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Authorised and notified according to Article 10 of the Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products

MEMBER OF EOTA

European Technical Approval ETA-13/0551

Trade name:	DTF and DTS connections
Holder of approval:	SB Produksjon AS Öran Vest NO-6300 Åndalsnes Norway
Generic type and use of construction product:	Corbel free, load carrying beam connections
Valid from: to:	31.05.2013 31.05.2018
Manufacturing plant:	SB Produksjon AS Öran Vest NO-6300 Åndalsnes Norway
This European Technical Approval contains:	84 pages including 5 Annexes (76 pages) which form an integral part of the document

European Organisation for Technical Approvals

I LEGAL BASIS AND GENERAL CONDITIONS

1 This European Technical Approval is issued by SINTEF Building and Infrastructure, in the following called SINTEF, in accordance with:
- Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products[1], modified by the Council Directive 93/68/EEC[2] and Regulation (EC) Nº 1882/2003 of the European Parliament and of the Council[3]
- Common Procedural Rules for Requesting, Preparing and the Granting of European technical approvals set out in the Annex of Commission Decision 94/23/EC[4]

2 SINTEF is authorised to check whether the provisions of this European Technical Approval are met. Checking may take place in the manufacturing plant. Nevertheless, the responsibility for the conformity of the products to the European Technical Approval and for their fitness for the intended use remains with the holder of the European Technical Approval.

3 This European Technical Approval is not to be transferred to manufacturers or agents of manufacturers other than those indicated on page 1 of this European Technical Approval.

4 This European Technical Approval may be withdrawn by SINTEF in particular pursuant to information by the Commission according to Article 5(1) of Council Directive 89/106/EEC.

5 Reproduction of this European Technical Approval including transmission by electronic means shall be in full. However, partial reproduction can be made with the written consent of SINTEF. In this case partial reproduction has to be designated as such. Texts and drawings of advertising brochures shall not contradict or misuse the European Technical Approval.

6 The European Technical Approval is issued by the approval body in its official language. This version corresponds fully to the version circulated in EOTA. Translations into other languages have to be designated as such.

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[1] Official Journal of the European Communities N° L40, 11.2.1989, p. 12
[2] Official Journal of the European Communities N° L 220, 30.08.1993, p. 1
[3] Official Journal of the European Union N° L 284, 31.10.2003, p. 1
[4] Official Journal of the European Communities N° L17, 20.1.1994, p. 34

II SPECIFIC CONDITIONS OF THE EUROPEAN TECHNICAL APPROVAL

1 Definition of product and intended use

1.1 Definition of the product

DTF and DTS are corbel free connections applicable to dapped end support connections for precast concrete DT (double tee) elements, see Annex 1. The connection units are made of structural steel and consist primarily of a short beam unit with either a rectangular hollow section (RHS) or a massive vertical plate section. The units are manufactured in two versions:

- DTF (DT Fixed support) is intended for direct cast into the upper end of the DT ribs with a free projecting part
- DTS (DT Shooter extendable support) is positioned inside a rectangular outer tube made of thin steel forming a tubular recess in the concrete element from which the steel unit can be pulled out as a supporting extension during assembly of the concrete elements

The beam units are equipped with stress-distributing half-round steel at the top front and a steel plate at the bottom rear if necessary. These supplementary parts are welded to the DTF beam unit or incorporated in the outer tube of the DTS unit. The outer tube is cast into the DT elements with a small angle to obtain horizontality of the projecting steel unit when loaded.

Detailed product definition including material qualities and load categories in the range 120 – 200 kN are given in Annex 2. Dimensions are given in Annex 1.

The beam units are anchored vertically by special reinforcement over the unit close to the beam end. The design layout of the special reinforcement is given in Annex 3. The general reinforcement of beam ends are to be designed by the costumer by application of general design rules with guidance by design examples given in Annex 4.

1.2 Intended use

The connection units are designed for transferring vertical support loads between precast concrete DT elements (or similar ribbed floor and roof elements) and the supporting spandrel beam or wall elements. Horizontal loads parallel or normal to the joint are assumed transferred by separate connection details. Standard units are used indoor in dry conditions. Connections made of hot dip galvanized or stainless steel may be used for external exposure according to the requirements for the individual projects.

The provisions made in this European technical approval are based on an assumed working life of the DTS and DTF connections of 50 years, provided that the conditions laid down in this document are met. The indications given on the working life cannot be interpreted as a guarantee given by the producer, but are to be regarded only as a means for choosing the right products in relation to the expected economically reasonable working life of the works.

The assumed intended working life of the DTF and DTS connections depends especially on the corrosion protection by the concrete cover.

2 Characteristics of the product and methods of verification

2.1 Mechanical resistance and stability (ER1)

Design of load carrying capacity

The use of DTF and DTS connections requires that a complete structural design of the precast concrete elements according to the relevant design standards is carried out case by case. This includes the necessary reinforcement around the connections. The manufacturer has developed principles for calculation of reinforcement for the end region of the elements illustrated by design examples in Annex 4
The load carrying capacities for the units are given in Annex 2, table A2-1. The values assume standard anchoring reinforcement according to the manufacturer's specifications, which is given in Annex 3. The values given in table A2-1 assume that a minimum concrete grade of C30/37 is used. Horizontal loads parallel or normal to the joint are assumed transferred by separate connection details. The resistance of the steel units are however designed for accidental horizontal load, equal 15 % of the vertical design load.

The units are assumed supported by steel plates with shims. Design and position tolerances are given in Annex 2.

Beam dimensions

The minimum DT rib dimensions in order to achieve sufficient space for the units and reinforcement with standard cover are given in Annex 2.

Position tolerances

The steel units must be positioned in the precast concrete elements with a high degree of accuracy consistent with the required tolerances for the final structure. Fixing the position by bolts through the mould and the prepared hole in the half round steel is recommended for the DTS unit.

2.2 Safety in case of fire (ER2)

2.2.1 Reaction to fire

The DTF and DTS connections satisfy Class A1 of EN 13501-1 in accordance with the provisions of EC Decision 96/603/EC (as amended) without the need for testing on the basis of the listing in that Decision.

2.2.2 Resistance to fire

The method of verification of the fire resistance of the concrete element including shear and anchorage of the reinforcement may be taken from Eurocode 2, Part 1-2 Structural fire design. The structural steel part of the connection will be encased by mortar fill in the support pocket and by concrete in the element, see Annex 5. The necessary thickness of the insulating concrete cover in the required fire resistance class may be estimated by the relevant part of Eurocode 4, Design of composite steel and concrete structures Part 1-2 Structural fire design.

2.3 Hygiene, health and environment (ER 3)

No special environmental declaration has been worked out for DTF and DTS connections. The products do not contain any chemical substances listed on the Norwegian environmental authorities' observation list of compounds hazardous to human health or the environment, and are not regarded as emitting any particles, gases or radiation that have a perceptible impact on the indoor climate or that have any significant impact on health.

Note: In addition to the specific clauses relating to dangerous substances contained in this European Technical Approval, there may be other requirements applicable to the products falling within its scope (e.g. transposed European legislation and national laws, regulations and administrative provisions). In order to meet the provisions of the Construction Products Directive, these requirements need also to be complied with, when and where they apply.

Steel parts and concrete elements may be recycled under given circumstances. Alternatively they may be delivered to a public waste deposit site at the end of the working life. There is no cadmium in the steel details.

2.4 Safety in use (ER 4)

A stop device is mounted on the retraction string and will ensure that the inner tube is extracted to the correct cantilever position, see Annex 5.

2.5 Protection against noise (ER 5)

Not relevant.

2.6 Energy economy and heat retention (ER 6)

Not relevant.

2.7 Aspects of durability, serviceability and identification

Concrete cover gives normally a sufficient resistance against corrosion. However, the manufacturer recommends to treat the external surfaces and the RHS/ massive knife with a protective paint in order to prevent stain and rust during storage. The units may be delivered with galvanized or stainless steel for special cases.

2.8 Special conditions for use and installation

Installation on site

The DTS elements must hang horizontally in the lifting device during installation. When the beam is in the correct position, the shooter units are pulled out by attached strings into the recesses in the supporting element, see Annex 5. The beam is then lowered carefully to the supported position, making sure that the units have the correct extension. Before releasing the lifting device the joint width shall be checked. Normal joint width is 15 - 20 mm. Maximum allowed gap between the end of the element and the edge of the shim at the support is 40 mm.

Joint between DT-element and support

The joint between the DT-element and support is filled with a low shrinkage quick setting concrete based mortar to protect the connection against fire as shown in Annex 5. If installation is executed under winter conditions, a frost resistant mortar shall be used for filling the joint between the DT-element and support.

2.9 Further technical information

Further technical information can be found at the ETA holders home site:
http://invisibleconnection.no

3 Evaluation and attestation of conformity and CE marking

3.1 System of attestation of conformity

According to Decision 97/597/EC of 02.09.1997 the European Commission has decided that System 2+ of attestation of conformity applies. This system of attestation of conformity is defined as follows:

Certification of the conformity of the product by a notified certification body on the basis of:

(a) Tasks for the manufacturer:

- (1) initial type testing of the product;
- (2) factory production control;
- (3) testing of samples taken at the factory in accordance with a prescribed test plan.

(b) Tasks for the approved body:

- (4) certification of factory production control on the basis of:
  - – initial inspection of factory and of factory production control;
  - – continuous surveillance, assessment and approval of factory production control

3.2 Responsibilities

3.2.1 Tasks of the manufacturer

3.2.1.1 Factory production control

The manufacturer shall exercise permanent internal control of the production. All the elements, requirements and provisions adopted by the manufacturer shall be documented in a systematic manner in the form of written policies and procedures, including records of results performed. This production control system shall insure that the product is in conformity with this European technical approval.

The manufacturer may only use constituent materials stated in the technical documentation of this European technical approval.

The factory production control shall be in accordance with the Control Plan for DTF and DTS beam connections relating to the this European technical approval. The Control Plan is part of the technical documentation of this European technical approval, and is laid down in the context of the factory production control system operated by the manufacturer. The Control Plan is deposited at SINTEF.[5]

The results of factory production control shall be recorded and evaluated in accordance with the provisions of the Control Plan.

[5] The "control plan" is a confidential part of the European technical approval and only handed over to the notified body or bodies involved in the procedure of attestation of conformity. See section 3.2.2.

3.2.1.2 Other tasks of manufacturer

The manufacturer shall, on the basis of a contract, involve a body (bodies) which is (are) notified for the tasks referred to in section 3.1 in the field of reinforcement steel products in order to undertake the actions laid down in section 3.2.2. For this purpose, the Control Plan referred to in sections 3.2.1.1 and 3.2.2 shall be handed over by the manufacturer to the notified body or bodies involved.

3.2.2 Tasks of the notified body

The approval body (bodies) shall perform the

- initial inspection of factory and of factory production control
- continuous surveillance, assessment and approval of factory production control

in accordance with the provisions laid down in the Control Plan relating to this European technical approval ETA.

The approval body (bodies) shall retain the essential points of its (their) actions referred to above and state the results obtained and conclusions drawn in written reports.

The approved certification body involved by the manufacturer shall issue an EC certificate of conformity of the factory production control stating the conformity with the provisions of this European technical approval.

In cases where the provisions of the European technical approval and its Control Plan are no longer fulfilled the certification body shall withdraw the certificate of conformity and inform SINTEF without delay.

3.3 CE marking

The CE marking shall be affixed to the packaging or accompanying commercial documents. The letters „CE“ shall be followed by the identification number of the notified certification body and be accompanied by the following additional information:

- the name and address of the producer (legal entity responsible for the manufacture),
- the last two digits of the year in which the CE marking was affixed,
- the number of the EC certificate for the factory production control
- the number of the European technical approval,
- identification of the product

4 Assumptions under which the fitness of the product for the intended use was favourably assessed

4.1 Manufacturing

The European technical approval is issued for DTF and DTS connections on the basis of agreed data/information deposited with SINTEF, which identifies the product that has been assessed and judged. Changes to the product or production process, which could result in this deposited data/information being incorrect, should be notified to SINTEF before the changes are introduced. SINTEF will decide whether or not such changes affect the ETA and consequently the validity of the CE marking on the basis of the ETA, and if so whether further assessment or alterations to the ETA is necessary.

4.2 Installation

The DTF and DTS connections shall be installed in accordance with detailed construction drawings worked out for the individual works, based on the structural design for the works according to applicable design standards.

5 Indications to the manufacturer and supplier

5.1 Packaging, transport and storage

The DTF and DTS connections must be transported and stored in such a way that the material is protected against salt and other harmful chemicals due to the risk of corrosion.

On behalf of
SINTEF Building and Infrastructure
Trondheim, 31.05.2013

Terje Jacobsen
Research Director

Hans Boye Skogstad
Approval Manager

Annex 1: Product description
Annex 2: Technical specifications and design load capacity for DTF and DTS
Annex 3: Reinforcement design for DTF/DTS 120 – 150 – 200
Annex 4: Design examples
Annex 5: Assembling of the DTS unit and fire protection of the joint

Annex 1 Product description

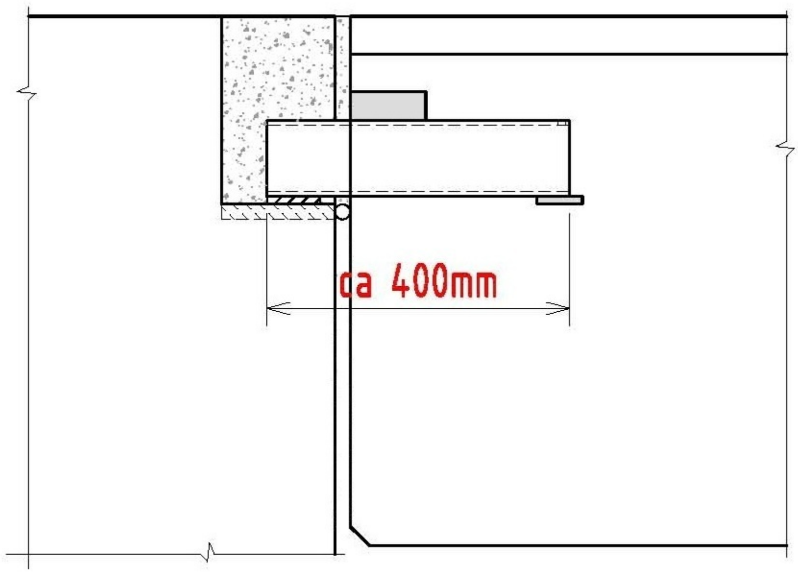
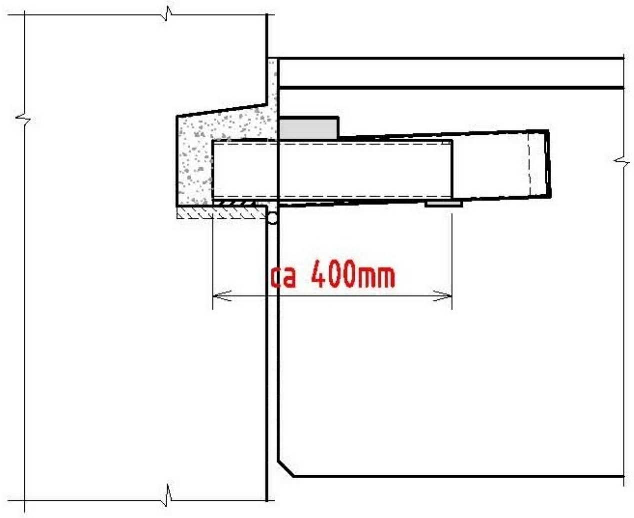


Figure A1-1: Principle design of DTF (DT Fixed Support)



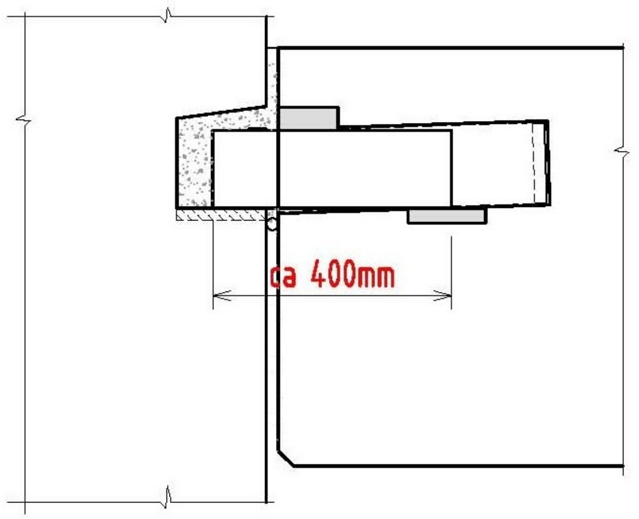


Figure A1-2: Principle design of DTS (DT Shooter extendable support)**.** To the left: The knife shown as a rectangular hollow section (RHS). To the right: The knife shown as a massive vertical plate

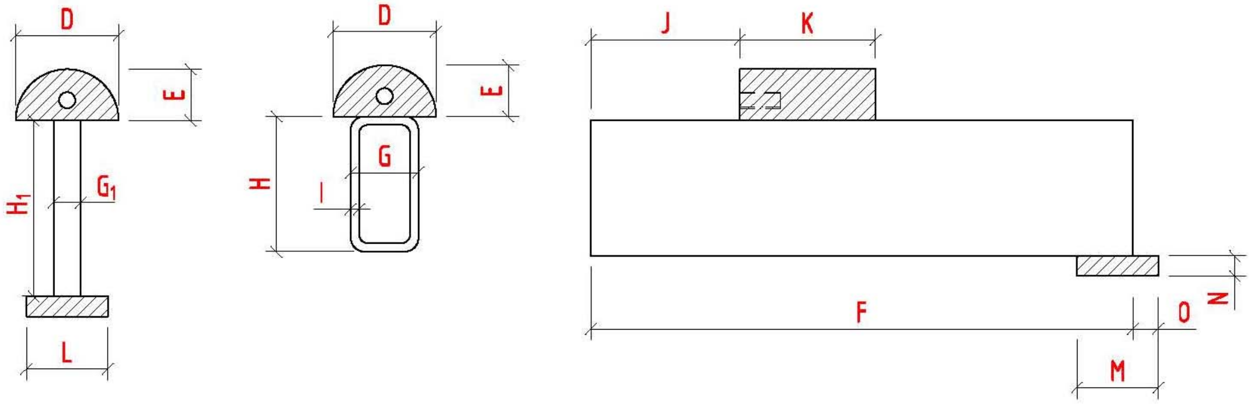


Figure A1-3: Main dimensions DTF. See also Table A1-1.

Table A1- 1: Main dimensions DTF in mm

Type	A	B	C	D	E	F	G	G_1	H	H_1	I	J	K	L	M	N	O
DTF120	-	-	-	76	38	425	50	-	100	-	6	110	100	-	-	-	-
DTF150	-	-	-	76	38	435	50	-	100	-	8	110	100	-	-	-	-
DTF200	-	-	-	76	38	400	-	20	-	130	-	110	100	50	130	25	57

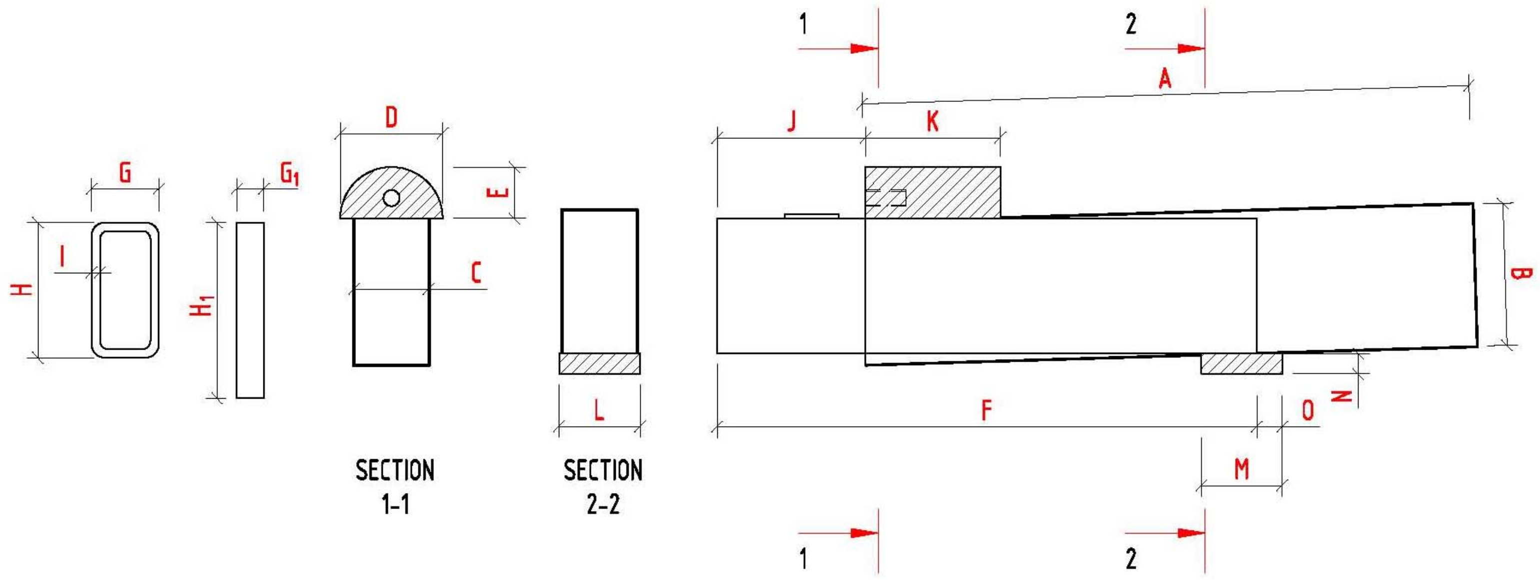


Figure A1-4: Main dimensions DTS in mm. See also Table A1-2.

Table A1-2: Main dimensions for DTS in mm

Type	A	B (Internal)	C (Internal)	D	E	F	G	G_1	H	H_1	I	J	K	L	M	N	O
DTS120	450	105	55	76	38	400	50	-	100	-	6	110	100	60	60	10	17
DTS150	450	105	55	76	38	400	50	-	100	-	8	110	100	60	75	15	26
DTS200	450	135	25	76	38	400	-	20	-	130	-	110	100	50	130	25	57

Annex 2 Technical specification and design load capacity for DTF and DTS

Table A2-1: Design load carrying capacity at ultimate limit state for DTF and DTS connections with standard reinforcement

Connection	Vertical load kN
DTF 120	120
DTF 150	150
DTF 200	200
DTS 120	120
DTS 150	150
DTS 200	200

The maximum load carrying capacity of the steel units has been calculated in accordance with Eurocode 2 and 3 with the following conservative safety parameters:

Table A2-2: NDPs in EC2

Parameter	γ_c	γ_s	α_{cc}	α_{ct}
Value	**1,5**	**1,15**	**0,85**	**0,85**

Table A2-3: NDPs in EC3

Parameter	γ_{M0}	γ_{M1}	γ_{M2}
Value	**1,1**	**1,1**	**1,25**

The maximum utilization of the steel beam units sections subjected to the nominal support forces 120, 150 and 200 kN respectively calculated according to the assumptions above is 0,88.

Technical specifications

DIMENSIONS AND CROSS-SECTION PARAMETERS

UNIT

Inner tube:

DTS120: CFRHS 100x50x6, L=400mm. Cold formed, S355. Used on edge.

DTF120: CFRHS 100x50x6, L=425mm. Cold formed, S355. Used on edge.

Plastic section modulus on edge: $W_{pl}=46900mm^3$

Cross section area: $A=1560mm^2$

Shear area: $A_v=A\times h/(b+h)=1560\times 100/(50+100)$

$=1040mm^2$ EC3, Clause 6.2.6

Outer tube:

DTS120: Thin steel plate (1mm) with PVC end cap. L=450mm. Internal dimensions: 105×55.

DTF120: Without outer tube.

Half round steel:

DTS120: Diameter Ø=76mm, Length=100mm, S275.

DTF120: Diameter Ø=76mm, Length=100mm, S275.

Additional steel plate at back:

DTS120: b×t×l=60×10×60, S355.

DTF120: Without steel plate at back.

Additional steel plate welded to upper flange in front (locking plate):

DTS120: b×t×l=30×3×40, S355.

DTF120: Without locking plate in front.

LOADS DTF120/DTS120

Vertical ultimate limit state load: F_V = 120kN.

Horizontal ultimate limit state load in transverse direction: F_T=0kN.

Horizontal ultimate limit state load in axial direction: F_H = 0kN.*)

*) The hollow core profile of the unit is designed for a vertical load in combination with a horizontal load equal to 15% of the ultimate limit state vertical load:⇒ $F_H=0{,}15F_V$=18kN.

IMPORTANT!

The anchoring of the DTF/DTS120 unit in the pre-cast element is not designed to transfer the horizontal force that may occur due to friction at the support, and may be introduced in the joint due to creep, shrinkage etc. in the pre-cast elements. Use and utilization of the DTF/DTS120 is therefore only acceptable in joints where all possible horizontal forces are transferred via other connections. However, with respect to cross-section integrity of the DTF/DTS120 hollow core profile, this profile is designed for the vertical ultimate limit state load in combination with a horizontal load equal to 15% of the vertical load.

A 70mm long shim should always be used on the support, with a fixed location 5mm from the edge of the supporting element, see Figure 3. This shim will give a distributed load on the unit, and ensure the centre of load is located maximum 75mm from the edge of the DT. The width of the shim is recommended minimum 70mm. The thickness is selected based on the vertical tolerances on support.

Technical specifications

SPESIFICATIONS DTF120

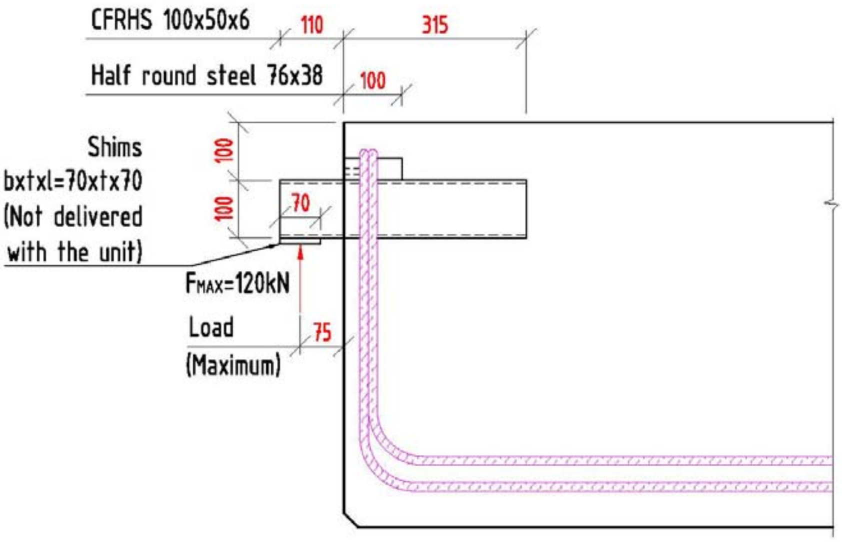


Figure 1: DTF120.

SPESIFICATIONS DTS120

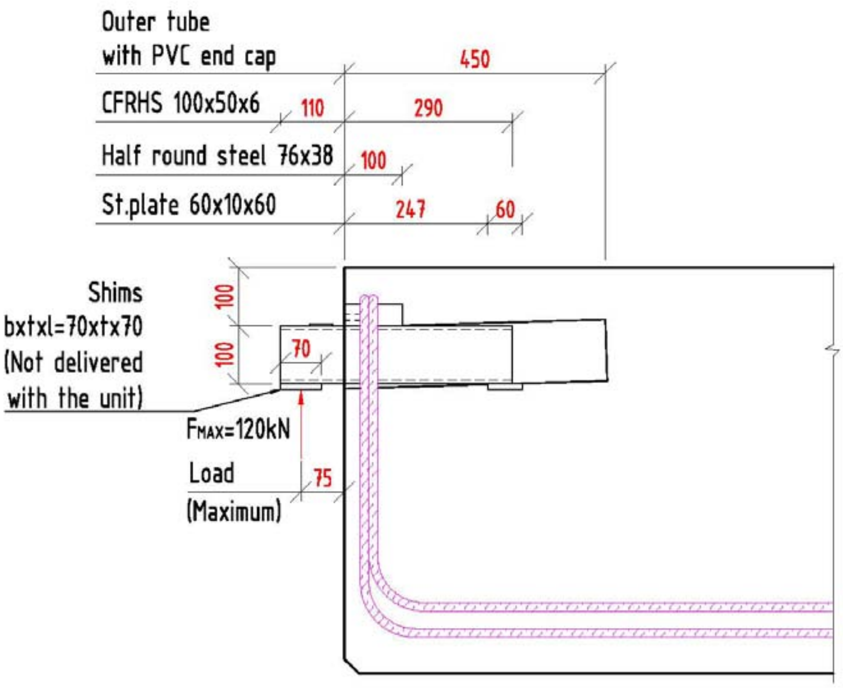


Figure 2: DTS120.

Technical specifications

TOLRANCES AND SOLUTION AT THE SUPPORT

The unit is designed with the hollow core tube cantilevering 110mm and with a maximum of 75mm to the centre of the load. (The 110mm is a fixed length for the DTF, while a safety device on the DTS-unit ensures the inner tube is not extracted beyond 110mm.) A 70mm long shim with a fixed location 5mm from the edge of the supporting element should always be used on the support. The fixed location of the shim ensures the design assumption with respect to centre of load is fulfilled for the specified tolerances on gap between the elements. The tolerances are stated below and illustrated in Figure 3.

The nominal gap and tolerances are: 20mm ±15mm.

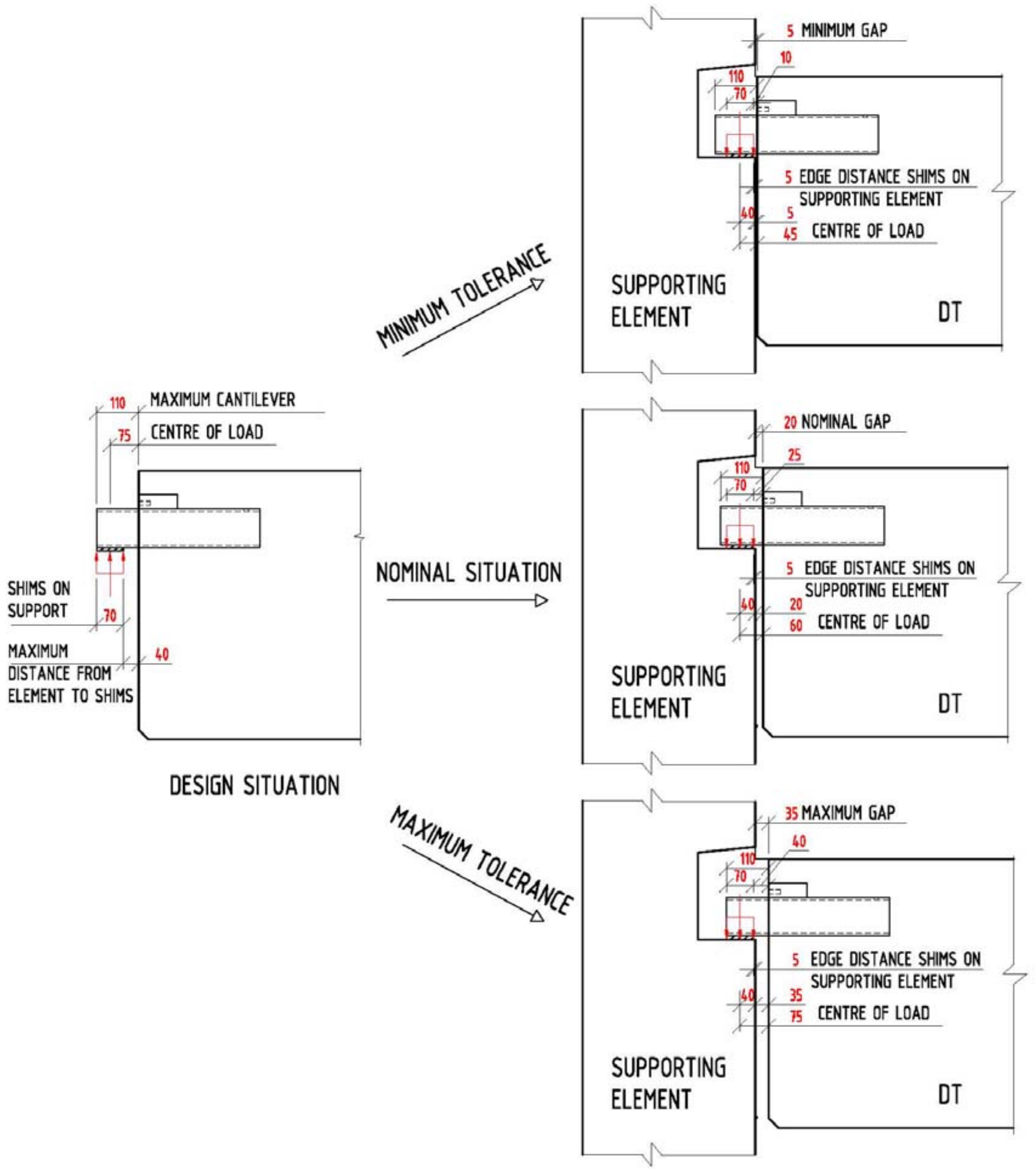


Figure 3: Tolerances. (Both DTF and DTS)

Technical specifications

The specified shim on the support will not be sufficient to ensure distribution of the reaction force into the concrete in the supporting element in a proper way. Thus, this issue has to be dealt with and solved on a case to case basis. One way of designing the support is by embedding a thick steel plate in the supporting element. This solution is illustrated in Figure 4 and documented in the following calculations.

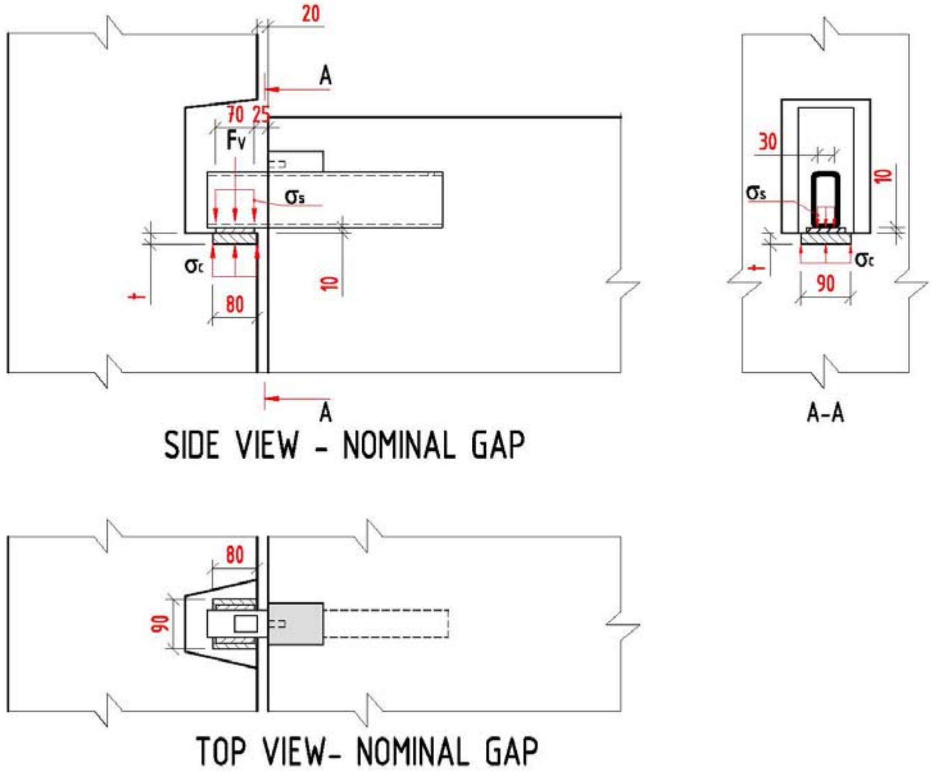


Figure 4: Solution at the support.

I: Stress at support from unit:

$$\sigma_s = \frac{120kN}{70mm \times 30mm} = 57{,}2MPa$$

II: Required concrete area (assuming f_{cd}=17MPa):

$$A_C = \frac{120kN}{17MPa} = 7059mm^2$$

Assuming shims 5 mm from the edge ⇒Symmetry around the centre of the load gives the effective length of the steel plate as: l= 80mm

⇒Select width of steel plate area b=7059/80=89mm ⇒Select b=90mm⇒A=90×80=7200mm^2

III: Uniform concrete stress beneath steel plate:

$$\sigma_c = \frac{120kN}{7200mm^2} = 16{,}7MPa$$

IV: Bending moment in centre of steel plate.

The steel plate is assumed to bend about an axis longitudinal to the axial direction of the unit:

$$M_{Ed,plate} = 16{,}7MPa \times (90mm)^2 \ / 8 \times 80mm$$

$$= 1352700\,Nmm$$

V: Required thickness of steel plate (assuming steel grade S355 and f_{yd}=322MPa):

$$t = \sqrt{\frac{6 \times M}{l \times f_{yd}}} = \sqrt{\frac{6 \times 1352700\,mm}{80mm \times 322\,MPa}} = 17{,}8mm$$

$\Rightarrow$ Select: t=20mm.

$\Rightarrow$Selected support plate: bxlxt=90x80x20

REQUIREMENTS TO DT-DIMENTIONS AND RECESS AT THE SUPPORT

Due to the variety of cross sections, and different standard reinforcement solutions, it has to be evaluated on a case to case basis if the unit will fit into the DT element with a suitable reinforcement. However, some minimum requirements to the cross section of the DT are listed below and illustrated in Figure 5.

The minimum width of the web at top (W1) is found based on the requirements in front of the DT at the level of the unit. The maximum width at bottom (W2) is based on a minimum inclination of the compression strut from the corner of the stirrup to the corner of the unit. This is recommended not to be less than 3/2 as illustrated in Figure 5. This requirement is essential for recommending use of the normal DT shear stirrups to carry the reaction force from the back of the unit. The requirement leads to a ratio between H and W2 at bottom of the DT that usually is fulfilled in normal DT-cross sections. As a minimum, the height H below the bottom of the unit shall not be less than 100mm.

The recess in the supporting element must ensure easy access for proper grouting of the joint after mounting of the elements. The depth of the recess is recommended at least 130mm to account for the tolerances on gap between the elements.

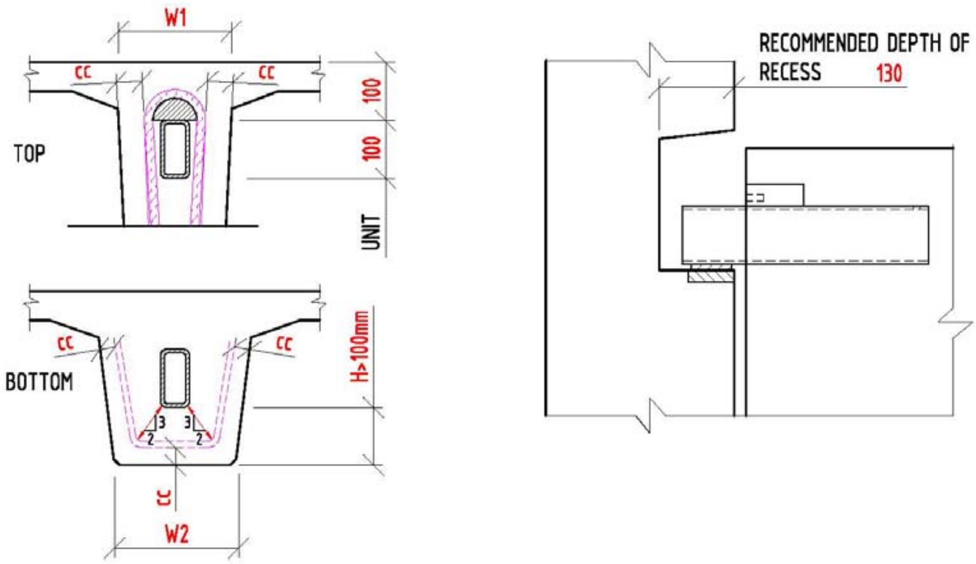


Figure 5: Requirements to the DT-element. (Both DTF and DTS)

1) Minimum width of DT at the level of the unit:

W1=Width of half round steel+2×Ø12bars+2×concrete cover

Assume concrete cover: 20mm

$\Rightarrow W1=76+2\times15+2\times20=146mm$

2) Ratio between H and W2:

$W2<4/3H+50$

3) H minimum=100mm

Technical specifications

DIMENSIONS AND CROSS-SECTION PARAMETERS

UNIT

Inner tube:

DTS150: RHS 100x50x8, L=400mm. Hot rolled, S355. Used on edge.

DTF150: RHS 100x50x8, L=435mm. Hot rolled, S355. Used on edge.

Plastic section modulus on edge: W_{pl}=63100mm^3

Cross section area: A=2110mm^2

Shear area: A_v=A×h/(b+h)=2110×100/(50+100) =1407mm^2 EC3, Clause 6.2.6

Outer tube:

DTS150: Thin steel plate (1mm) with PVC end cap. L=450mm. Internal dimensions: 105×55.

DTF150: Without outer tube.

Half round steel:

DTS150: Diameter Ø=76mm, Length=100mm, S275.

DTF150: Diameter Ø=76mm, Length=100mm, S275.

Additional steel plate at back:

DTS150: b×t×l=60×15×75, S355.

DTF150: Without steel plate at back.

Additional steel plate welded to upper flange in front (locking plate):

DTS150: b×t×l=30×3×40, S355.

DTF150: Without locking plate in front.

LOADS DTF150/DTS150

Vertical ultimate limit state load: F_V = 150kN.

Horizontal ultimate limit state load in transverse direction: F_T=0kN.

Horizontal ultimate limit state load in axial direction: F_H = 0kN. .*)

*) The hollow core profile of the unit is designed for a vertical load in combination with a horizontal load equal to 15% of the ultimate limit state vertical load:⇒ F_H=0,15F_V=22,5kN.

IMPORTANT!

The anchoring of the DTF/DTS150 unit in the pre-cast element is not designed to transfer the horizontal force that may occur due to friction at the support, and may be introduced in the joint due to creep, shrinkage etc. in the pre-cast elements. Use and utilization of the DTF/DTS150 is therefore only acceptable in joints where all possible horizontal forces are transferred via other connections. However, with respect to cross-section integrity of the DTF/DTS150 hollow core profile, this profile is designed for the vertical ultimate limit state load in combination with a horizontal load equal to 15% of the vertical load.

A 70mm long shim should always be used on the support, with a fixed location 5mm from the edge of the supporting element, see Figure 3. This shim will give a distributed load on the unit, and ensure the centre of load is located maximum 75mm from the edge of the DT. The width of the shim is recommended minimum 70mm. The thickness is selected based on the vertical tolerances on support.

Technical specifications

SPESIFICATIONS DTF150

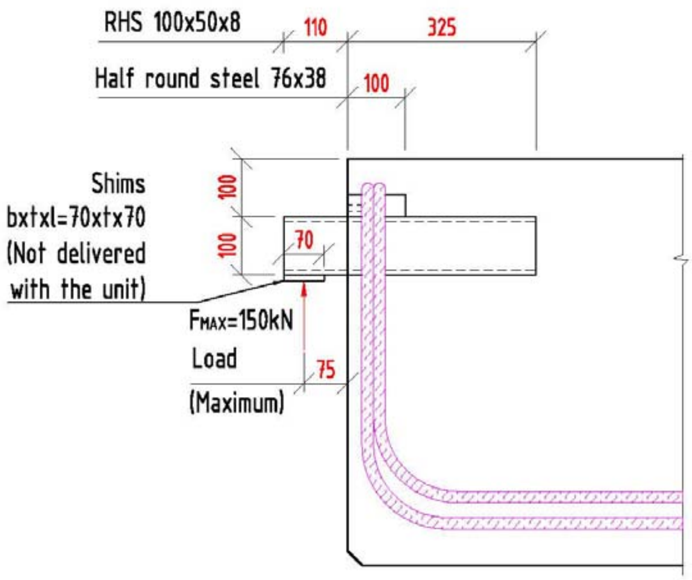


Figure 1: DTF150.

SPESIFICATIONS DTS150

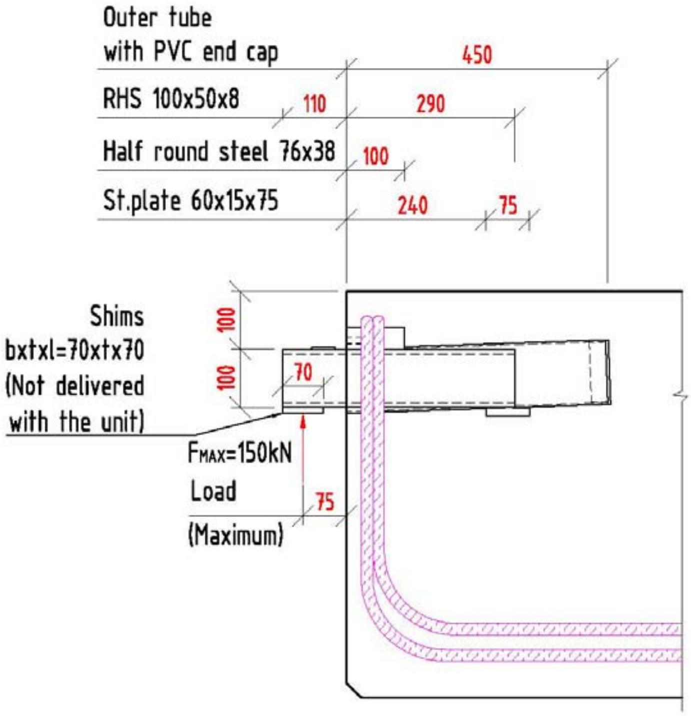


Figure 2: DTS150.

Technical specifications

TOLRANCES AND SOLUTION AT THE SUPPORT

The unit is designed with the hollow core tube cantilevering 110mm and with a maximum of 75mm to the centre of the load. (The 110mm is a fixed length for the DTF, while a safety device on the DTS-unit ensures the inner tube is not extracted beyond 110mm.) A 70mm long shim with a fixed location 5mm from the edge of the supporting element should always be used on the support. The fixed location of the shim ensures the design assumption with respect to centre of load is fulfilled for the specified tolerances on gap between the elements. The tolerances are stated below and illustrated in Figure 3.

The nominal gap and tolerances are: 20mm ±15mm.

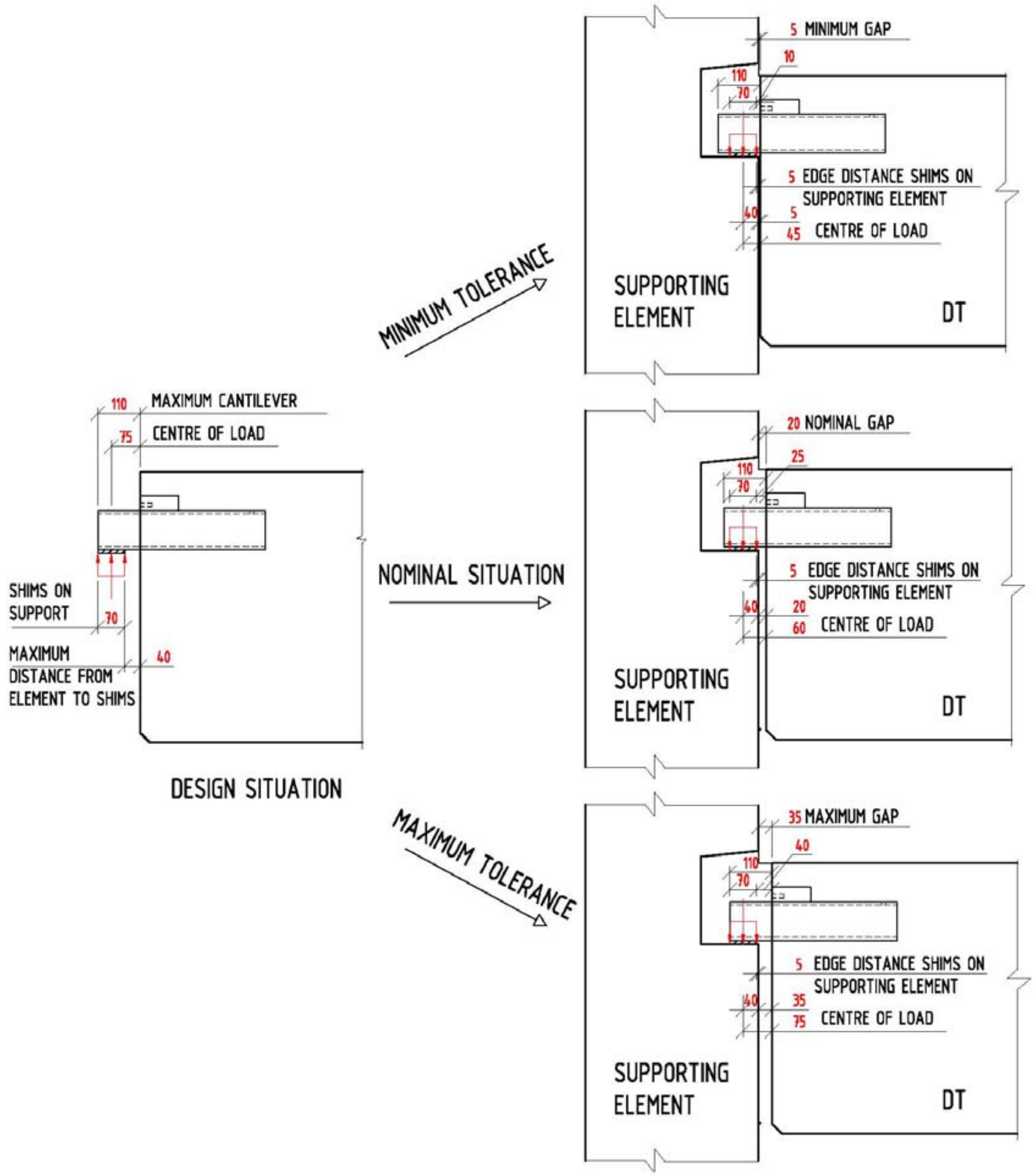


Figure 3: Tolerances. (Both DTF and DTS)

Technical specifications

The specified shim on the support will not be sufficient to ensure distribution of the reaction force into the concrete in the supporting element in a proper way. Thus, this issue has to be dealt with and solved on a case to case basis. One way of designing the support is by embedding a thick steel plate in the supporting element. This solution is illustrated in Figure 4 and documented in the following calculations.

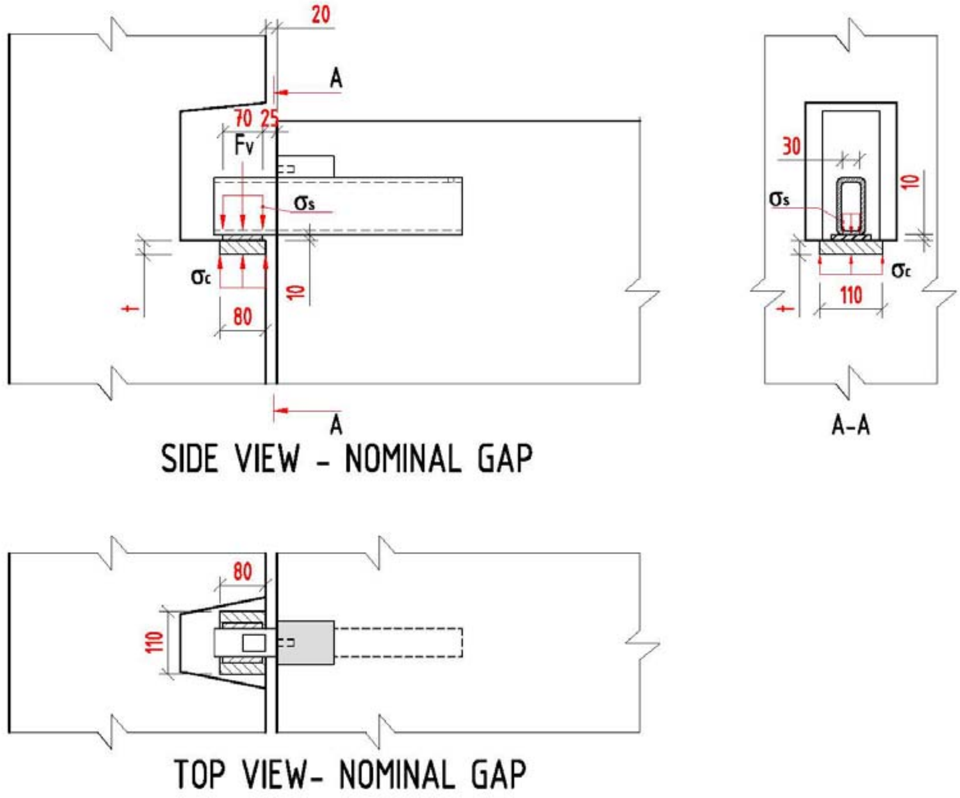


Figure 4: Solution at the support.

I: Stress at support from unit:

$$\sigma_s = \frac{150kN}{70mm \times 30mm} = 71{,}4MPa$$

II: Required concrete area (assuming f_{cd}=17MPa):

$$A_C = \frac{150kN}{17MPa} = 8824mm^2$$

Assuming shims 5 mm from the edge ⇒Symmetry around the centre of the load gives the effective length of the steel plate as: l= 80mm

⇒Select width of steel plate: b=8824/80≈110mm ⇒Select 110mm⇒A=110×80=8800mm^2

III: Uniform concrete stress beneath steel plate:

$$\sigma_c = \frac{150kN}{8800mm^2} \approx 17MPa$$

Technical specifications

IV: Bending moment in centre of steel plate.

The steel plate is assumed to bend about an axis longitudinal to the axial direction of the unit:

$$M_{Ed,plate} = 17MPa \times (110mm)^2 / 8 \times 80mm$$
$$= 2057000\,Nmm$$

V: Required thickness of steel plate (assuming steel grade S355 and f_{yd}=322MPa):

$$t = \sqrt{\frac{6 \times M}{l \times f_{yd}}} = \sqrt{\frac{6 \times 2057000\,mm}{80mm \times 322\,MPa}} = 21{,}9mm$$

$\Rightarrow$ Select: t=25mm.

$\Rightarrow$Selected support plate: bxlxt=110x80x25

REQUIREMENTS TO DT-DIMENTIONS AND RECESS AT THE SUPPORT

Due to the variety of cross sections, and different standard reinforcement solutions, it has to be evaluated on a case to case basis if the unit will fit into the DT element with a suitable reinforcement. However, some minimum requirements to the cross section of the DT are listed below and illustrated in Figure 5.

The minimum width of the web at top (W1) is found based on the requirements in front of the DT at the level of the unit. The maximum width at bottom (W2) is based on a minimum inclination of the compression strut from the corner of the stirrup to the corner of the unit. This is recommended not to be less than 3/2 as illustrated in Figure 5. This requirement is essential for recommending use of the normal DT shear stirrups to carry the reaction force from the back of the unit. The requirement leads to a ratio between H and W2 at bottom of the DT that usually is fulfilled in normal DT-cross sections. As a minimum, the height H below the bottom of the unit shall not be less than 100mm.

The recess in the supporting element must ensure easy access for proper grouting of the joint after mounting of the elements. The depth of the recess is recommended at least 130mm to account for the tolerances on gap between the elements.

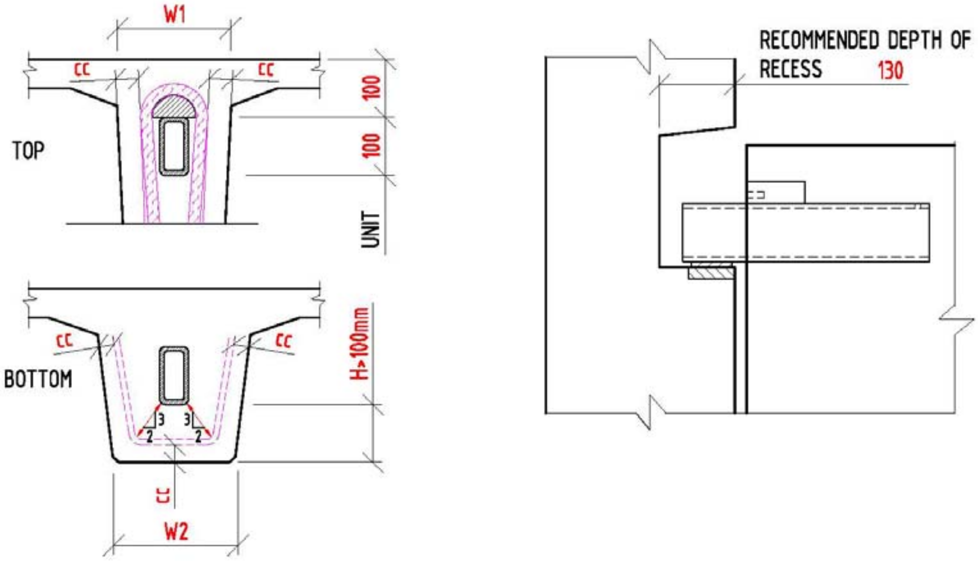


Figure 5: Requirements to the DT-element. (Both DTF and DTS)

1) Minimum width of DT at the level of the unit:
   W1=Width of half round steel+2×Ø16bars+2×concrete cover
   Assume concrete cover: 20mm
   ⇒W1=76+2×20+2×20=156mm
2) Ratio between H and W2:
   $W2 < 4/3H+50$
3) H minimum=100mm

Technical specifications

DIMENSIONS AND CROSS-SECTION PARAMETERS

UNIT

Knife:

DTS200: 130x20, L=400, S355.
DTF200: 130x20, L=400, S355.

Plastic section modulus:	W_{pl}=84500mm^3
Cross section area:	A=2600mm^2
Shear area:	A_v=2600mm^2

Outer tube:

DTS200: Thin steel plate (1mm) with PVC end cap. L=450mm. Internal dimensions: 135×25.
DTF200: Without outer tube.

Half round steel:

DTS200: Diameter Ø=76mm, Length=100mm, S275.
DTF200: Diameter Ø=76mm, Length=100mm, S275..

Additional steel plate at back:

DTS200: b×t×l=50×25×130, S355.
DTF200: b×t×l=50×25×130, S355.

Additional steel plate welded to upper flange in front (locking plate):

DTS200: b×t×l=30×3×40, S355.
DTF200: Without locking plate in front.

LOADS DTF200/DTS200

Vertical ultimate limit state load: F_V = 200kN.
Horizontal ultimate limit state load in transverse direction: F_T=0kN.
Horizontal ultimate limit state load in axial direction: F_H = 0kN. *)

*) The knife is designed for a vertical load in combination with a horizontal load equal to 15% of the ultimate limit state vertical load:⟹ F_H=0,15F_V=30kN.

IMPORTANT!

The anchoring of the DTF/DTS200 unit in the pre-cast element is not designed to transfer the horizontal force that may occur due to friction at the support, and may be introduced in the joint due to creep, shrinkage etc. in the pre-cast elements. Use and utilization of the DTF/DTS200 is therefore only acceptable in joints where all possible horizontal forces are transferred via other connections. However, with respect to cross-section integrity of the DTF/DTS200 knife, this profile is designed for the vertical ultimate limit state load in combination with a horizontal load equal to 15% of the vertical load.

A 70mm long shim should always be used on the support, with a fixed location 5mm from the edge of the supporting element, see Figure 3. This shim will give a distributed load on the unit, and ensure the centre of load is located maximum 75mm from the edge of the DT. The width of the shim is recommended minimum 70mm. The thickness is selected based on the vertical tolerances on support.

Technical specifications

SPESIFICATIONS DTF200

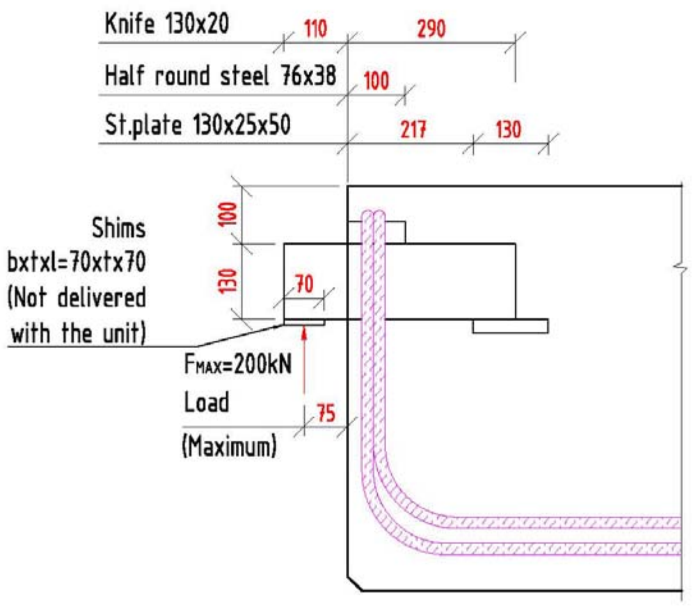


Figure 1: DTF200.

SPESIFICATIONS DTS200

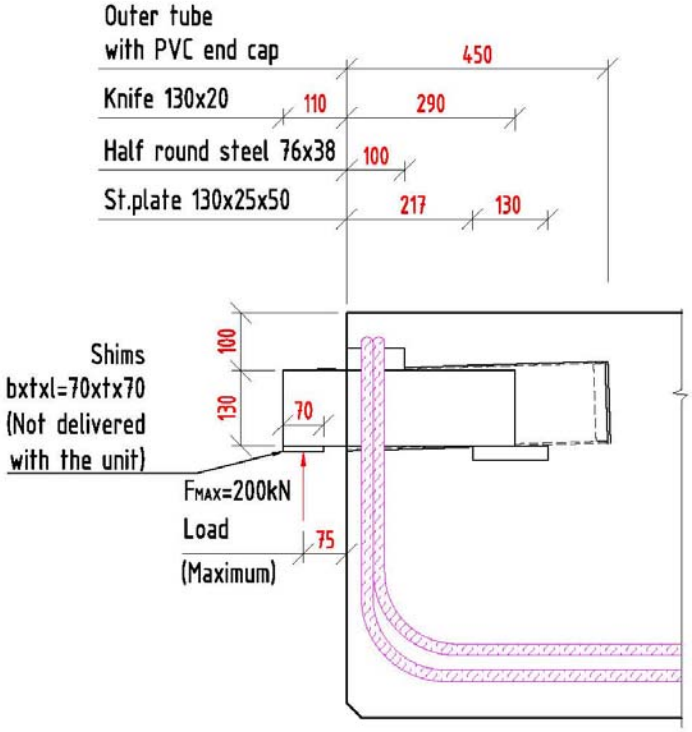


Figure 2: DTS200.

Technical specifications

TOLRANCES AND SOLUTION AT THE SUPPORT

The unit is designed with the knife cantilevering 110mm and with a maximum of 75mm to the centre of the load. (The 110mm is a fixed length for the DTF, while a safety device on the DTS-unit ensures the knife is not extracted beyond 110mm.) A 70mm long shim with a fixed location 5mm from the edge of the supporting element should always be used on the support. The fixed location of the shim ensures the design assumption with respect to centre of load is fulfilled for the specified tolerances on gap between the elements. The tolerances are stated below and illustrated in Figure 3.

The nominal gap and tolerances are: 20mm ±15mm.

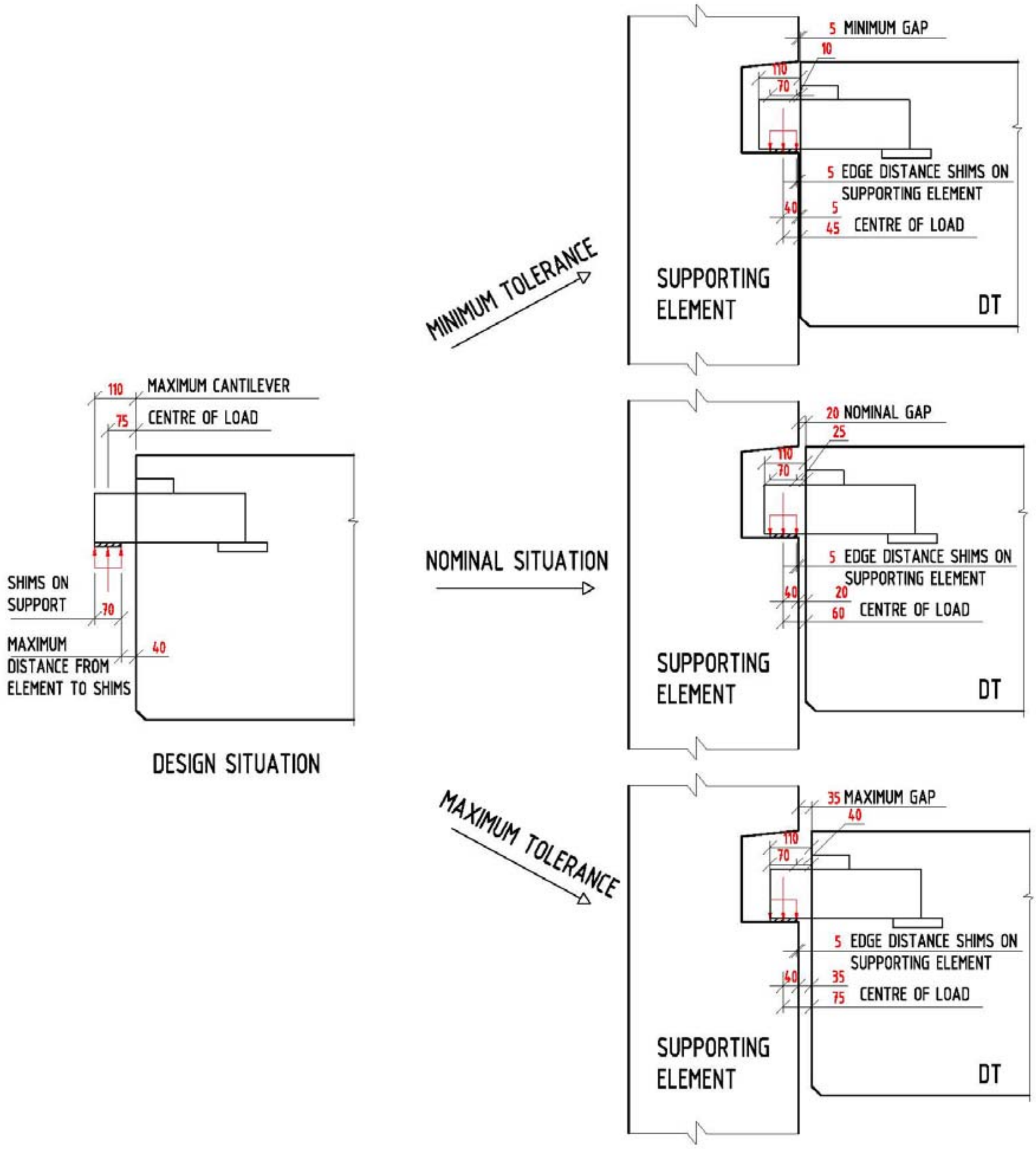


Figure 3: Tolerances. (Both DTF and DTS)

Technical specifications

The specified shim on the support will not be sufficient to ensure distribution of the reaction force into the concrete in the supporting element in a proper way. Thus, this issue has to be dealt with and solved on a case to case basis. One way of designing the support is by embedding a thick steel plate in the supporting element. This solution is illustrated in Figure 4 and documented in the following calculations.

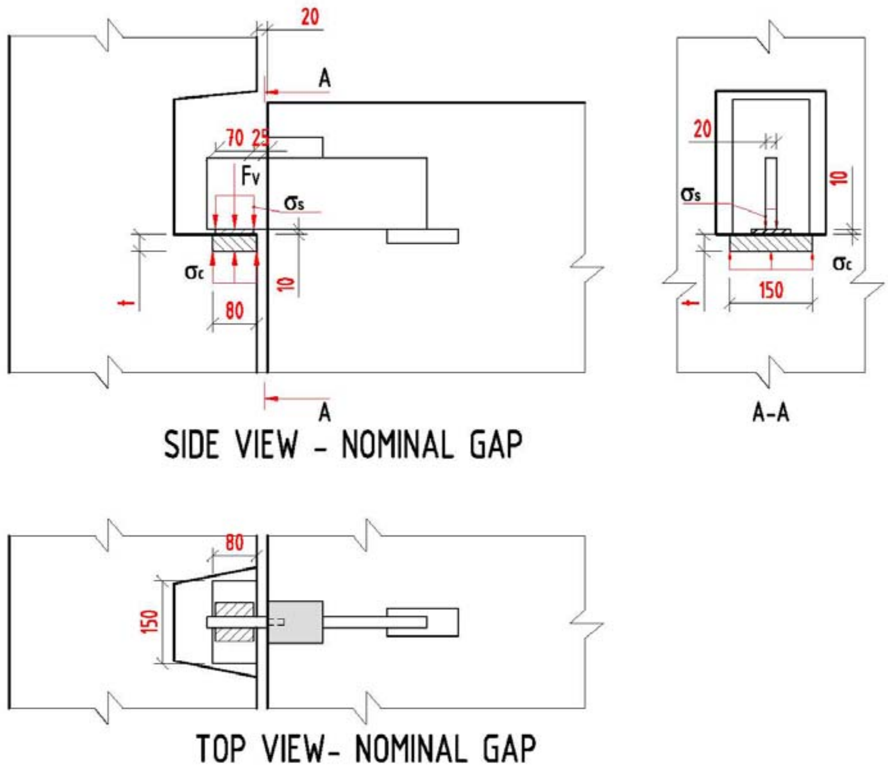


Figure 4: Solution at the support.

I: Stress at support from unit:

$$\sigma_s = \frac{200kN}{70mm \times 20mm} = 143MPa$$

II: Required concrete area (assuming f_{cd}=17MPa):

$$A_C = \frac{200kN}{17MPa} = 11765mm^2$$

Assuming shims 5 mm from the edge ⇒Symmetry around the centre of the load gives the effective length of the steel plate as: l= 80mm

⇒Select width of steel plate: b=11765/80=147mm ⇒Select 150mm⇒A=150×80=12000mm^2

III: Uniform concrete stress beneath steel plate:

$$\sigma_c = \frac{200kN}{12000mm^2} = 16,7MPa$$

Technical specifications

IV: Bending moment in centre of steel plate.

The steel plate is assumed to bend about an axis longitudinal to the axial direction of the unit:

$$M_{Ed,plate} = \left[16{,}7MPa \times (150mm)^2 / 8 - 143MPa \times 10mm \times 5mm\right] \times 80mm$$

$$= 3185500\,Nmm$$

V: Required thickness of steel plate (assuming steel grade S355 and f_{yd}=322MPa):

$$t = \sqrt{\frac{6 \times M}{l \times f_{yd}}} = \sqrt{\frac{6 \times 3185500\,mm}{80mm \times 322\,MPa}} = 27{,}2mm$$

$\Rightarrow$ Select: t=30mm.

$\Rightarrow$Selected support plate: bxlxt=150x110x30

REQUIREMENT TO DT-DIMENTIONS AND RECESS AT THE SUPPORT

Due to the variety of cross sections, and different standard reinforcement solutions, it has to be evaluated on a case to case basis if the unit will fit into the DT element with a suitable reinforcement. However, some minimum requirements to the cross section of the DT are listed below and illustrated in Figure 5.

The minimum width of the web at top (W1) is found based on the requirements in front of the DT at the level of the unit. The maximum width at bottom (W2) is based on a minimum inclination of the compression strut from the corner of the stirrup to the corner of the unit. This is recommended not to be less than 3/2 as illustrated in Figure 5. This requirement is essential for recommending use of the normal DT shear stirrups to carry the reaction force from the back of the unit. The requirement leads to a ratio between H and W2 at bottom of the DT that usually is fulfilled in normal DT-cross sections. As a minimum, the height H below the bottom of the unit shall not be less than 100mm.

The recess in the supporting element must ensure easy access for proper grouting of the joint after mounting of the elements. The depth of the recess is recommended at least 130mm to account for the tolerances on gap between the elements.

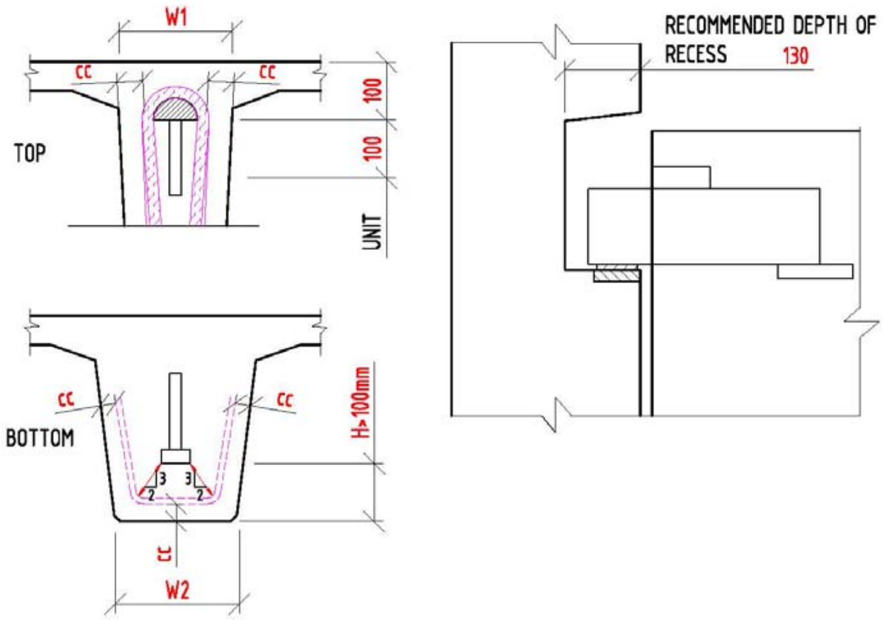


Figure 5: Requirements to the DT-element. (Both DTF and DTS)

1) Minimum width of DT at the level of the unit:

W1=Width of half round steel+2×Ø12bars+2×concrete cover

Assume concrete cover: 20mm

⇒W1=76+2×20+2×20=156mm

2) Ratio between H and W2:

W2<4/3H+50

3) H minimum=100mm

Annex 3 Reinforcement design for DTF/ DTS 120 - 150 - 200

Reinforcement design DTF/DTS120

CONTENTS

PART 1 – BASIC ASSUMTIONS

GENERAL

The following calculations of anchorage of the units and the corresponding reinforcement must be considered as an example illustrating the design model. The calculations give the reaction forces from the unit to the element, and the recommended reinforcement includes only the reinforcement necessary to anchor these forces to the concrete. The unit may be used in DT-elements with various cross-sections. Thus, no recommendations on the reinforcement layout of the element are given, as this cannot be generalized. The DT-element must be designed for the forces R_1 and R_2 and it must always be checked that the forces from the anchorage reinforcement can be transferred to the main reinforcement of the concrete element.

The information found here and in the memos assumes that the design of the elements and the use of the units in structural elements are carried out under the supervision of a structural engineer with knowledge about the behaviour of concrete structures. Be aware of the increase in shear force (R_1) in the end of the element, compared to the situation with underlying support where the shear force equals the support reaction force.

To ensure structural integrity of the steel unit itself the position of the anchoring reinforcement relative to the unit shall be as illustrated in Figure 3.

STANDARDS

The calculations are carried out in accordance with:

- Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings.

The selected values for the NDP's in the following calculations are:

Parameter	γ_c	γ_s	α_{cc}	α_{ct}
Value	1,5	1,15	0,85	0,85

Table 1: NDP's in EC2.

QUALITIES

Concrete grade C30/37:

$f_{ck} = 30{,}0$ MPa	EC2, Table 3.1
$f_{cd} = \alpha_{cc}\times f_{ck}/\gamma_c = 0{,}85\times30/1{,}5 = 17{,}0$ MPa	EC2, Pt.3.15
$f_{ctd} = \alpha_{ct}\times f_{ctk,0,05}/\gamma_c = 0{,}85\times2{,}00/1{,}5 = 1{,}13$ MPa	EC2, Pt.3.16
$f_{bd} = 2{,}25\times\eta_1\times\eta_2\times f_{ctd} = 2{,}25\times0{,}7\times1{,}0\times1{,}13 = 1{,}78$ MPa	EC2, Pt.8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s = 500/1{,}15 = 435$ MPa	EC2, Pt.3.2.7

Reinforcement design DTF/DTS120

LOADS

Maximum cantilever (load location): 75mm

Vertical ultimate limit state load: F_V = 120kN.

Horizontal ultimate limit state load in axial direction: F_H = 0kN.

Horizontal ultimate limit state load in transverse direction: F_T=0kN.

PART 2 - REINFORCEMENT

EQUILIBRIUM

For evaluation of the reaction forces from the unit, the following geometry may be used. The assumed location of the reaction forces represents a conservative simplification with rounded values compared to the assumptions used when designing the unit. The geometry accounts for approximately 5mm tolerances on the location of the front reinforcement. However, the nominal planned location of anchoring reinforcement is equal for the DTS and DTF units and shall always be as illustrated in Figure 3.

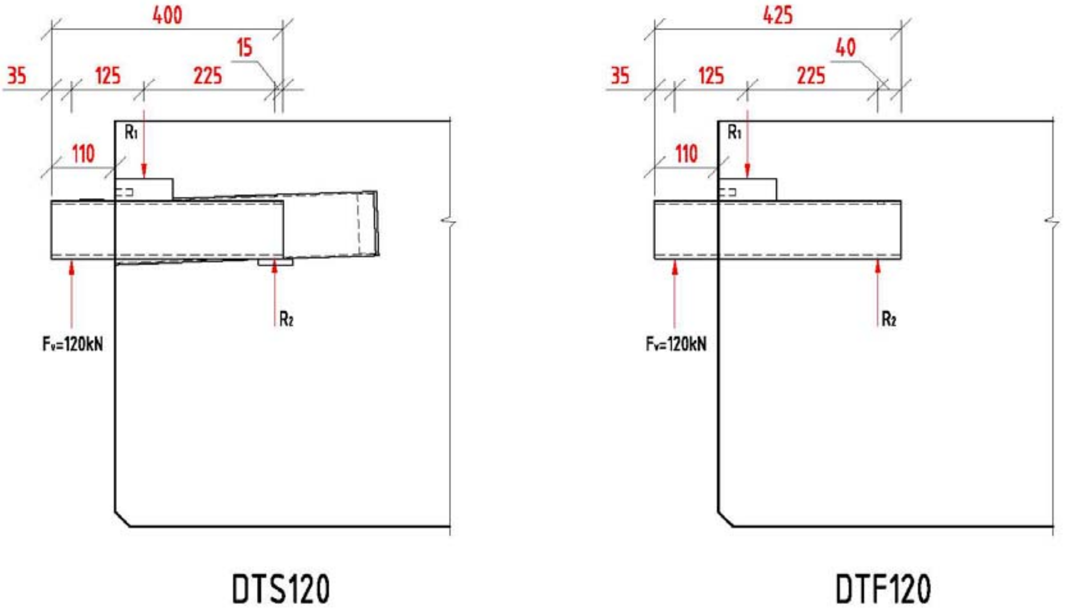


Figure 1: Forces acting on the unit.

F_V = External force on the inner tube

R_1, R_2= Support reaction forces of the inner tube.

The equilibrium equations for the inner tube become:

1): $\sum M=0$: $F_V \times 125 - R_2 \times 225 = 0$

2): $\sum F_y=0$: $F_v + R_2 - R_1 = 0$

Results:

$$R_2 = \frac{120kN \times 125mm}{225mm} \approx 67kN$$

Support reaction force at front of unit:

$$R_1 = 120kN + 67kN = 187kN$$

REINFORCEMENT NECESSARY TO ANCHOR THE UNIT TO THE CONCRETE

Reinforcement R_1:
$A_{s1}= R_1 /f_{sd}$=187000/435=430mm^2
Select 2Ø12 =2×2×113mm^2=452mm^2
Capacity selected reinforcement: R=452mm^2×435MPa=196kN
Stress: σ=187000/452=414MPa

Reinforcement R_2:
$A_{s2}= R_2 /f_{sd}$=67000/435=154mm^2
If the shear reinforcement in the DT is made from Ø8 bars, two additional bars (200mm^2) at back of the unit will be sufficient anchoring.

BENDING OF FRONT REINFORCEMENT

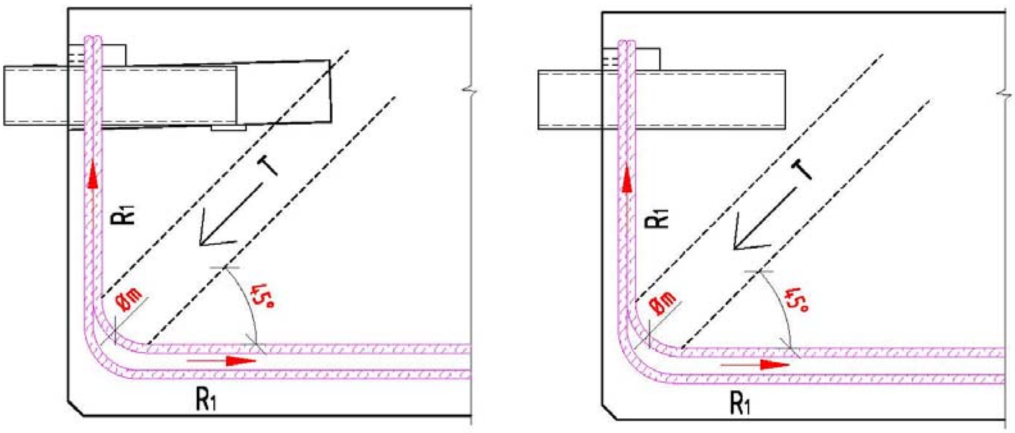


Figure 2: Compression diagonal.

Allowable concrete stress in node, EC2, clause 6.5.2:

$$f_{cd2} = 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

Concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times \O_m \times \sin\theta \times \cos\theta}$$

b =effective width of the web to transfer compression diagonal in the DT.

(if the compression diagonal crosses the unit, the width of the unit should be subtracted)

$\O_m$= Mandrel diameter of front reinforcement

θ=assume compression diagonal in 45degrees.

Solving for $\O_m$:

$$\O_m = \frac{R_1}{b \times \sigma_c \times \sin 45 \times \cos 45}$$

Minimum mandrel diameter is found for the maximum concrete stress in the node:

$$\O_{m,\min} = \frac{R_1}{b \times f_{cd2} \times 0{,}5}$$

When the effective width (b) is known, the minimum mandrel diameter may be calculated from the above formula.

Reinforcement design DTF/DTS120

ANCHORAGE

See Figure 3. According to EC2 clauses 8.4.3 and 8.4.4:

$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}$

Ø12: $l_{b,req'd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{12}{4} \times \frac{414}{1{,}78} = 698$ mm

$l_{b,min} = \max(0{,}3 \times l_{b,reqd};\ 10 \times Ø;\ 100mm) = 209$ mm

Straight bar:

$\alpha_1 = 1{,}0$

Concrete cover:

$\alpha_2 = 1 - 0{,}15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $\alpha_2 = 1{,}0$

Confinement by reinforcement:

$\alpha_3 = 1 - K \times \lambda$

Neglecting any positive effect of transverse reinforcement, selecting $\alpha_3 = 1{,}0$

Confinement by welded transverse reinforcement:

α_4 = Not relevant.

Confinement by transverse pressure:

α_5 = Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5 = 1{,}0 \times 1{,}0 \times 1{,}0 = 1{,}0 > 0{,}7$ – OK

$l_{bd} = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 698 = 698$mm

⇒Select l=700mm

IMPORTANT:

- It must always be checked that the beam's main reinforcement has sufficient anchorage at the end of the horizontal part of the front anchorage. This may lead to greater lengths for the horizontal part of the front anchorage than calculated here.

Reinforcement design DTF/DTS120

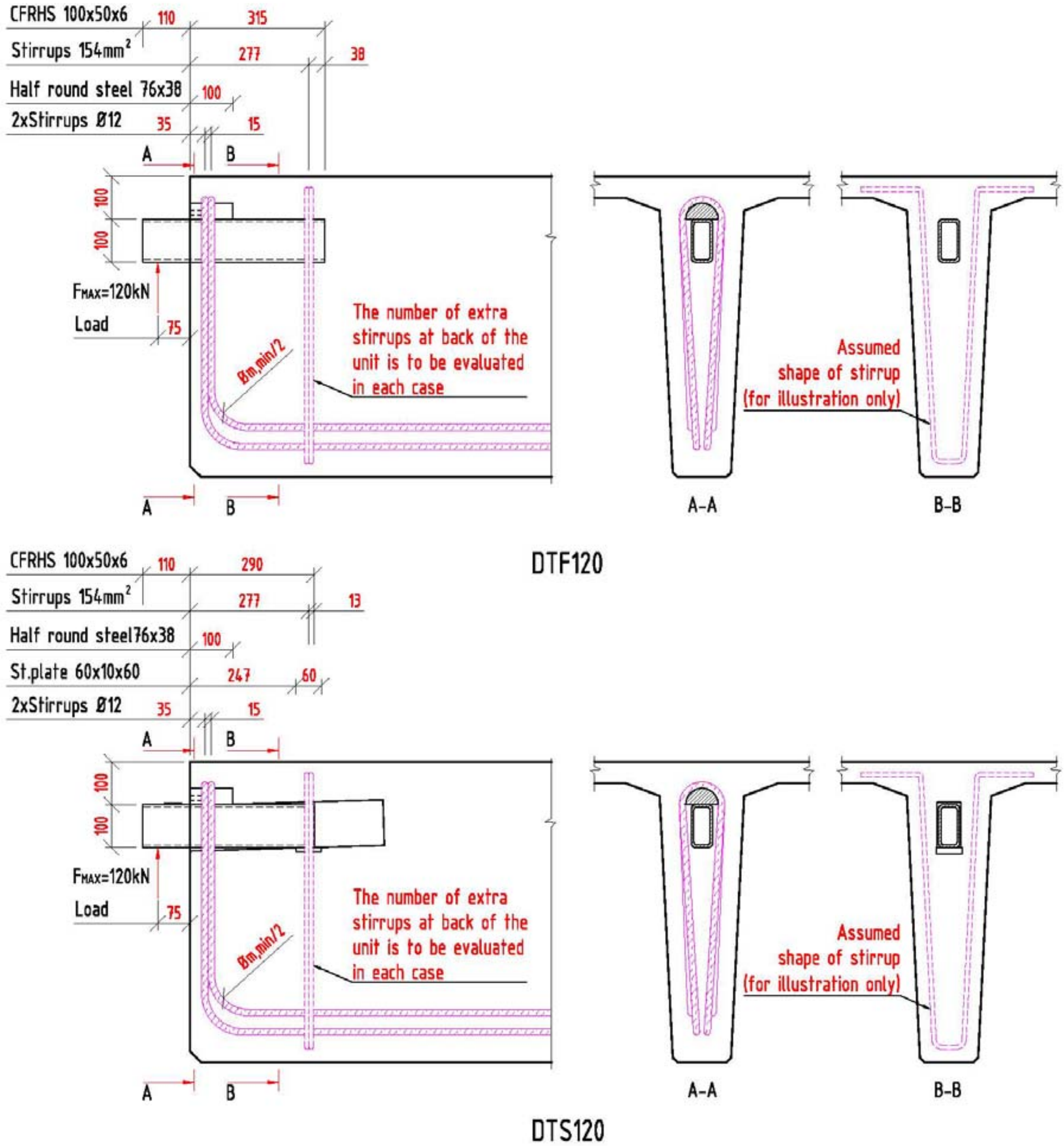


Figure 3: Anchoring reinforcement.

The integrity of the steel unit is based on the location of the reinforcement bars given in Figure 3. The position of the bars should not be changed.

Reinforcement design DTF/DTS150

CONTENTS

PART 1 – BASIC ASSUMTIONS

GENERAL

The following calculations of anchorage of the units and the corresponding reinforcement must be considered as an example illustrating the design model. The calculations give the reaction forces from the unit to the element, and the recommended reinforcement includes only the reinforcement necessary to anchor these forces to the concrete. The unit may be used in DT-elements with various cross-sections. Thus, no recommendations on the reinforcement layout of the element are given, as this cannot be generalized. The DT-element must be designed for the forces R_1 and R_2 and it must always be checked that the forces from the anchorage reinforcement can be transferred to the main reinforcement of the concrete element.

The information found here and in the memos assumes that the design of the elements and the use of the units in structural elements are carried out under the supervision of a structural engineer with knowledge about the behaviour of concrete structures. Be aware of the increase in shear force (R_1) in the end of the element, compared to the situation with underlying support where the shear force equals the support reaction force.

To ensure structural integrity of the steel unit itself the position of the anchoring reinforcement relative to the unit shall be as illustrated in Figure 3.

STANDARDS

The calculations are carried out in accordance with:

- Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings.

The selected values for the NDP's in the following calculations are:

Parameter	γ_c	γ_s	α_{cc}	α_{ct}
Value	1,5	1,15	0,85	0,85

Table 1: NDP's in EC2.

QUALITIES

Concrete grade C30/37:

$f_{ck} = 30,0$ MPa — EC2, Table 3.1

$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c = 0,85 \times 30/1,5 = 17,0$ MPa — EC2, Pt.3.15

$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c = 0,85 \times 2,00/1,5 = 1,13$ MPa — EC2, Pt.3.16

$f_{bd} = 2,25 \times \eta_1 \times \eta_2 \times f_{ctd} = 2,25 \times 0,7 \times 1,0 \times 1,13 = 1,78$ MPa — EC2, Pt.8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s = 500/1,15 = 435$ MPa — EC2, Pt.3.2.7

Reinforcement design DTF/DTS150

LOADS

Maximum cantilever (load location): 75mm

Vertical ultimate limit state load: F_V = 150kN.
Horizontal ultimate limit state load in axial direction: F_H = 0kN.
Horizontal ultimate limit state load in transverse direction: F_T=0kN.

PART 2 - REINFORCEMENT

EQUILIBRIUM

For evaluation of the reaction forces from the unit, the following geometry may be used. The assumed location of the reaction forces represents a conservative simplification with rounded values compared to the assumptions used when designing the unit. The geometry accounts for approximately 5mm tolerances on the location of the front reinforcement. However, the nominal planned location of anchoring reinforcement is equal for the DTS and DTF units and shall always be as illustrated in Figure 3.

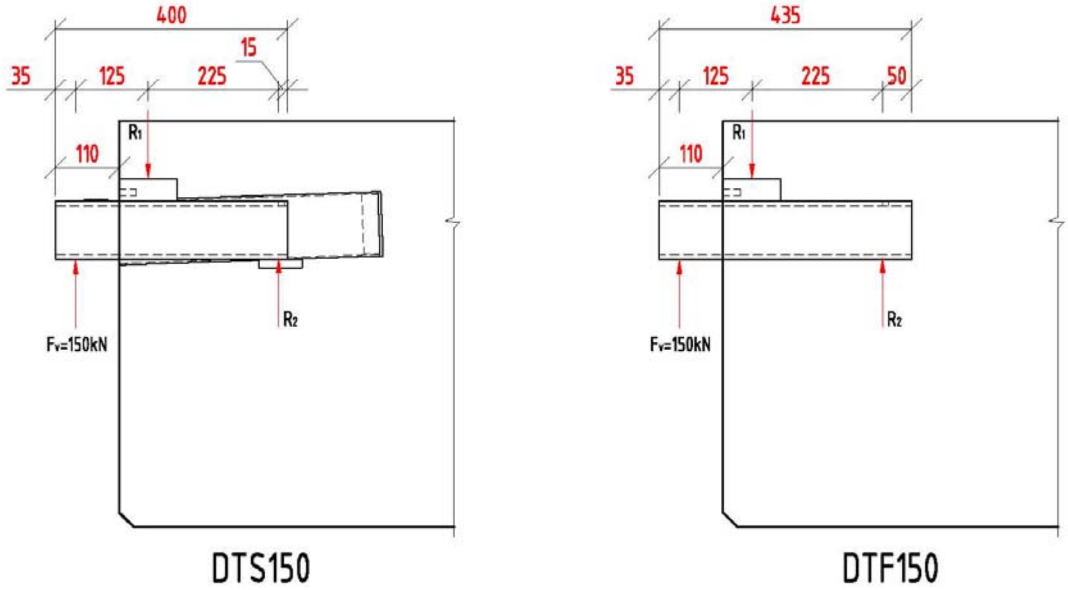


Figure 1: Forces acting on the unit.

F_V = External force on the inner tube
R_1, R_2= Support reaction forces of the inner tube.

The equilibrium equations for the inner tube become:

1): $\sum M=0$: $F_V \times 125 - R_2 \times 225 = 0$

2): $\sum F_y=0$: $F_v + R_2 - R_1 = 0$

Results:

$$R_2 = \frac{150kN \times 125mm}{225mm} \approx 83kN$$

Support reaction force at front of unit:

$$R_1 = 150kN + 83kN = 233kN$$

Reinforcement design DTF/DTS150

REINFORCEMENT NECESSARY TO ANCHOR THE UNIT TO THE CONCRETE

Reinforcement R_1:
$A_{s1}= R_1 /f_{sd}$=233000/435=536mm^2
Select 2Ø16 =2×2×201mm^2=804mm^2
Capacity selected reinforcement: R=804mm^2×435MPa=350kN
Stress: σ=233000/804=290MPa

Reinforcement R_2:
$A_{s2}= R_2 /f_{sd}$=83000/435=191mm^2
If the shear reinforcement in the DT is made from Ø8 bars, two additional bars (200mm^2) at back of the unit will be sufficient anchoring.

BENDING OF FRONT REINFORCEMENT

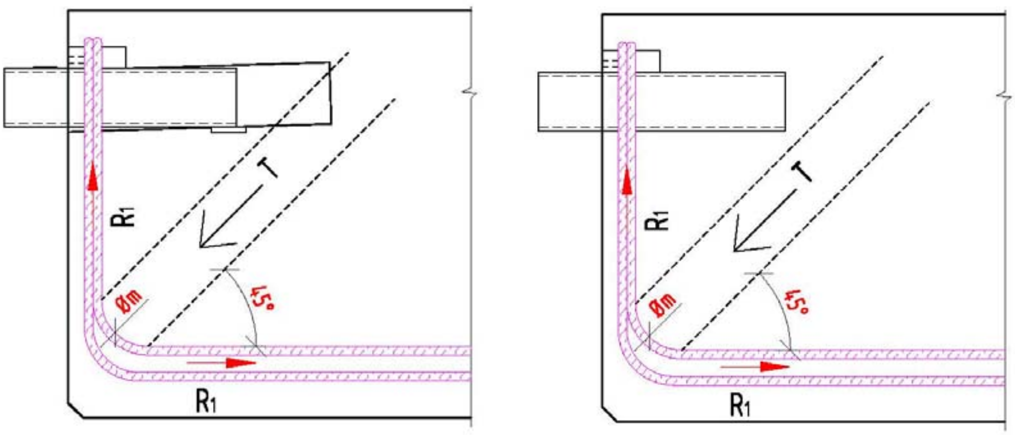


Figure 2: Compression diagonal.

Allowable concrete stress in node, EC2, clause 6.5.2:

$$f_{cd2} = 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

Concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times \varnothing_m \times \sin\theta \times \cos\theta}$$

b =effective width of the web to transfer compression diagonal in the DT.
(if the compression diagonal crosses the unit, the width of the unit should be subtracted)
$\varnothing_m$= Mandrel diameter of front reinforcement
θ=assume compression diagonal in 45degrees.

Solving for $\varnothing_m$:

$$\varnothing_m = \frac{R_1}{b \times \sigma_c \times \sin 45 \times \cos 45}$$

Minimum mandrel diameter is found for the maximum concrete stress in the node:

$$\varnothing_{m,\min} = \frac{R_1}{b \times f_{cd2} \times 0{,}5}$$

When the effective width (b) is known, the minimum mandrel diameter may be calculated from the above formula.

Reinforcement design DTF/DTS150

ANCHORAGE

See Figure 3. According to EC2 clauses 8.4.3 and 8.4.4:

$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}$

Ø16: $l_{b,req'd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{16}{4} \times \frac{290}{1,78} = 652$ mm

$l_{b,min} = \max(0,3 \times l_{b,reqd}; 10 \times Ø; 100mm) = 196$ mm

Straight bar:

$\alpha_1 = 1,0$

Concrete cover:

$\alpha_2 = 1 - 0,15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $\alpha_2 = 1,0$

Confinement by reinforcement:

$\alpha_3 = 1 - K \times \lambda$

Neglecting any positive effect of transverse reinforcement, selecting $\alpha_3 = 1,0$

Confinement by welded transverse reinforcement:

α_4 = Not relevant.

Confinement by transverse pressure:

α_5 = Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5 = 1,0 \times 1,0 \times 1,0 = 1,0 > 0,7$ – OK

$l_{bd} = 1,0 \times 1,0 \times 1,0 \times 1,0 \times 1,0 \times 652 = 652$mm

$\Rightarrow$Select l=700mm

IMPORTANT:

- It must always be checked that the beam's main reinforcement has sufficient anchorage at the end of the horizontal part of the front anchorage. This may lead to greater lengths for the horizontal part of the front anchorage than calculated here.

Reinforcement design DTF/DTS150

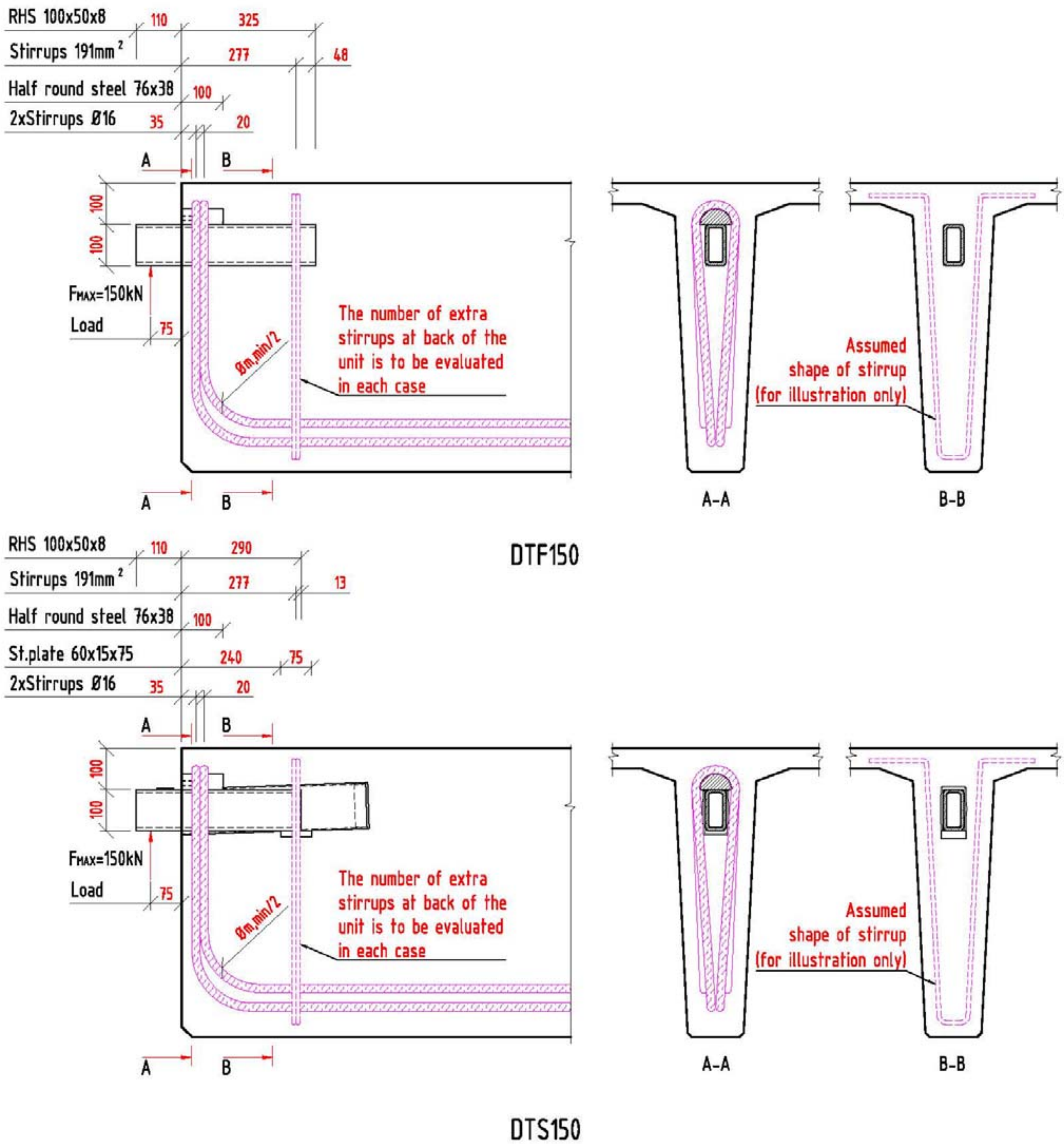


Figure 3: Anchoring reinforcement.

The integrity of the steel unit is based on the location of the reinforcement bars given in Figure 3. The position of the bars should not be changed.

Reinforcement design DTF/DTS200

CONTENTS

PART 1 – BASIC ASSUMTIONS

GENERAL

The following calculations of anchorage of the units and the corresponding reinforcement must be considered as an example illustrating the design model. The calculations give the reaction forces from the unit to the element, and the recommended reinforcement includes only the reinforcement necessary to anchor these forces to the concrete. The unit may be used in DT-elements with various cross-sections. Thus, no recommendations on the reinforcement layout of the element are given, as this cannot be generalized. The DT-element must be designed for the forces R_1 and R_2 and it must always be checked that the forces from the anchorage reinforcement can be transferred to the main reinforcement of the concrete element.

The information found here and in the memos assumes that the design of the elements and the use of the units in structural elements are carried out under the supervision of a structural engineer with knowledge about the behaviour of concrete structures. Be aware of the increase in shear force (R_1) in the end of the element, compared to the situation with underlying support where the shear force equals the support reaction force.

To ensure structural integrity of the steel unit itself the position of the anchoring reinforcement relative to the unit shall be as illustrated in Figure 3.

STANDARDS

The calculations are carried out in accordance with:

- Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings.

The selected values for the NDP's in the following calculations are:

Parameter	γ_c	γ_s	α_{cc}	α_{ct}
Value	1,5	1,15	0,85	0,85

Table 1: NDP's in EC2.

QUALITIES

Concrete grade C30/37:

$f_{ck} = 30{,}0$ MPa	EC2, Table 3.1
$f_{cd} = \alpha_{cc}\times f_{ck}/\gamma_c = 0{,}85\times 30/1{,}5 = 17{,}0$ MPa	EC2, Pt.3.15
$f_{ctd} = \alpha_{ct}\times f_{ctk,0,05}/\gamma_c = 0{,}85\times 2{,}00/1{,}5 = 1{,}13$ MPa	EC2, Pt.3.16
$f_{bd} = 2{,}25\times\eta_1\times\eta_2\times f_{ctd} = 2{,}25\times 0{,}7\times 1{,}0\times 1{,}13 = 1{,}78$ MPa	EC2, Pt.8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s = 500/1{,}15 = 435$ MPa	EC2, Pt.3.2.7

Reinforcement design DTF/DTS200

LOADS
Maximum cantilever (load location): 75mm

Vertical ultimate limit state load: F_V = 200kN.
Horizontal ultimate limit state load in axial direction: F_H = 0kN.
Horizontal ultimate limit state load in transverse direction: F_T=0kN.

PART 2 - REINFORCEMENT

EQUILIBRIUM
For evaluation of the reaction forces from the unit, the following geometry may be used. The assumed location of the reaction forces represents a conservative simplification with rounded values compared to the assumptions used when designing the unit. The geometry accounts for approximately 5mm tolerances on the location of the front reinforcement. However, the nominal planned location of anchoring reinforcement is equal for the DTS and DTF units and shall always be as illustrated in Figure 3.

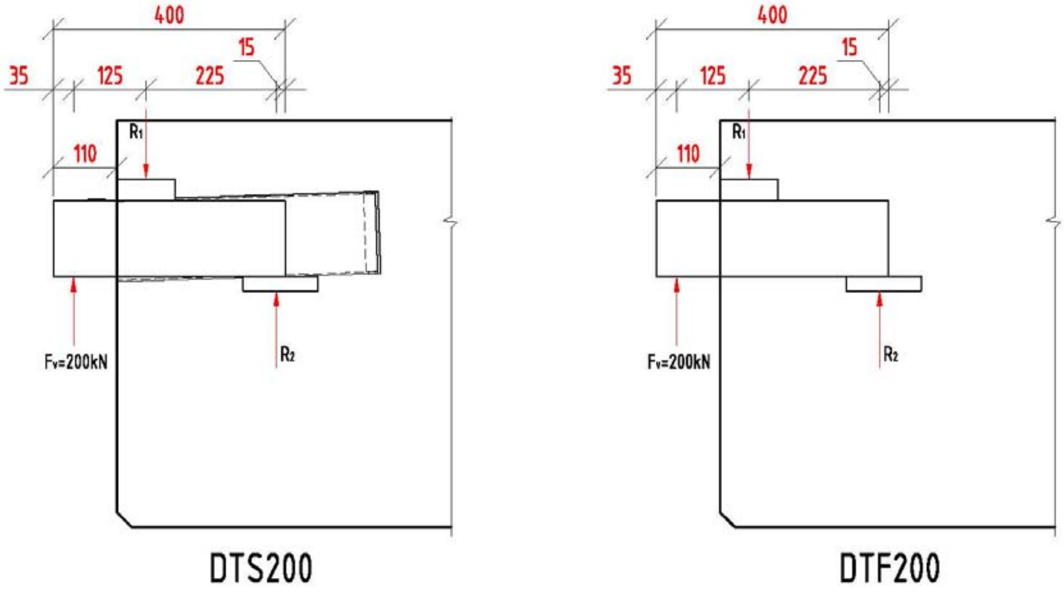


Figure 1: Forces acting on the unit.

F_V = External force on the knife.
R_1, R_2= Support reaction forces of the inner tube.

The equilibrium equations for the knife become:

1): $\sum M=0$: $F_V \times 125 - R_2 \times 225 = 0$

2): $\sum F_y=0$: $F_v + R_2 - R_1 = 0$

Results:

$$R_2 = \frac{200kN \times 125mm}{225mm} \approx 111kN$$

Support reaction force at front of unit:

$$R_1 = 200kN + 111kN = 311kN$$

Reinforcement design DTF/DTS200

REINFORCEMENT NECESSARY TO ANCHOR THE UNIT TO THE CONCRETE

<u>Reinforcement R_1:</u>
$A_{s1}= R_1 / f_{sd}$=311000/435=714mm^2
Select 2Ø16 =2×2×201mm^2=804mm^2
Capacity selected reinforcement: R=804mm^2×435MPa=350kN
Stress: σ=311000/804=387MPa

<u>Reinforcement R_2:</u>
$A_{s2}= R_2/f_{sd}$=111000/435=255mm^2

If the shear reinforcement in the DT is made from Ø10 bars, two additional bars (314mm^2) at back of the unit will be sufficient anchoring.

BENDING OF FRONT REINFORCEMENT

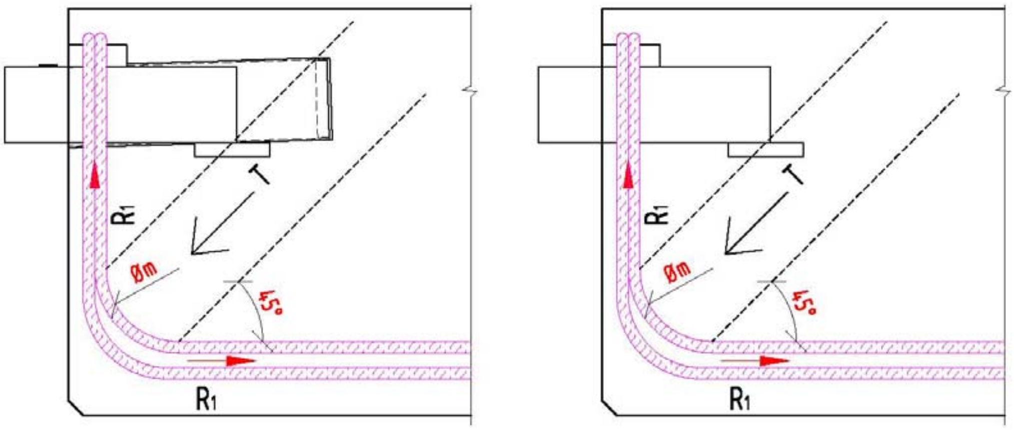


Figure 2: Compression diagonal.

Allowable concrete stress in node, EC2, clause 6.5.2:

$$f_{cd2} = 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

Reinforcement design DTF/DTS200

Concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times \varnothing_m \times \sin\theta \times \cos\theta}$$

b =effective width of the web to transfer compression diagonal in the DT.
(if the compression diagonal crosses the unit, the width of the unit should be subtracted)
$\varnothing_m$= Mandrel diameter of front reinforcement
θ=assume compression diagonal in 45degrees.

Solving for $\varnothing_m$:

$$\varnothing_m = \frac{R_1}{b \times \sigma_c \times \sin 45 \times \cos 45}$$

Minimum mandrel diameter is found for the maximum concrete stress in the node:

$$\varnothing_{m,\min} = \frac{R_1}{b \times f_{cd2} \times 0{,}5}$$

When the effective width (b) is known, the minimum mandrel diameter may be calculated from the above formula.

Reinforcement design DTF/DTS200

ANCHORAGE

See Figure 3. According to EC2 clauses 8.4.3 and 8.4.4:

$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}$

Ø16: $l_{b,req'd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{16}{4} \times \frac{387}{1{,}78} = 870$ mm

$l_{b,min} = \max(0{,}3 \times l_{b,reqd};\ 10 \times Ø;\ 100mm) = 261$ mm

Straight bar:

$\alpha_1 = 1{,}0$

Concrete cover:

$\alpha_2 = 1 - 0{,}15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $\alpha_2 = 1{,}0$

Confinement by reinforcement:

$\alpha_3 = 1 - K \times \lambda$

Neglecting any positive effect of transverse reinforcement, selecting $\alpha_3 = 1{,}0$

Confinement by welded transverse reinforcement:

α_4 = Not relevant.

Confinement by transverse pressure:

α_5 = Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5 = 1{,}0 \times 1{,}0 \times 1{,}0 = 1{,}0 > 0{,}7$ – OK

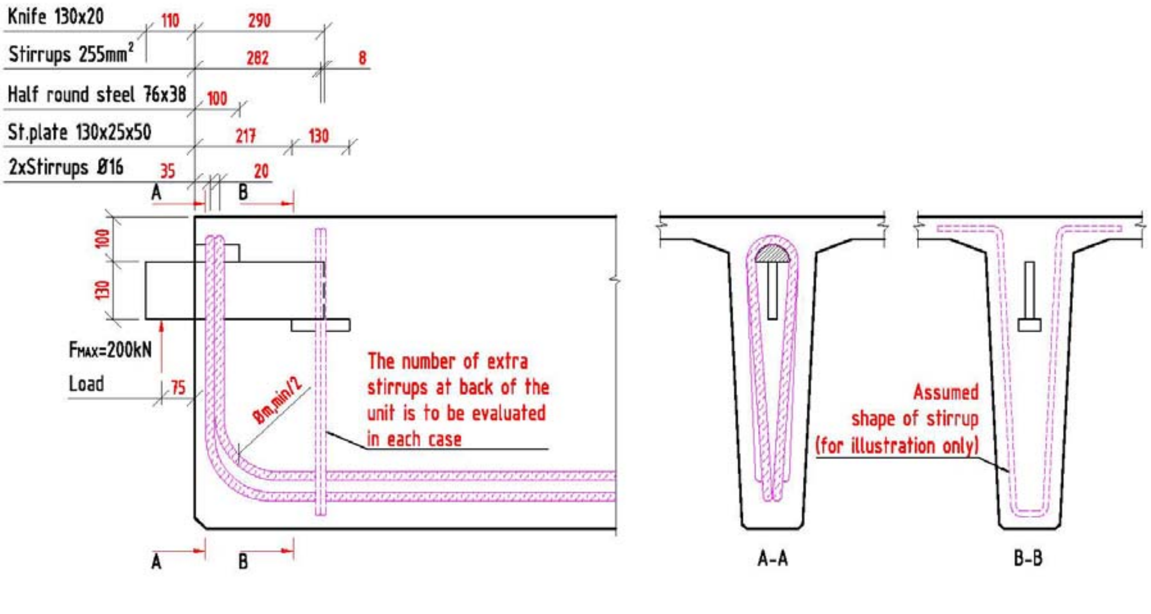
$l_{bd} = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 870 = 870$mm

$\Rightarrow$Select l=900mm

IMPORTANT:

- It must always be checked that the beam's main reinforcement has sufficient anchorage at the end of the horizontal part of the front anchorage. This may lead to greater lengths for the horizontal part of the front anchorage than calculated here.

Reinforcement design DTF/DTS200



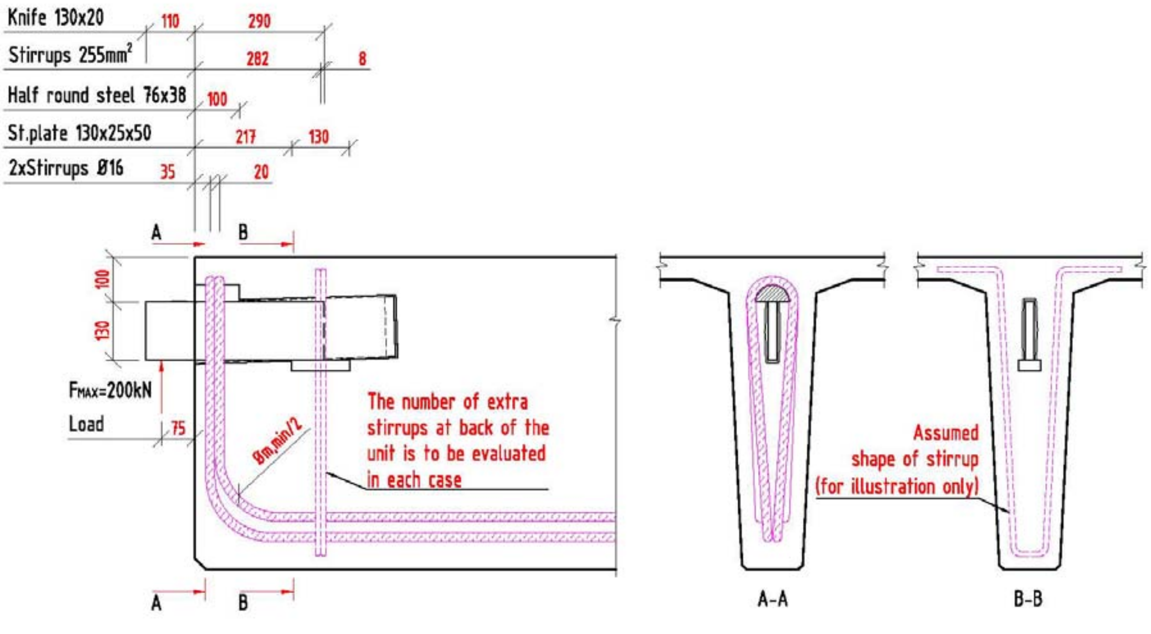


Figure 3: Anchoring reinforcement.

The integrity of the steel unit is based on the location of the reinforcement bars given in Figure 3. The position of the bars should not be changed.

Annex 4 Design examples

In this Annex two design examples are given:

- DTF 120 used in DT450
- DTF 200 used in a high DT-element

EXAMPLE CALCULATION

Date:	06.12.2012	Sign: sss
Last Rev:	27.03.2013	Sign: sss
		Control:ps
Page 1 of 12		

DTF120 USED IN SPENNCON DT450

CONTENT

DTF120 USED IN SPENNCON DT450

GENERAL

QUALITIES

Concrete C45/55:

f_{ck} = 45,0 MPa	EC2, Table 3.1
$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c$ = 0,85×45/1,5 = 25,5 MPa	EC2, Clause 3.15
$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c$ = 0,85×2,70/1,5 = 1,53 MPa	EC2, Clause 3.16
$f_{bd} = 2{,}25 \times \eta_1 \times \eta_2 \times f_{ctd}$ = 2,25×0,7×1,0×1,53 = 2,41 MPa	EC2, Clause 8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s$ = 500/1,15 = 435 MPa	EC2, Clause 3.2.7

Tendons:

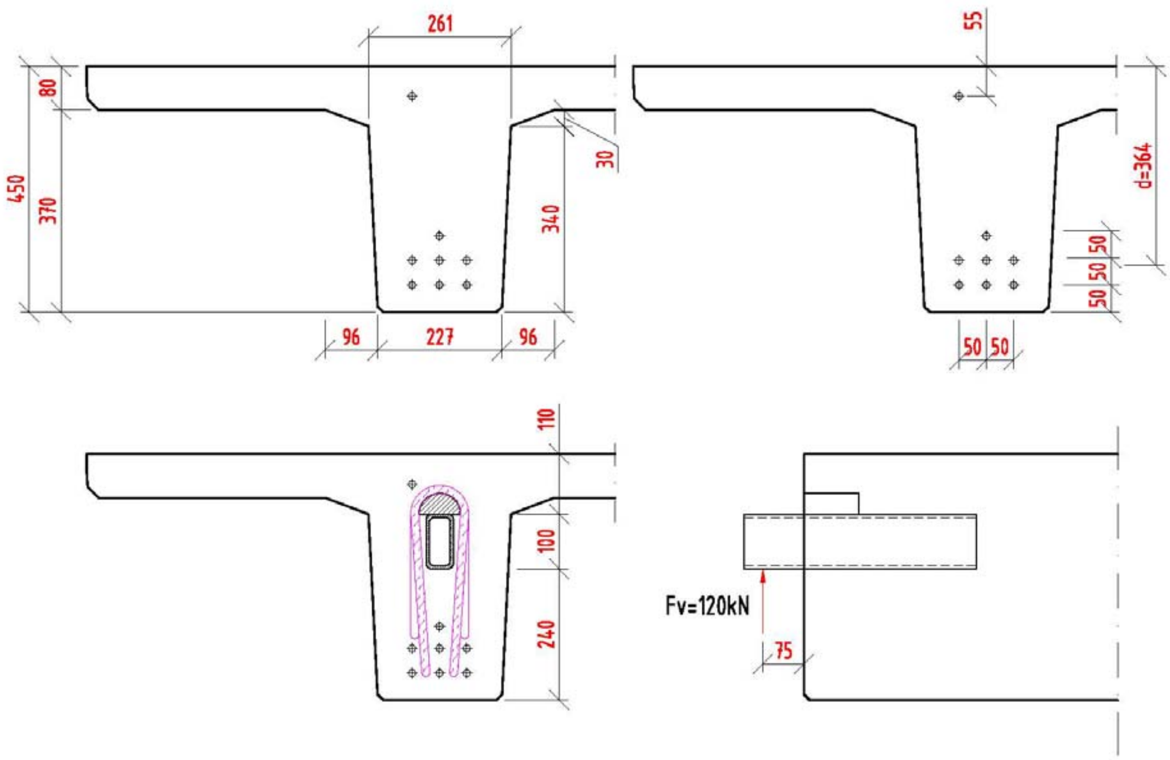
Diameter: Ø=12,7mm. (Nominal diameter. Real diameter=11,3mm)

Assumed tension after elastic loss: P=120kN.

LOAD

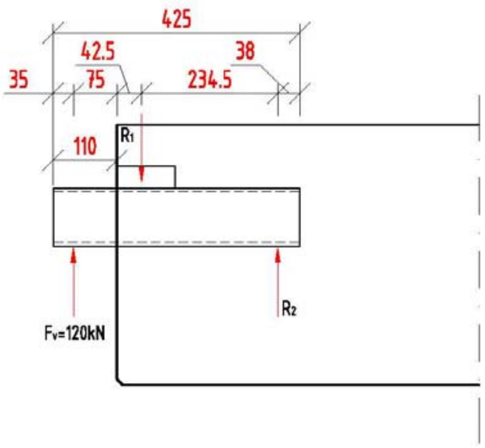
Design load F_v=120kN

GEOMETRY



CALCULATIONS

1) Equilibrium:



$$R_2 = \frac{F_V \times (75mm + 42{,}5mm)}{234{,}5mm} = \frac{120kN \times (75mm + 42{,}5mm)}{234{,}5mm} \approx 61kN$$

$$R_1 = F_v + R_2 = 120kN + 61kN = 181kN$$

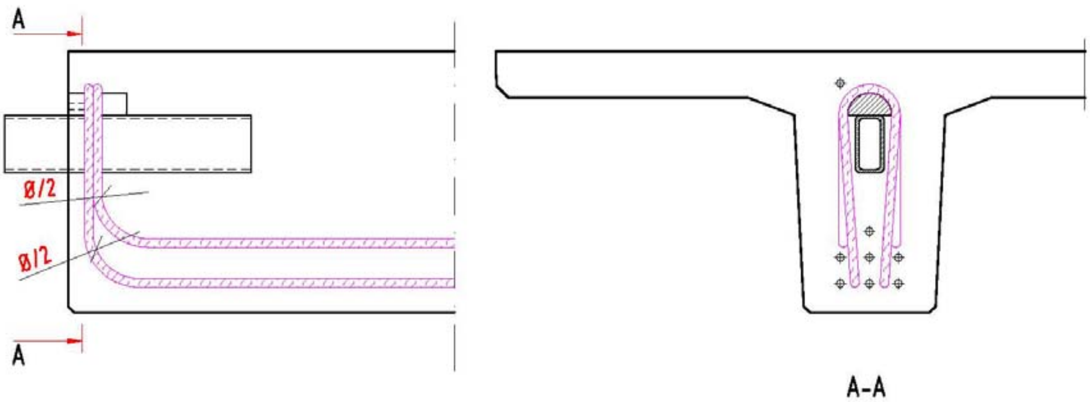
2) Reinforcement:

$$A_{R1} = \frac{181kN}{435MPa} = 416mm^2 \rightarrow 2ø12stirrups = 452mm^2$$

$$A_{R2} = \frac{61kN}{435mm} \approx 140mm^2$$

3) Bending of anchoring reinforcement:

Minimum mandrel diameter, $Ø_{m,min}$:



DTF120 USED IN SPENNCON DT450

Allowable concrete stress in node, EC2, clause 6.5.2:

$$f_{cd2} = 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

$$= 0{,}6 \times (1 - \frac{45}{250}) \times 25{,}5$$

$$= 12{,}5 MPa$$

Actual concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times \varnothing_m \times \sin\theta \times \cos\theta}$$

b=227mm
$\varnothing_m$= Mandrel diameter of front reinforcement
θ=assume concrete strut in 45degrees.

Solving for $\varnothing_m$:

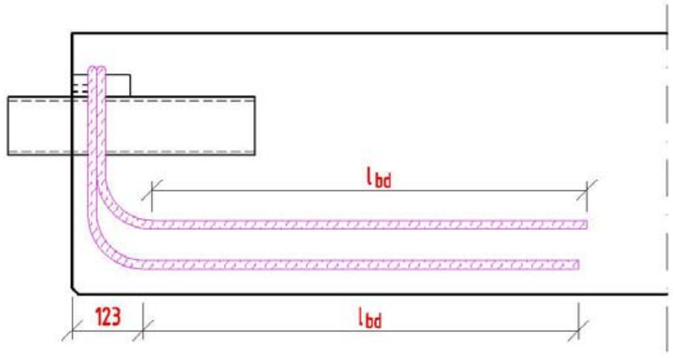
$$\varnothing_m = \frac{R_1}{b \times \sigma_c \times \sin\theta \times \cos\theta}$$

$$\Rightarrow \varnothing_{m,\min} = \frac{181000N}{227mm \times 12{,}5MPa \times \sin(45) \times \cos(45)} = 128mm$$

⇒ Select mandrel diameter: $\varnothing_m$=160mm

DTF120 USED IN SPENNCON DT450

4) Anchoring of Ø12 stirrups in front, EC2 clause 8.4.3 and 8.4.4:



$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}$

$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}}$

Stress in stirrup: $\sigma_{sd} = \frac{181000/4}{\pi \times 6^2} = 400MPa$

$l_{b,reqd} = \frac{12}{4} \times \frac{400}{2{,}41} = 497\text{mm}$

$l_{b,min}$ = max(0,3×$l_{b,reqd}$; 10×Ø; 100mm) = 150 mm

Table 8.2: Straight bar:

α_1= 1,0

Table 8.2: Concrete cover:

α_2 = 1−0,15×(c_d−3×Ø)/Ø

Neglecting any positive effect of concrete cover, selecting α_2=1,0

Table 8.2: Confinement by reinforcement:

α_3 = 1−K×λ

Neglecting any positive effect of transverse reinforcement, selecting α_3 =1,0

Table 8.2: Confinement by welded transverse reinforcement:

α_4 = 1,0

Not relevant.

Table 8.2: Confinement by transverse pressure:

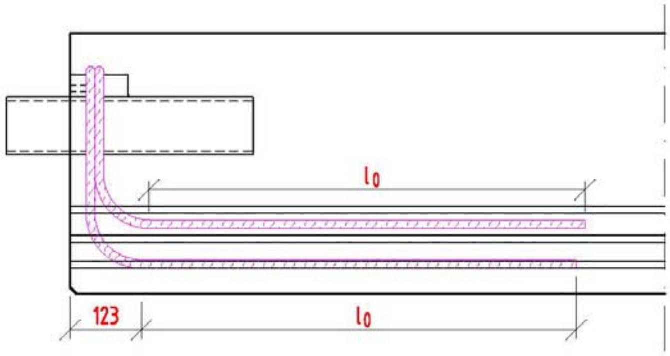
α_5 =1,0

Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5$=1,0×1,0×1,0=1,0 > 0,7 – OK

l_{bd} = 1,0×1,0×1,0×1,0×1,0×497mm= 497 mm

5) Lap of Ø12 stirrups, EC2 clause 8.7.3:



$l_0 = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_5 \times \alpha_6 \times l_{b,reqd} \geq l_{0,min}$

Required lap length, Ø12:

$$l_{b,reqd} = \frac{\varnothing}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{12}{4} \times \frac{400}{2,41} = 497\text{mm}$$

$l_{0,min}$ = max(0,3×α_6×$l_{b,reqd}$; 15×Ø; 200mm)=224mm

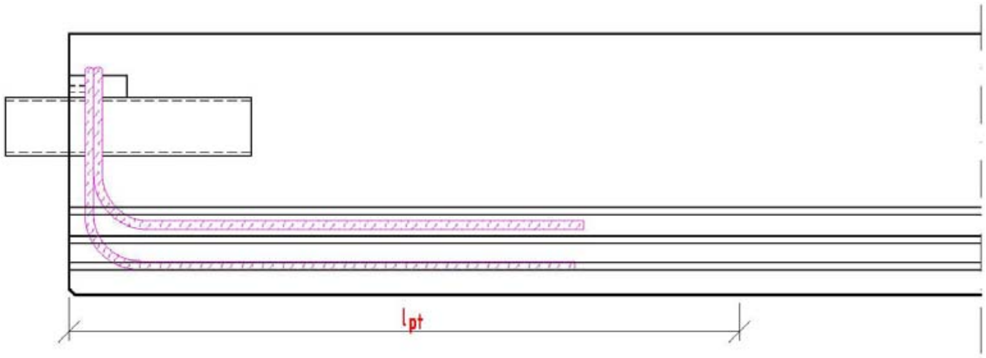
Table 8.2: α_1,α_2,α_3,og α_5=1,0 as calculated in clause 2).

Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0$ = 1,0×1,0×1,0×1,0×1,5×497mm=746mm ⇒≈750mm

DTF120 USED IN SPENNCON DT450

6) Transmission length – tendons, EC2 clause 8.10.2.2:



Bond stress:

$f_{bpt}=\eta_{p1}\times\eta_1\times f_{ctd}(t)$

$\eta_{p1}=3,2$ (assume 3 or7-wire tendons)

$\eta_1=1,0$ (assume "good bond conditions")

$f_{ctd}(t)=\alpha_{ct}\times 0,7\times f_{ctm}(t)/\gamma_c$

$\alpha_{ct}=0,85$

$f_{ctm}(t)=(\beta_{cc}(t))^{\alpha}\times f_{ctm}$

$\beta_{cc}(t)=\exp(s(1-28/t)^{1/2})$

Assume: Release after t= 1day

Assume: s=0,2

$\Rightarrow\beta_{cc}(t)=\exp[0,2\times\{1-(28/1)^{1/2}\}]=0,423$

$\alpha=1$ (t<28days)

$f_{ctm}=3,8MPa$

$\Rightarrow f_{ctm}(t)=0,423^{1}\times 3,8MPa=1,60MPa$

$f_{ctd}(t)=0,85\times 0,7\times 1,60MPa/1,5=0,635MPa$

$\Rightarrow f_{bpt}=3,2\times 1,0\times 0,635MPa=2,03MPa$

Transmission length:

$l_{pt}=\alpha_1\times\alpha_2\times\emptyset\times\sigma_{pmo}/f_{bpt}$

$\alpha_1=1,0$ (assume gradual release)

$\alpha_2=0,19$ (assume 3 or7-wire tendons)

$\emptyset=12,7mm$ (Nominal diameter of tendon. Real diameter=11,3mm)

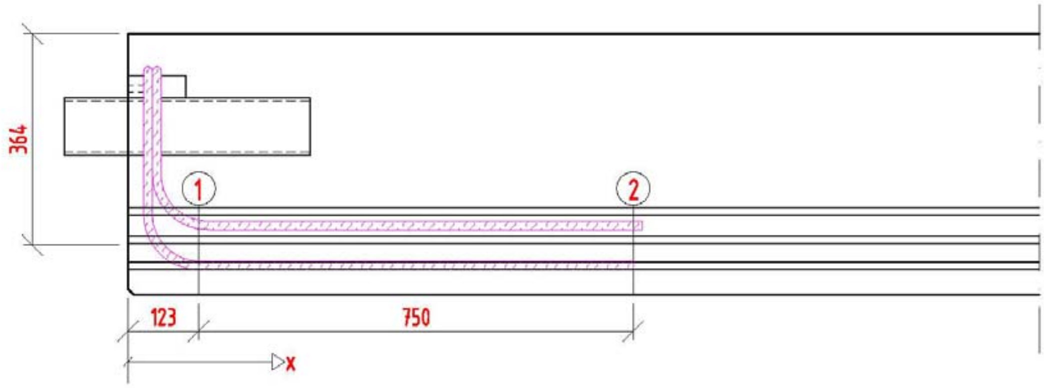
$\sigma_{pmo}=1200MPa$

$\Rightarrow l_{pt}=1,0\times 0,19\times 12,7mm\times 1200MPa/2,03MPa=1426mm$

$\Rightarrow l_{pt1}=0,8\times l_{pt}=0,8\times 1426mm=1141mm$. To be used in evaluation of local cross section stresses.

$\Rightarrow l_{pt2}=1,2\times l_{pt}=1,2\times 1426mm=1711mm$. To be used in evaluation of anchorage. Stress after all losses assumed as $0,9\sigma_{pmo}$. (10% loss)

7) Anchoring:



Assuming the horizontal part of the front anchoring bar is 750mm (≈ equals the minimum calculated lap length). I.e. the bar ends at x=123+750=873mm.

Section 1:

Force anchored in the tendons (7 tendons) at x=123mm:

Assume 10% loss of pre-stressing force:

F_{sp1}=7×P×0,9×123mm/1711mm=7×120kN×0,9×123mm/1711mm=54kN

Force anchored in Ø12:

$F_{Ø12}$=181kN

Total anchored force:

F=F_{sp1}+$F_{Ø12}$=54kN+181kN=235kN

Tension in reinforcement at x=123mm: (clause 6.2.3(7))

S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))

=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90)) (assume 45degrees concrete struts and vertical links)

= M(x)/z+0,5×V_{Ed}× (1-0)

= M(x)/z+0,5×V_{Ed}

Moment at x=123:

M (x=123)=120kN×(123+75)mm=23,8kNm

Assume: z=0,9d=0,9×364mm=328mm (approximately)

S (x=123)=23,8kNm/0,328m+181kN/2=163kN

⇒ The anchoring at x=123mm is sufficient.

Section 2:

Force anchored in the tendons (7 tendons) at x=873mm:

Assume 10% loss of pre-stressing force:

F_{sp1}=7×P×0,9×873mm/1711mm=7×120kN×0,9×873mm/1711mm=386kN

Force anchored in Ø12:

$F_{Ø12}$=0kN

Total anchored force:

F=F_{sp1}+$F_{Ø12}$=386kN+0kN=386kN

Tension in reinforcement at x=873mm: (clause 6.2.3(7))

S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))

=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90)) (assume 45degrees concrete struts and vertical links)

= M(x)/z+0,5×V_{Ed}× (1-0)

= M(x)/z+0,5×V_{Ed}

Moment at x=873:

M (x=873)=120kN×(873+75)mm=113,8kNm

Assume: z=0,9d=0,9×364mm=328mm

S (x=873)=113,8kNm/0,328m+120kN/2=407kN

⇒ The tendons will not have sufficient anchorage at x=873mm.

Calculating the point where the tendons are sufficient anchored to carry the load:

Tension in reinforcement at x: S(x)=120kN×(x+75mm)/328mm+120kN/2

Force anchored in the tendons at x (if x<1711m): F(x)=7×120kN×0,9×x/1711mm

Hence:

$$120kN \times (x+75mm)/328mm + 120kN/2 = 756kN \times x/1711$$
$$0{,}366x + 87{,}4 = 0{,}442x$$
$$0{,}076x = 87{,}4$$
$$x = 87{,}4/0{,}076$$
$$x = 1150mm$$

⇒The horizontal part of the Ø12 anchoring bars has to be extended beyond the calculated required lap length (evaluated in clause 5), and end at x>=1150.

8) Reinforcement due to splitting stress:

A_s=0,22×P_{u1}/f_s

⇒A_s=0,22×7×120000N/300MPa

=616mm^2

To be located within: 0,5×(l_{lpt1}+h_1)=0,5×(1141mm+450mm)=796mm ≤ h_1=450mm ⇒450mm

Corresponds to: 616mm^2/0,450m=1369mm^2/m

9) Links:

a) Required shear reinforcement x<277:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{R_1}{z \times f_{ywd} \times \cot\theta} = \frac{181000N}{0{,}328m \times 435MPa \times \cot(45)} = 1269mm^2/m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)

b_w=227mm-50mm=177mm

z=328mm

υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492

θ=assume 45degrees

$$V_{Rd} = \frac{1{,}0 \times 177mm \times 328mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 364{,}2kN > R_1 \rightarrow OK$$

b) Required shear reinforcement 277<x<606:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{F_V}{z \times f_{ywd} \times \cot\theta} = \frac{120000N}{0{,}328m \times 435MPa \times \cot(45)} = 841mm^2 / m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)
b_w=227mm
z=328mm
υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492
θ= assume 45degrees

$$V_{Rd} = \frac{1{,}0 \times 227mm \times 328mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 467kN > F_v \rightarrow OK$$

DTF120 USED IN SPENNCON DT450

Summary – reinforcement in end of the DT:

X<≈450mm: Links due to splitting stresses (8)

$$\frac{A_s}{s} = 1369mm^2 / m$$

Select Ø8 stirrups c/c70 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}07m} = 1436mm^2 / m$$

≈450<X<≈606mm: Links due to shear force (9).

$$\frac{A_s}{s} = 841mm^2 / m$$

Select Ø8 stirrups c/c100

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}1m} = 1005mm^2 / m$$

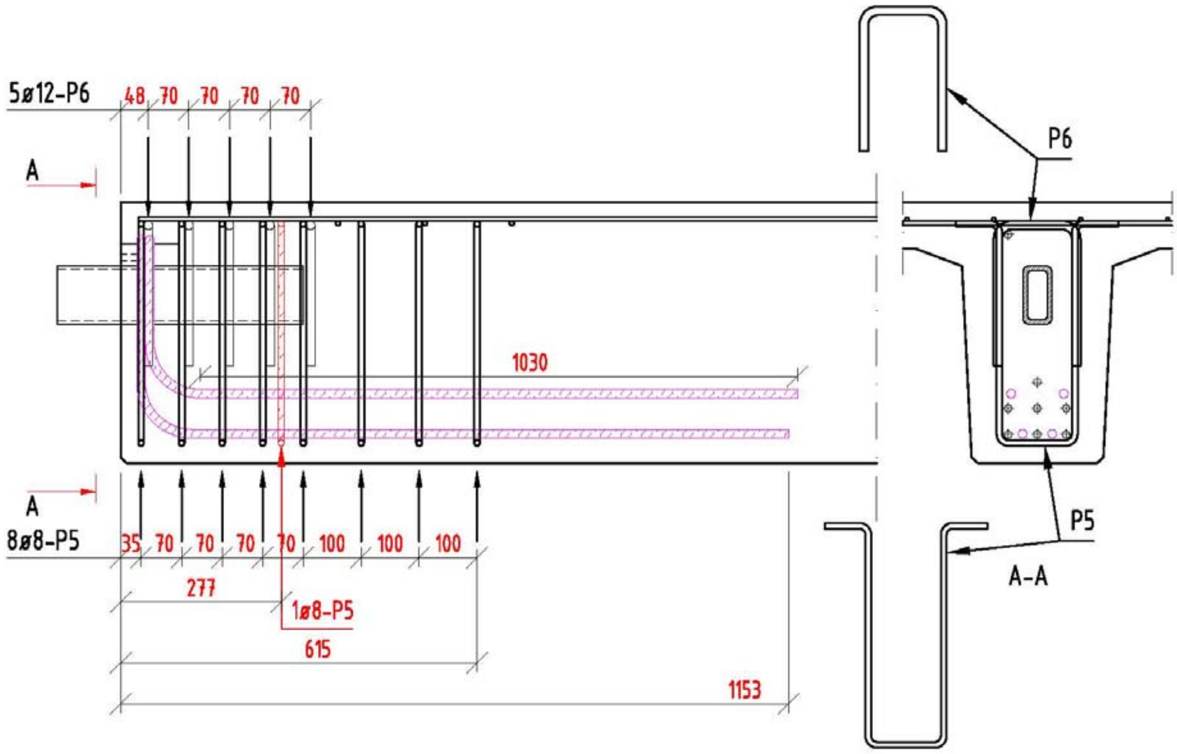
606<X: Required shear reinforcement to be evaluated according to shear force distribution in the DT.

At x=277mm:

Required reinforcement: 140mm^2 $\Rightarrow$1 extra Ø8 link (100mm^2) at this location. The remaining 40mm^2 can be carried by the specified distributed links.

DTF120 USED IN SPENNCON DT450

Suggested reinforcement in end of the DT:



DTF200 USED IN A HIGH DT

CONTENT

GENERAL

QUALITIES

Concrete C45/55:

f_{ck} = 45,0 MPa	EC2, Table 3.1
$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c$ = 0,85×45/1,5 = 25,5 MPa	EC2, Clause 3.15
$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c$ = 0,85×2,70/1,5 = 1,53 MPa	EC2, Clause 3.16
$f_{bd} = 2{,}25 \times \eta_1 \times \eta_2 \times f_{ctd}$ = 2,25×0,7×1,0×1,53 = 2,41 MPa	EC2, Clause 8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s$ = 500/1,15 = 435 MPa	EC2, Clause 3.2.7

Tendons:

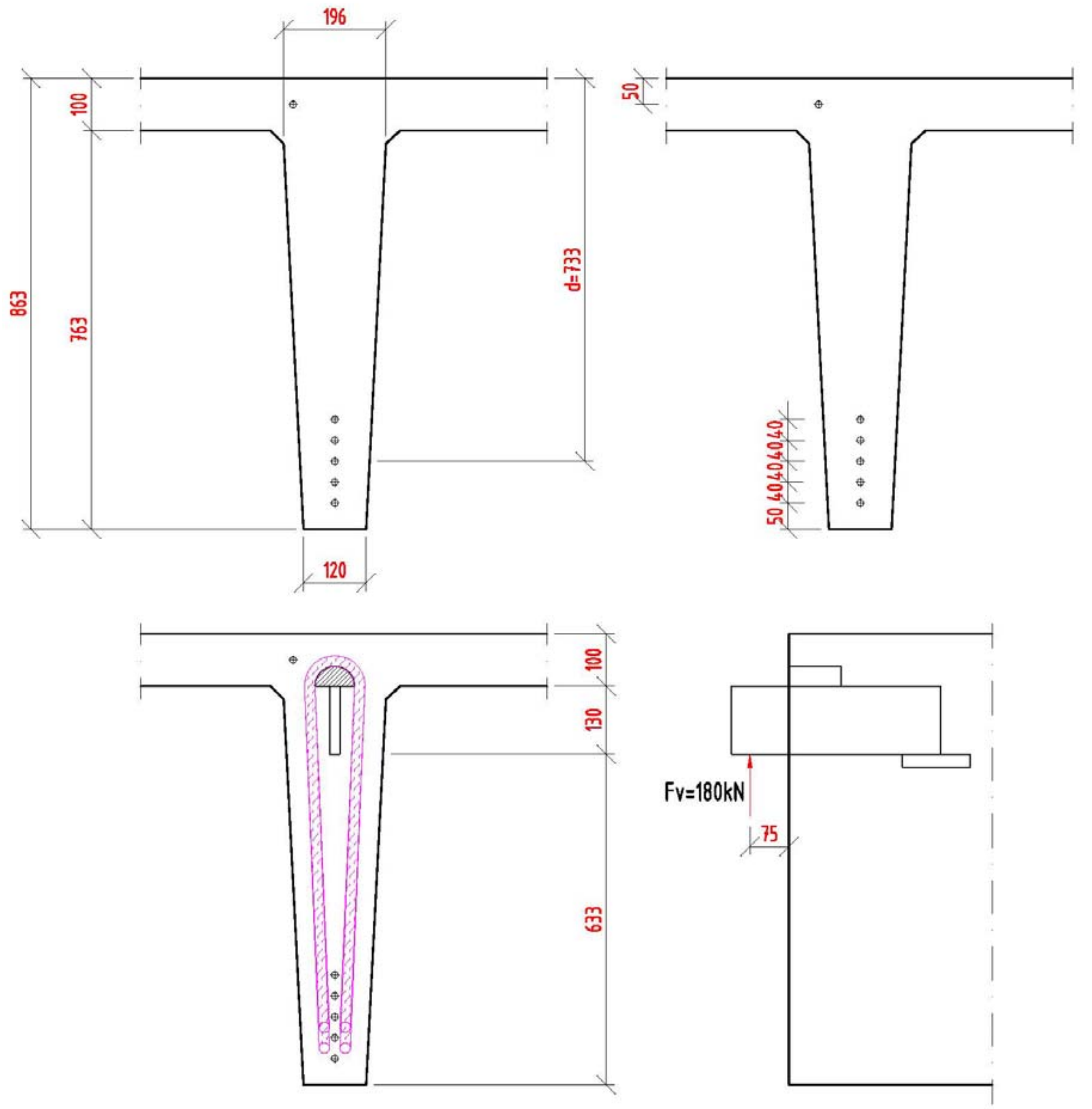
Diameter: Ø=12,7mm. (Nominal diameter. Real diameter=11,3mm)
Assumed tension after elastic loss: P=120kN.

LOAD

Design load F_v=180kN
(NB: The design load in the example is less than the ultimate limit load of the unit.)

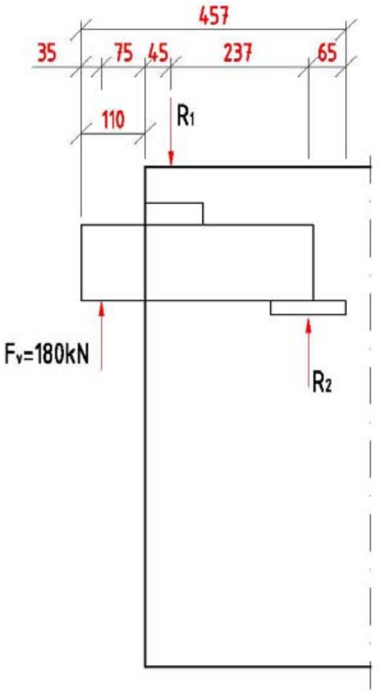
DTF200 USED IN A HIGH DT

GEOMETRY



CALCULATIONS

1) Equilibrium:



$$R_2 = \frac{F_V \times (75mm + 45mm)}{237mm} = \frac{180kN \times (75mm + 45mm)}{237mm} \approx 91kN$$

$$R_1 = F_v + R_2 = 180kN + 91kN = 271kN$$

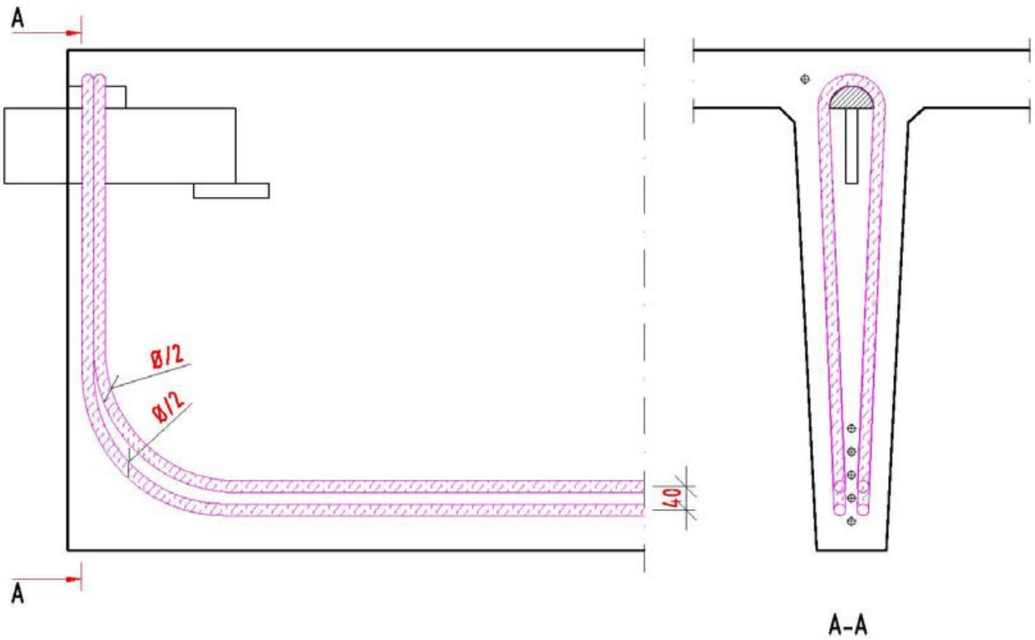
2) Reinforcement:

$$A_{R1} = \frac{271kN}{435MPa} = 623mm^2 \rightarrow 2ø16stirrups = 804mm^2$$

$$A_{R2} = \frac{91kN}{435mm} \approx 210mm^2$$

3) Bending of anchoring reinforcement:

Minimum mandrel diameter, $Ø_{m,min}$:



Allowable concrete stress in node, EC2, clause 6.5.2:

$$f_{cd2} = 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

$$= 0,6 \times (1 - \frac{45}{250}) \times 25,5$$

$$= 12,5 MPa$$

Actual concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times Ø_m \times \sin\theta \times \cos\theta}$$

b=120mm
$Ø_m$= Mandrel diameter of front reinforcement
θ=assume concrete strut in 45degrees.

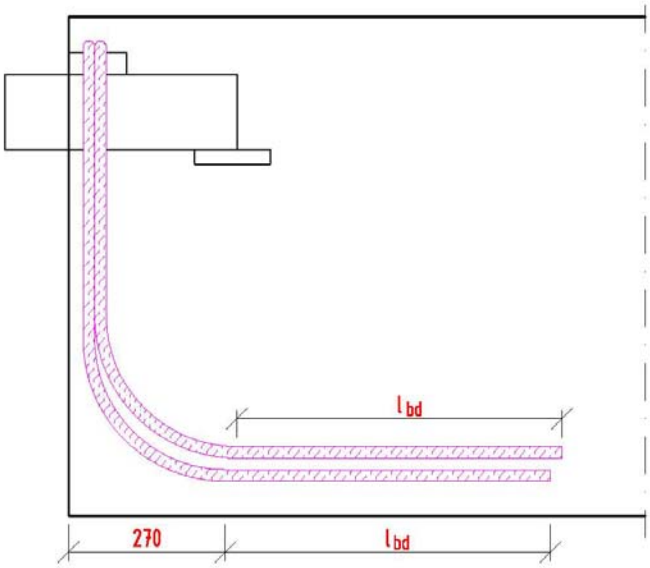
Solving for $Ø_m$:

$$Ø_m = \frac{R_1}{b \times \sigma_c \times \sin\theta \times \cos\theta}$$

$$\Rightarrow Ø_{m,\min} = \frac{271000N}{120mm \times 12,5MPa \times \sin(45) \times \cos(45)} = 361mm$$

⇒ Select mandrel diameter: $Ø_m$=450mm

4) Anchoring of Ø16 stirrups in front, EC2 clause 8.4.3 and 8.4.4:



$l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}$

$l_{b,reqd} = \dfrac{Ø}{4} \times \dfrac{\sigma_{sd}}{f_{bd}}$

Stress in stirrup: $\sigma_{sd} = \dfrac{271000/4}{\pi \times 8^2} = 337 MPa$

$l_{b,reqd} = \dfrac{16}{4} \times \dfrac{337}{2{,}41} = 560\text{mm}$

$l_{b,min} = \max(0{,}3 \times l_{b,reqd};\ 10 \times Ø;\ 100\text{mm}) = 168$ mm

Table 8.2: Straight bar:

$\alpha_1 = 1{,}0$

Table 8.2: Concrete cover:

$\alpha_2 = 1 - 0{,}15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $\alpha_2 = 1{,}0$

Table 8.2: Confinement by reinforcement:

$\alpha_3 = 1 - K \times \lambda$

Neglecting any positive effect of transverse reinforcement, selecting $\alpha_3 = 1{,}0$

Table 8.2: Confinement by welded transverse reinforcement:

$\alpha_4 = 1{,}0$

Not relevant.

Table 8.2: Confinement by transverse pressure:

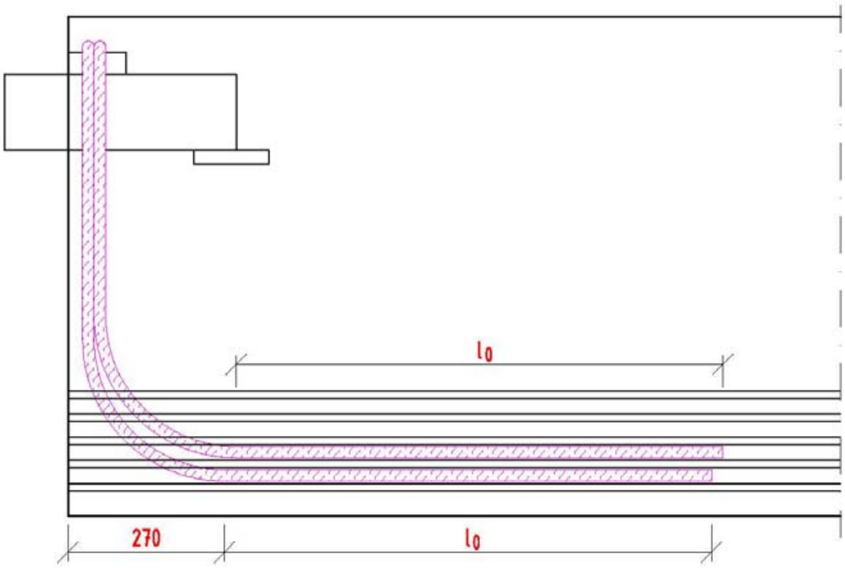
$\alpha_5 = 1{,}0$

Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5 = 1{,}0 \times 1{,}0 \times 1{,}0 = 1{,}0 > 0{,}7$ – OK

$l_{bd} = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 560\text{mm} = 560$ mm

5) Lap of Ø16 stirrups, EC2 clause 8.7.3:



$l_0 = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_5 \times \alpha_6 \times l_{b,reqd} \geq l_{0,min}$

Required lap length, Ø16:

$$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{16}{4} \times \frac{337}{2,41} = 560\text{mm}$$

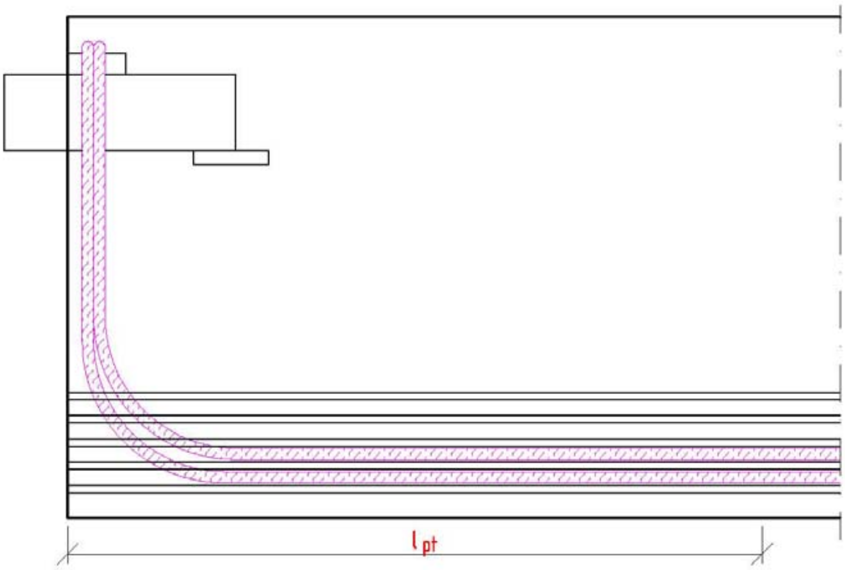
$l_{0,min}$ = max(0,3×α_6×$l_{b,reqd}$; 15×Ø; 200mm)=251mm

Table 8.2: α_1,α_2,α_3,og α_5=1,0 as calculated in clause 2).

Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0$ = 1,0×1,0×1,0×1,0×1,5×560mm= 840mm

6) Transmission length – tendons, EC2 clause 8.10.2.2:



Bond stress:

$f_{bpt}=\eta_{p1}\times\eta_1\times f_{ctd}(t)$

$\eta_{p1}=3{,}2$ (assume 3 or7-wire tendons)

$\eta_1=1{,}0$ (assume "good bond conditions")

$f_{ctd}(t) = \alpha_{ct}\times 0{,}7\times f_{ctm}(t)/\gamma_c$

$\alpha_{ct}=0{,}85$

$f_{ctm}(t)=(\beta_{cc}(t))^{\alpha}\times f_{ctm}$

$\beta_{cc}(t)=\exp(s(1-28/t)^{1/2})$

Assume: Release after t= 1day

Assume: s=0,2

$\Rightarrow\beta_{cc}(t)=\exp[0{,}2\times\{1-(28/1)^{1/2}\}]=0{,}423$

$\alpha=1$ (t<28days)

$f_{ctm}=3{,}8\text{MPa}$

$\Rightarrow f_{ctm}(t)=0{,}423^1\times 3{,}8\text{MPa}=1{,}60\text{MPa}$

$f_{ctd}(t) = 0{,}85\times 0{,}7\times 1{,}60\text{MPa}/1{,}5=0{,}635\text{MPa}$

$\Rightarrow f_{bpt}=3{,}2\times 1{,}0\times 0{,}635\text{MPa}=2{,}03\text{MPa}$

Transmission length:

$l_{pt}=\alpha_1\times\alpha_2\times\varnothing\times\sigma_{pmo}/ f_{bpt}$

$\alpha_1=1{,}0$ (assume gradual release)

$\alpha_2=0{,}19$ (assume 3 or7-wire tendons)

$\varnothing=12{,}7\text{mm}$ (Nominal diameter of tendon. Real diameter=11,3mm)

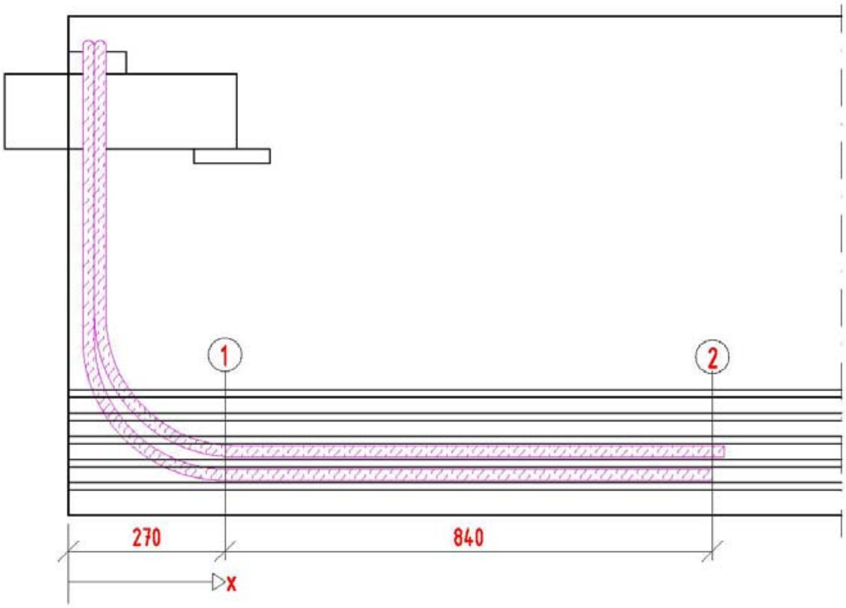
$\sigma_{pmo}= 1200\text{MPa}$

$\Rightarrow l_{pt}=1{,}0\times 0{,}19\times 12{,}7\text{mm}\times 1200\text{MPa}/2{,}03\text{MPa}=1426\text{mm}$

$\Rightarrow l_{pt1}=0{,}8\times l_{pt} =0{,}8\times 1426\text{mm}=1141\text{mm}$. To be used in evaluation of local cross section stresses.

$\Rightarrow l_{pt2}=1{,}2\times l_{pt} =1{,}2\times 1426\text{mm}=1711\text{mm}$. To be used in evaluation of anchorage. Stress after all losses assumed as $0{,}9\sigma_{pmo}$. (10% loss)

7) Anchoring:



Assuming the horizontal part of the front anchoring bar is 840mm (≈ equals the minimum calculated lap length). I.e. the bar ends at x=270+840=1110mm.

Section 1:
Force anchored in the tendons (5 tendons) at x=270mm:
Assume 10% loss of pre-stressing force:
F_{sp1}=5×P ×0,9×270mm/1711mm=5×120kN×0,9×270mm/1711mm=85kN
Force anchored in Ø16:
$F_{Ø16}$=271kN
Total anchored force:
F=F_{sp1}+$F_{Ø16}$=85kN+271=356kN
Tension in reinforcement at x=270mm: (clause 6.2.3(7))
S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))
=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90)) (assume 45degrees concrete struts and vertical links)
= M(x)/z+0,5×V_{Ed}× (1-0)
= M(x)/z+0,5×V_{Ed}
Moment at x=270:
M (x=270)=180kN×(270+75)mm=62,1kNm
Assume z=0,9d=0,9×733mm=660mm (approximately)
S (x=270)=62,1kNm/0,660m+271kN/2=230kN

⇒ The anchoring at x=270mm is sufficient.

DTF200 USED IN A HIGH DT

Section 2:

Force anchored in the tendons (5 tendons) at x=1110mm:

F_{sp1}=5×P ×0,9×1205mm/1711mm=5×120kN×0,9×1110mm/1711mm=350kN

Force anchored in Ø16:

$F_{Ø16}$=0kN

Total anchored force:

F=F_{sp1}+$F_{Ø16}$=350kN+0kN=350kN

Tension in reinforcement at x=1110mm: (clause 6.2.3(7))

S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))

=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90)) (assume 45degrees concrete struts and vertical links)

= M(x)/z+0,5×V_{Ed}× (1-0)

= M(x)/z+0,5×V_{Ed}

Moment at x=1110:

M (x=1110)=180kN×(1110+75)mm=213,3kNm

Assume z=0,9d=0,9×733mm=660mm (approximately)

S (x=1110)=213,3kNm/0,660m+180kN/2=413kN

⇒ The tendons will not have sufficient anchorage at x=1110mm.

Calculating the point where the tendons are sufficient anchored to carry the load:

Tension in reinforcement at x: S(x)=180kN×(x+75mm)/660mm+180kN/2

Force anchored in the tendons at x:

If x<1711m: F(x)=5×120kN×0,9×x/1711mm

If x>1711m: F(x)=5×120kN×0,9+$\Delta\sigma_{sp}$(x)×A_{sp}×5

$\Delta\sigma_{sp}(x)=f_{bpd}/(\alpha_2 \times Ø) \times (x-1711) \times 10^{-3}$

⇒F(x)= 5×120kN×0,9+$f_{bpd}/(\alpha_2 \times Ø) \times (x-1711) \times 10^{-3} \times A_{sp} \times 5$

⇒F(x)= 540kN+2,03MPa/(0,19×12,7) × (x-1711) ×10^{-3}×100mm^2×5

⇒F(x)= 540+0,420x-720=0,420x-180

Try if x<1711:

$$180kN \times (x + 75mm) / 660mm + 180kN / 2 = 540kN \times x / 1711$$

$$0{,}273x + 110{,}5 = 0{,}316x$$

$$0{,}043x = 110{,}5$$

$$x = 110{,}5 / 0{,}043$$

$$x = 2570mm$$

Calculated x>1711 ⇒ the second expression shall be used:

$$180kN \times (x + 75mm) / 660mm + 180kN / 2 = 0{,}420x - 180$$

$$0{,}273x + 110{,}5 = 0{,}420x - 180$$

$$0{,}147x = 290{,}5$$

$$x = 290{,}5 / 0{,}147$$

$$x = 1976mm$$

⇒The horizontal part of the Ø16 anchoring bars has to be extended beyond the calculated required lap length (evaluated in clause 5), and end at x>=1976.

8) Reinforcement due to splitting stress:

$A_s=0,22\times P_{u1}/f_s$

$\Rightarrow A_s=0,22\times 5\times 120000N/300MPa$

$=440mm^2$

To be located within: $0,5\times(l_{lpt1}+h_1)=0,5\times(1141mm+863mm)=1002mm \leq h_1=863mm \Rightarrow 863mm$

Corresponds to: $440mm^2/0,863m=510mm^2/m$

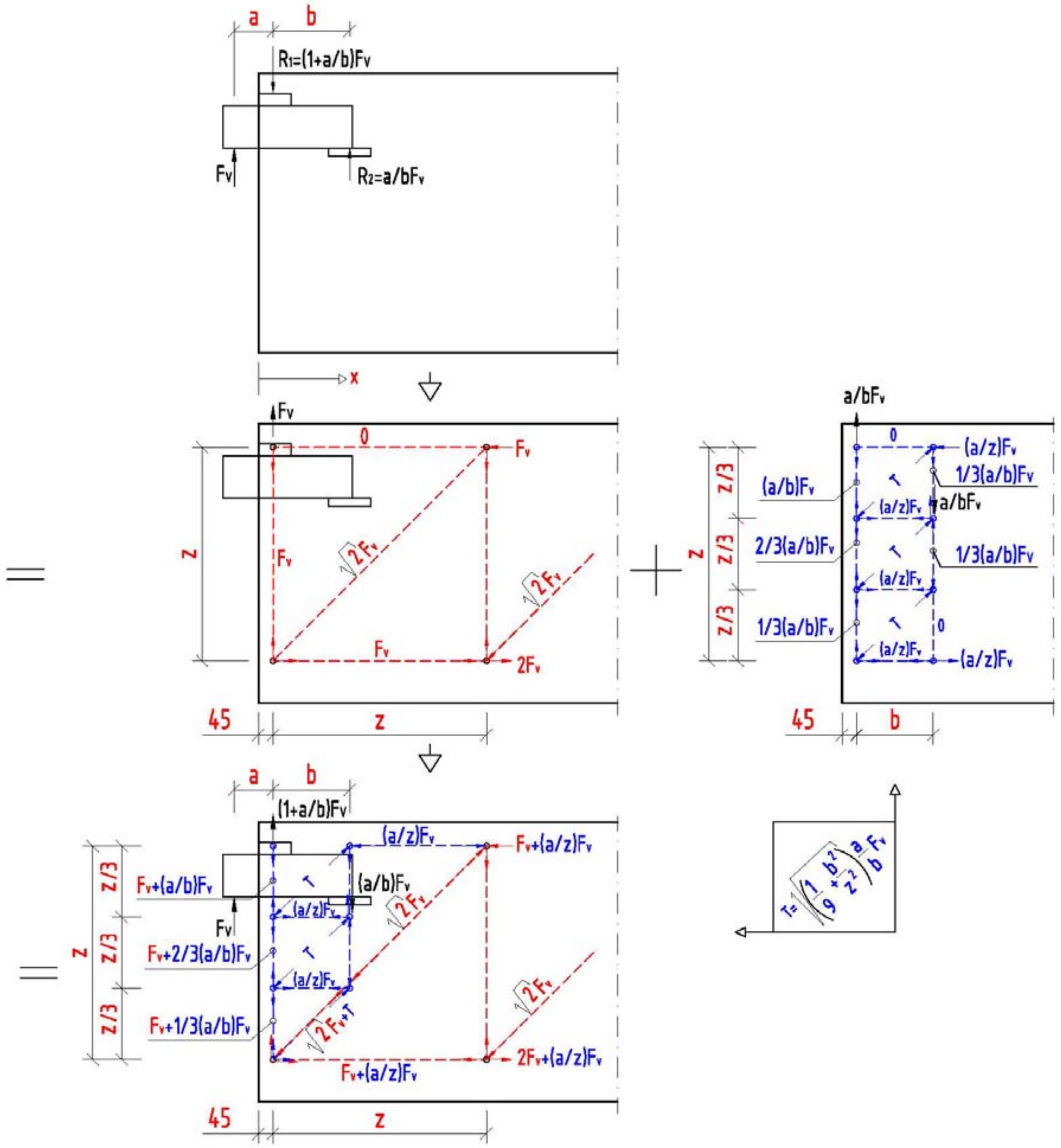
9) Links/strut and tie model:

For this particular DT, the height z is approximately equal to 3xb. Hence, the bending moment from the cantilevering may be assumed transferred to the main reinforcement of the beam through a local truss with three levels. This is illustrated as a blue truss in the end of the DT, see below Figure. The compression struts in this truss will be angled in approximately 45 degrees.

The support reaction force/shear force itself may be carried by a truss with a height equal to z. This is illustrated as a red truss.

The two trusses are both in equilibrium, and the forces may be superimposed.

DTF200 USED IN A HIGH DT



Evaluation of local strut and tie model:

- The model implies that only 1/3 of the force R_2 have to be carried by the vertical link at back of the unit. Nevertheless, it is chosen to calculate the required extra reinforcement at this point based on the value of R_2. (conservative assumption)

- Considering the two horizontal ties towards the end of the DT as smeared, the horizontal force per unit height of the DT becomes: $(a/z)\times F_v/(z/3)$. Where $z/3 \approx b$, hence this corresponds to: $(a/z)\times F_v/b=(a/b)\times F_v/z=R_2/z$. $\Rightarrow$ Prescribe horizontal bars anchoring this force.

DTF200 USED IN A HIGH DT

a) Required shear reinforcement x<45+b:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{R_1}{z \times f_{ywd} \times \cot\theta} = \frac{271000\,N}{0{,}660m \times 435MPa \times \cot(45)} = 944mm^2/m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)
b_w=120mm
z=660mm
υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492
θ=assume 45grader

$$V_{Rd} = \frac{1{,}0 \times 120mm \times 660mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 497kN > R_1 \rightarrow OK$$

b) Required shear reinforcement 45+b<x<45+z:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{F_V}{z \times f_{ywd} \times \cot\theta} = \frac{180000\,N}{0{,}660m \times 435MPa \times \cot(45)} = 627mm^2/m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)
b_w=120mm
z=660mm
υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492
θ=assume 45grader

$$V_{Rd} = \frac{1{,}0 \times 120mm \times 660mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 497kN > F_v \rightarrow OK$$

c) Horizontal stirrups at the end of the DT:

$$\frac{A_s}{s} = \frac{R_2}{z \times f_{ywd}} = \frac{91000\,N}{0{,}660m \times 435MPa} = 317mm^2/m$$

Amount of reinforcement below the unit:

$$A_s = 317mm^2/m \times 2/3z = 317mm^2/m \times 2/3 \times 0{,}66m = 140mm^2$$

⇒2 x U-shaped Ø8 bars (A_s=200mm^2).

DTF200 USED IN A HIGH DT

Summary – reinforcement in end of the DT:

The required amount of reinforcement due to splitting stresses is less than the required amount of shear reinforcement calculated in 9a and 9b.

⇒ X<≈282mm: Links due to shear force (9a)

$$\frac{A_s}{s} = 944mm^2 / m$$

Select Ø8 stirrups c/c75 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0,075m} = 1340mm^2 / m$$

⇒ 282<X<≈705mm: Links due to shear force (9b)

$$\frac{A_s}{s} = 627mm^2 / m$$

Select Ø8 stirrups c/c150 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0,150m} = 670mm^2 / m$$

705<X: Required shear reinforcement to be evaluated according to shear force distribution in the DT.

At X=282:

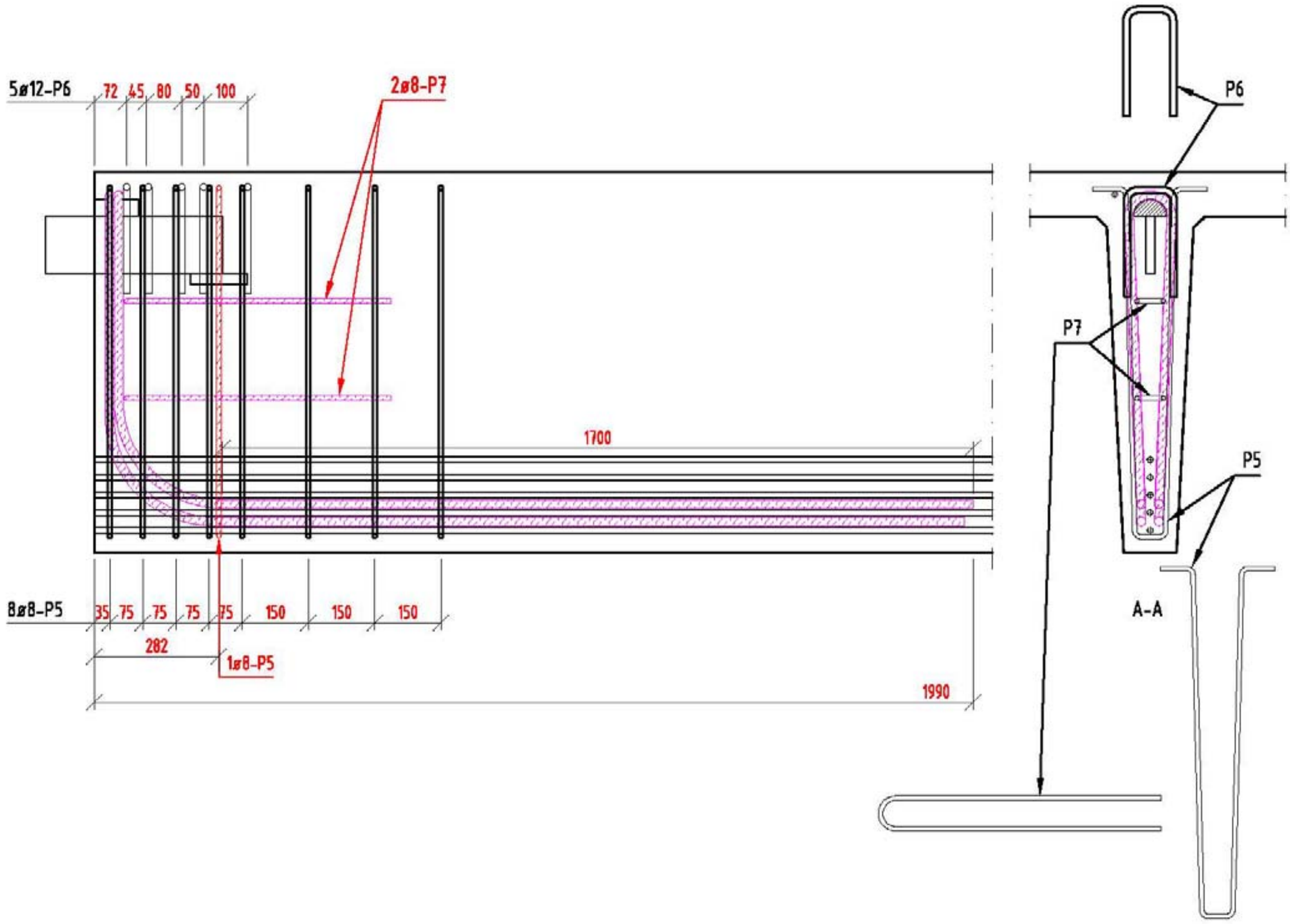
Required reinforcement: 210mm^2. ⇒ 1 extra Ø8 (100mm^2) at this location. The remaining 110mm^2 can be carried by the specified distributed links.

Anchoring (7):

⇒ Horizontal part of Ø16 anchoring bars in front =1700mm. (Ends at x>1976mm)

DTF200 USED IN A HIGH DT

Suggested reinforcement in end of the DT:



Annex 5 Assembling of the DTS unit and fire protection of the joint

The DTS elements must hang horizontally in the lifting device during installation. When the beam is in the correct position, the shooter units are pulled out by attached strings into the recesses in the supporting element, see figure A5-1. The beam is then lowered carefully to the supported position, making sure that the units have the correct extension. Generally, before releasing the lifting device the joint width shall be checked. Normal joint width is 15 - 20 mm.

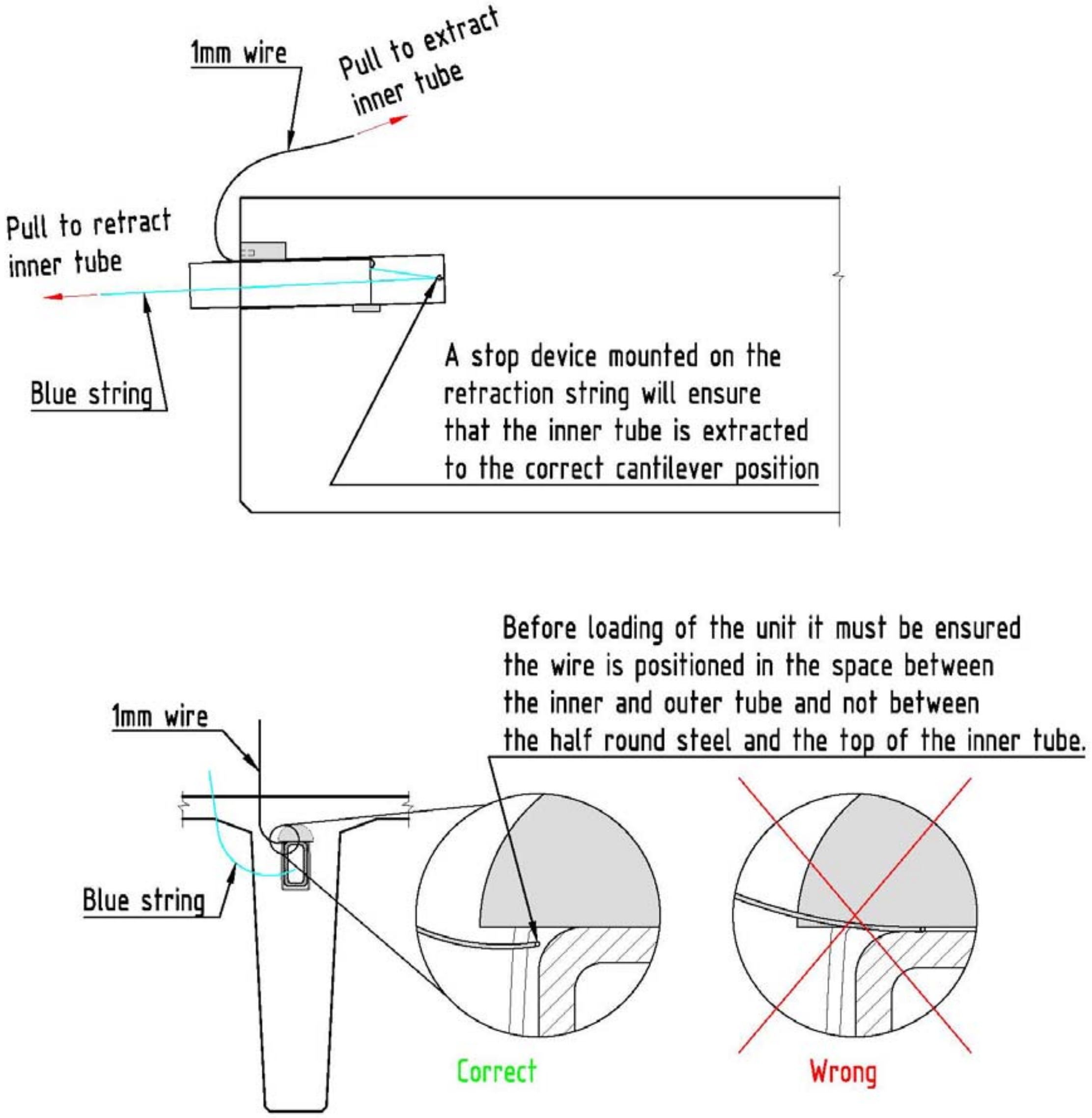


Figure A5-1

Assembling of the shooter unit, DTS.

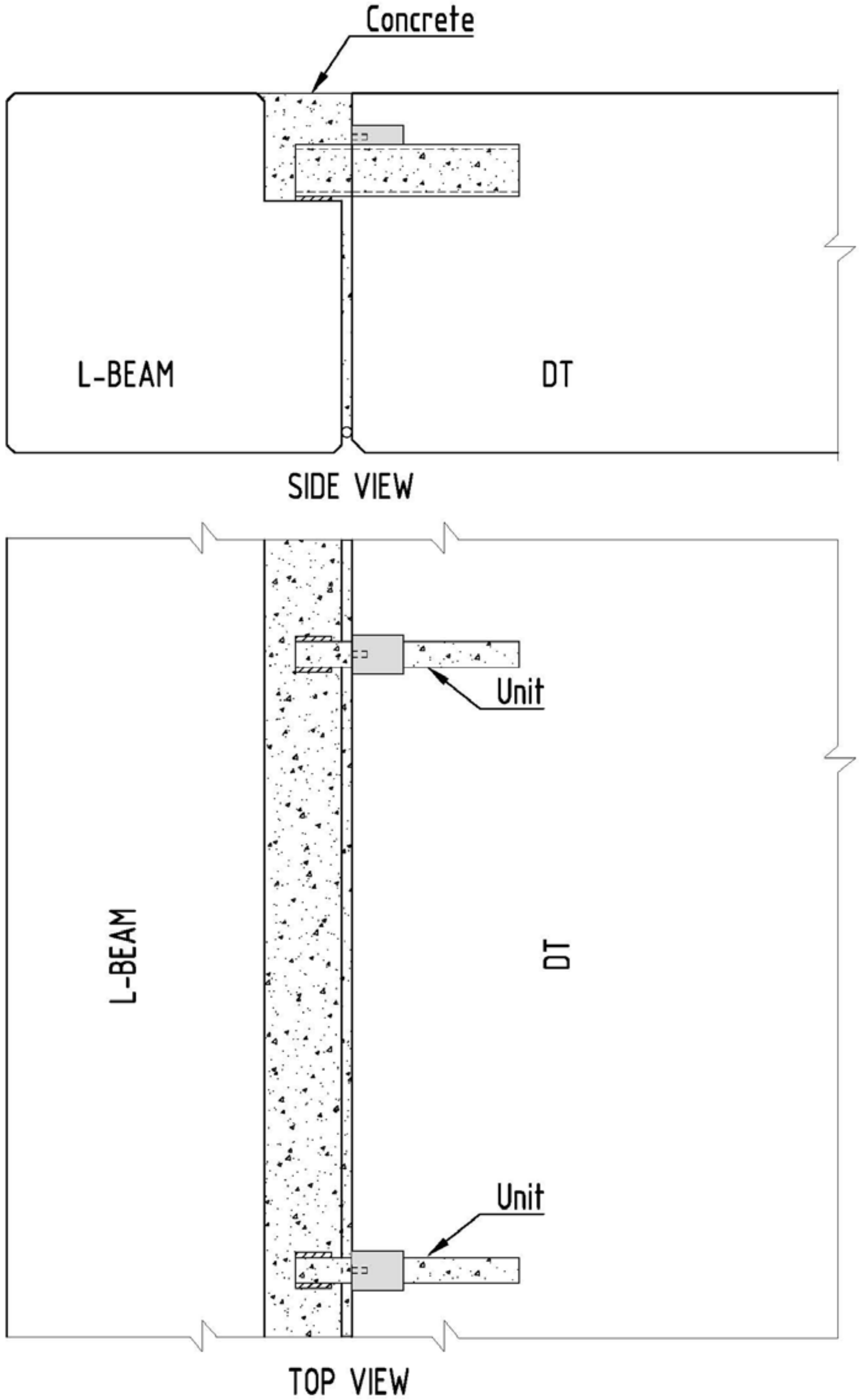


Figure A5-2a

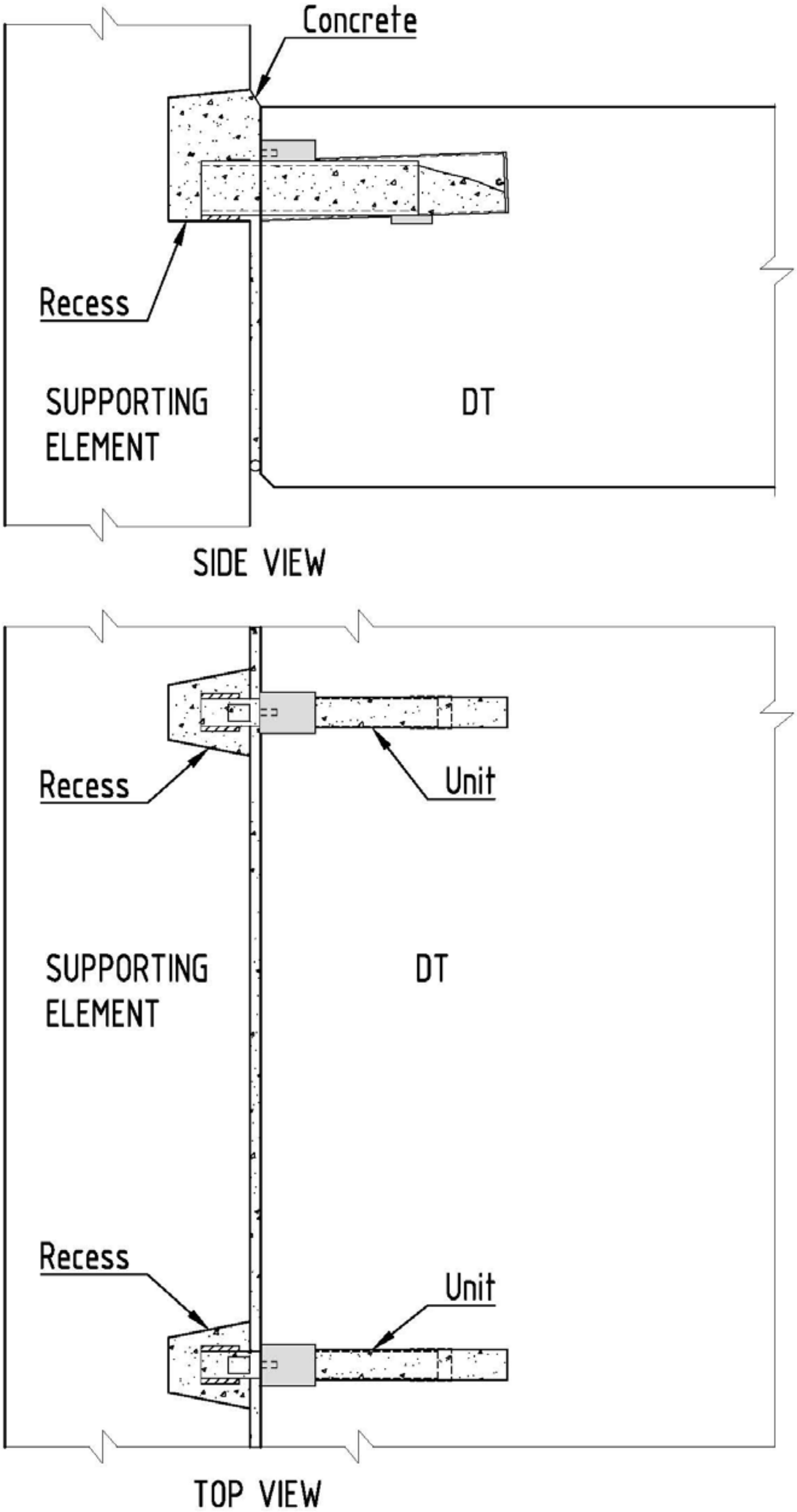


Figure A5-2b

Fire protection of a) DTF and b) DTS: The joint between the DT-element and support is filled with a low shrinkage quick setting concrete based mortar.