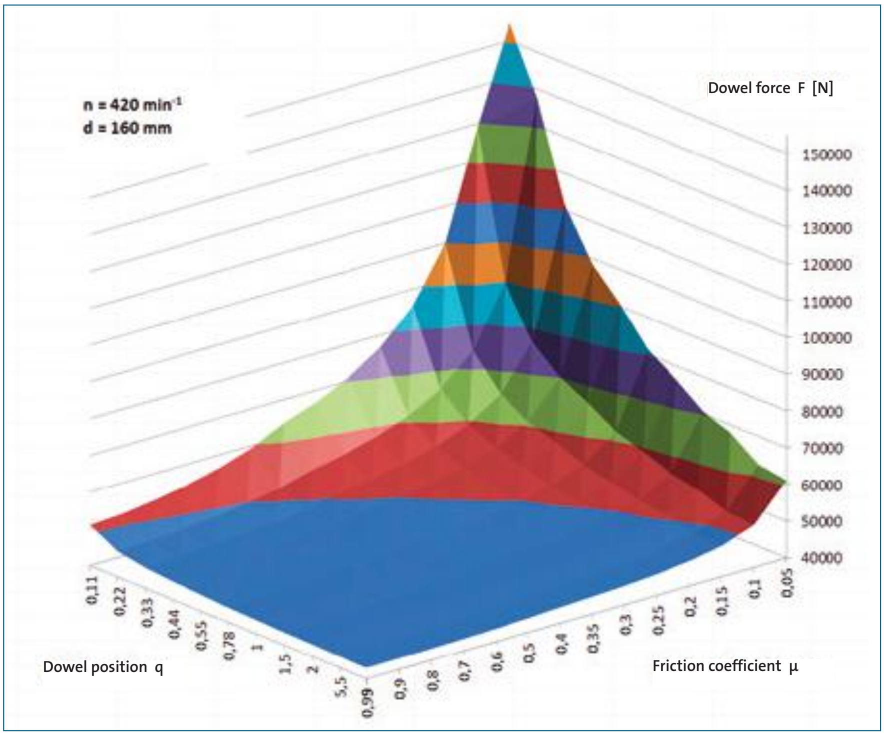


Figure 4-8 Source: Prof. Borstell

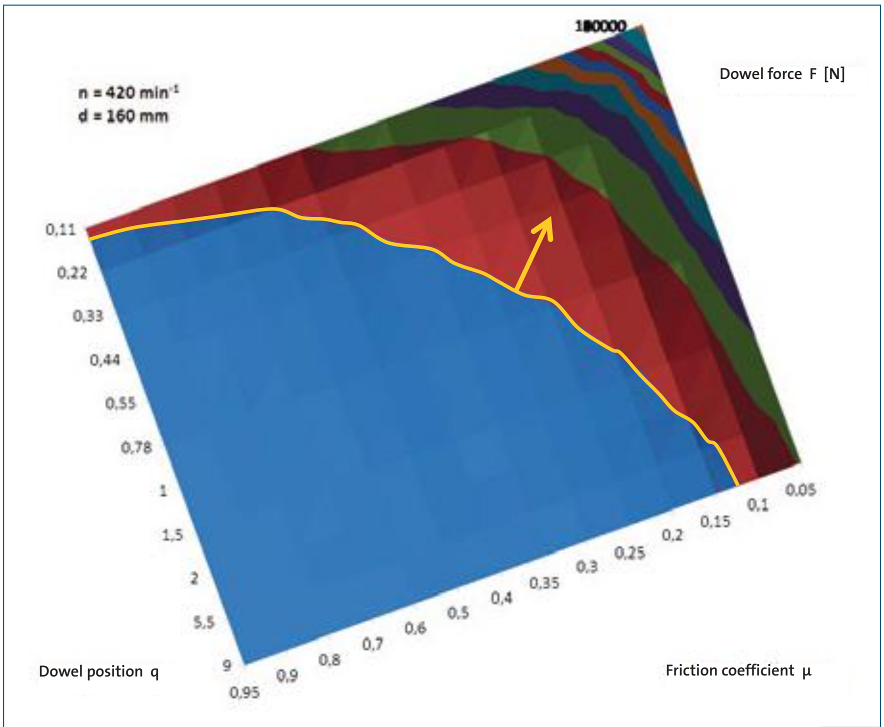


Figure 4-9 (Figure 4-8 seen from above)) Source: Prof. Borstell

These diagrams show that

- moving the dowel position away from the centre towards the rear baseplate support (small q) combined with small friction coefficients will result in great dowel forces;
- really extreme changes in the dowel force can be seen in the zone behind the orange line in the direction of the arrow (cf. figure 4-9)..

4.3 Selection of a dowel

The selection of the dowel will mainly be dictated by the dowel force required. The equations discussed in this brochure can, however, not be used to derive reliable and thus generally valid numerical values for the dowel force. This conclusion has been proved by measurements and FEM analyses made by the manufacturers [1] [2] [4].

The fact that a general statement for the dowel force is not existing makes it necessary therefore that the company performing the work includes in its decision regarding the selection of a dowel all possible sources and experts with the corresponding know-how to help with the selection of a suitable fastening system, as for instance:

- own experience (best practice),
- collaboration with the dowel manufacturer,
- taking advantage of the knowledge about the effects of all influencing variables discussed in this information brochure.

5 Reference List

[1] D. Borstell, Prof. Dr.-Ing., „Abschlussbericht zum Projekt 5200006, Messwertverifikation durch FEM“, Koblenz University of Applied Sciences, Koblenz 2013.

[2] FA10 / Hersteller, „EXCEL-Tabellen der Messergebnisse der Kraftmessungen bei CEDIMA 2009“.

[3] D. Borstell, Prof. Dr.-Ing., „Kurzbericht: Statistische Auswertungen der Messungen aus 2009“, Koblenz University of Applied Sciences, Koblenz 2012.

[4] Hilti, „Präsentation zu den Messergebnissen der Kraftmessungen im Jahr 2009“.

[5] VDI Standard 2230, Systematic calculation of highly stressed bolted joints – Joints with one cylindrical bolt, Part 1, Berlin: Beuth-Verlag 2003.

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