VSL – A REPUTATION FOR EXCELLENCE SINCE 1956

The VSL culture

VSL’s aim is always to offer not only the best post-tensioning solutions but also innovative construction techniques, designed to increase site safety, save time, improve durability and reduce costs.

VSL likes to work in partnership with clients right from the conceptual stage and is always keen for our design and methods engineers to work closely with their estimating teams during the tender stage.

The group’s main strength is the quality of its highly experienced, multicultural staff. VSL’s technical sales personnel are dedicated to listening to - and understanding - our clients’ needs and preparing customised solutions for their projects.

VSL’s ultimate goal is to deliver the best quality of service to our clients, including best-quality construction techniques, backed by our experience and the expertise of well-trained specialists in design, methods and construction.

VSL attracts the most talented and motivated people, all with one goal: to be your most valued construction partner.

VSL – guided by a strong QSE culture

VSL’s leading position is based on a rigorous and committed quality culture. Adherence to our QSE (quality, safety, environment) policy is VSL’s first priority. Local teams ensure co-ordination of actions, encourage sharing of experience and promote best practice, with the aim of continuously improving performance. In VSL’s culture, employees are vitally important to the competitiveness and prosperity of the company.

VSL’s company management system is certified to the following QSE standards:

- ISO 9001: Quality management
- ISO 14001: Environmental management
- OHSAS 18001: Health and safety management

KEY BENEFITS OF POST-TENSIONING

Some of the recognised advantages of post-tensioning are:

- Flexibility in design – post-tensioning allows greater flexibility in the design and fulfillment of demanding architectural requirements. Longer spans of floors create large spaces in buildings and offer significant flexibility and comfort to users.
- Shorter construction periods – post-tensioning enables fast cycle times for formwork and a reduced need for back-propping because of the load balancing produced by the tendons.
- Durability – the implementation of post-tensioning leads to increased crack control and delivers long-term durability of a structure.
- Reduced environmental impact due to a reduction in construction materials

Post-tensioning allows structural members to be more slender and brings reductions in the quantities of concrete and reinforcing steel required for the superstructure and the substructure. Using fewer construction materials creates fewer carbon emissions, reducing the carbon footprint of the structure.
- Economy – the shorter construction periods together with a reduction in construction materials optimise the construction costs, while the increased durability has a beneficial effect on the whole-life costs.

VSL – HISTORY OF THE GROUP

1956 - First use of VSL wire post-tensioning system
1966 - Introduction of the VSL Multistrand post-tensioning system, which can be stressed with centre hole jacks
1985 - World’s first electrically isolated Ground anchors installed by VSL (Stadelhofen Railway Station, Zürich, Switzerland)
1988 - Development of the VSL PT-PLUS® duct system
1990 - VSL is acquired and integrated into Bouygues Construction, a subsidiary of the Bouygues Group, one of the world’s leaders in the building, civils work and maintenance sectors
1993 - Integration of the Spanish company CTT Stronghold S.A. into the VSL Group
2008 - Foundation of the VSL Academy, the world’s first post-tensioning training centre
2009 - World premiere of the combined use of prefabricated segment construction together with electrically isolated post-tensioning tendons, carried out by VSL at the Lect Vladiuct, Geneva, Switzerland
2013 - Introduction of the new VSLab system
VSL – PROVIDING STATE-OF-THE-ART POST-TENSIONING SYSTEMS

The combination of certified state-of-the-art post-tensioning systems and highly qualified staff, associated with a strong R&D culture and specialised engineering support, provides the basis for VSL’s position as an innovative market leader.

TRAINING: AT THE HEART OF STRONG PERFORMANCE

VSL Academy – world’s first post-tensioning academy

In 2008, VSL launched the VSL Academy, an innovation in the field of post-tensioning. The aim of the VSL Academy is to strengthen the company culture and to develop knowledge-sharing by formalising and standardising the training of all post-tensioning foremen, supervisors and site engineers.

The VSL Academy provides a unique facility and resource within VSL, with hands-on practical training on post-tensioning mock-ups designed to cover all operational procedures and to train our personnel in the skills and techniques required to perform to the highest standards specified today. In addition, it harmonises working procedures and enhances knowledge.

INTERNATIONAL POST-TENSIONING CERTIFICATION

Post-tensioning systems for use in the European Community are required to have European Technical Approval (ETA), which is based on a set of defined testing procedures that must be fulfilled. Once the post-tensioning systems are put on the market, they are subjected to factory production control as well as independent and continuous monitoring. Post-tensioning systems must be installed by trained post-tensioning specialist companies, ensuring a professional installation that conforms to the system’s requirements.

Typical testing provisions

ETAG 013 – ‘Guideline for European Technical Approval of Post-Tensioning Systems’ (ETAG 013) – describes the full-scale tests the post-tensioning systems has to undergo. The basic testing provisions include the following:

- Static tensile tests for each anchorage and coupler type
- Fatigue tests for each anchorage and coupler type
- Load transfer tests for each anchorage type and concrete strength

Additional mandatory tests are described in ETAG 013, such as assembly and grouting tests as well as a whole range of tests for special applications, including cable tests for external post-tensioning and cryogenic conditions.

Factory production under controlled conditions

ETAG 013 specifies the minimum production control frequencies that have to be implemented. The complete factory production process, including compliance with these requirements, is fully audited by the Approved/Notified body and any non-conformity must be resolved prior to certification. The timings of the checks are as follows:

- The ETA holder and the manufacturer are audited every year
- Each component manufacturer is audited every five years by the ETA
- All components are selected on site annually for independent testing and checking of their properties

These provisions guarantee proper quality and compliance of the system components delivered to site.

An international passport ensuring the highest standards

The CE marking and the European Technical Approval create an international passport for post-tensioning systems. CE-marked post-tensioning systems installed by certified, professional specialist post-tensioning companies provide the highest level of quality. This gives assurance to the owners of the structures in which the post-tensioning is used that only high-quality and state-of-the-art products are being installed and that the required level of safety is being met.

R&D: THE KEY TO QUALITY AND DURABILITY

Research and development activity is VSL’s driving force. The issues of GSE and sustainability have long been priorities, together with the efficiency of construction methods and site works. In the case of post-tensioning products and services, it is also important to focus on durability, monitoring and inspection as well as competence in design and methods.

The key issue of durability is reflected in the conception, the working procedures and the design of VSL’s post-tensioning systems. Among other factors, durability is principally achieved by:

- High quality standards
- The combination of internationally certified state-of-the-art post-tensioning systems and qualified staff for installation ensures the high quality standard of the VSL post-tensioning systems.

Proven system components

The VSL post-tensioning systems feature the VSL PT-PLUS® duct system, which provides a leak-tight encapsulation of the tendon and increased fatigue resistance.

The implementation of VSL’s electrically isolated tendons (EIT) allows monitoring of the corrosion-protective encapsulation. The same principle had its initial success with another VSL world-first, the use of electrically isolated ground anchors in 1965.

Sustainable construction

The enhanced durability of VSL post-tensioning systems contributes to the sustainable construction of buildings and bridges.

Optimisation of the structure by implementing VSL’s post-tensioning systems reduces the volume of materials required - both concrete and passive reinforcement – and in consequence leads to a reduction in the carbon footprint of the structure.

ENGINEERING SUPPORT

The VSL Network - a global team of experts

With offices throughout the world, VSL offers a comprehensive and global range of professional, high-quality services for all kinds of projects, from feasibility studies and preliminary designs to alternative proposals, contractor consultancy services and permanent works design. All are aimed at finding the best possible solutions with the best value for money. VSL always seeks to provide fully customised approaches adapted to each client’s requirements.

Its worldwide network allows VSL to offer a high degree of expertise and flexibility, working in a spirit of co-operation to identify the most appropriate solutions. VSL’s goal is to be the first-choice partner for owners, engineers and contractors.

Each project presents unique challenges and, in recognition of this, members of VSL’s technical staff work with contractors, owners and engineers to evaluate schemes and determine optimal solutions.

VSL’s Technical Centres in Asia (Singapore, Bangkok, Chennai) and Europe (Switzerland and Spain) provide support for the group around the world. Customers benefit greatly from the continuing development of VSL’s special construction methods and from the exchange of information that takes place across the whole VSL Network.

VSL experts provide strong support and participation in the industry, in professional organisations and on committees as those of AB (Fédération internationale du béton) and PTI (Post-Tensioning Institute). In addition, VSL is involved in the preparation of new standards, guidelines and recommendations.

RESEARCH AND DEVELOPMENT HIGHLIGHTS

VSL PT-PLUS® duct segmental coupler

The VSL PT-PLUS® duct segmental coupler was developed in 2007 and is used for internal prestressing in match-cast precast segmental structures to optimise the encapsulation at segment joints. It consists of a base-seal ring that is compressed during the joining of segments against well-defined bearing surfaces on both segments.

The VSL PT-PLUS® duct segmental coupler has the following design features:

- Complete encapsulation of the post-tensioning tendons across segment joints
- Enables implementation of electrically isolated tendons in precast segmental structures
- Compact and similar in size to standard ducting
- Can be used when tendons cross the segment joint at an angle
- Testing for cryogenic applications

The construction of tanks for LNG and LPG (liquefied natural and petroleum gas) requires cryogenic testing of the post-tensioning tendons. During these tests, strands and anchorage are subjected to temperatures down to -196°C and are tested in accordance with ETAG 013 or other international standards.

Through its long experience and proven technology, VSL is in a position to supply post-tensioning systems for use on any LNG or LPG project worldwide.
**DURABILITY OF POST-TENSIONING TENDONS**

The importance of the design concept

The durability of post-tensioned tendons naturally depends on the durability of the materials used such as the surrounding concrete, prestressing steels, anchorages, ducts and filling materials (e.g. cement grout) and the installation of these materials. But there are design concept specifics that are also of major importance: in particular the post-tensioning layout, the layers of protection such as the concrete cover and the selection of materials in relation to the aggressive nature of the environment.

Decisions regarding the design concept, made during the conceptual design stage, have the largest influence on the durability of post-tensioned tendons. VSL is well qualified to assist engineers when post-tensioning strategies and measures are being evaluated and chosen.

**Protection levels of tendons**

The 6th (Fédération internationale du béton / International Federation for Structural Concrete) Bulletin 33 defines three different protection levels (PL) for post-tensioning tendons:

**PL 1:** A duct with a filling material providing durable corrosion protection

PL 1 is the standard protection level for internal tendons, where the tendon is placed in a corrugated steel duct and protected with VSL-HPI grout.

**PL 2:** PL 1 plus an envelope, enclosing the tensile element bundle over its full length and providing a permanent leak-tight barrier

For internal tendons, PL 2 is an enhanced protection level, using VSL PT-PLUS® ducts, which provide a leak-tight encapsulation of the tendon - which is further protected with VSL-HPI grout. This is the standard configuration for replaceable external tendons, since they lack the additional corrosion barrier of surrounding concrete that internal tendons have.

VSL unbonded monostand tendons feature PL 2, as they provide a strand with sheathing (HDPE) and a filling material (grease) as well as encapsulation of the anchorage zone.

PL 3:

- PL 2 plus the integrity of the tendon or encapsulation to be monitored at any time
- PL 3 is the protection level that allows monitoring of the integrity of the encapsulation. The VSL Electrical Isolated Tendon (EIT) system together with VSL PT-PLUS® ducts and VSL-HPI grout is a well-proven solution that provides an elevated protection level, PL 3, and also includes protection against stray-current corrosion.

**Notes:**
1. For all three protection levels the integrity of the filling material is the key factor for ensuring durability.
2. Only for external tendons.
3. The PT-PLUS® duct may be used for protection level PL 1 thanks to its reduced friction coefficient and its enhanced fatigue resistance.

**Choosing the appropriate protection level**

Resistance against the aggressive nature of the environment and the particular exposure conditions of the structural element results from a combination of the protection level (PL) provided to the post-tensioning tendons and the protection layers provided to the structure. In consequence, the PL of the post-tensioning tendons has to be selected based on assessment of these factors.

**The VSL STRAND POST-TENSIONING SYSTEMS - SOLUTIONS FOR ANY APPLICATION**

VSL post-tensioning technology includes several systems that are specifically designed for different applications and different requirements. The following table gives an overview of the systems and their main fields of application, which are further expanded in this brochure.

The choice of a suitable system can be made by considering the following criteria:

1. **Type of structural element**
   - The depth of the structural element influences the type of system to be used:
     - Multistrand tendons are generally used for structural elements with medium to large depths (e.g. bridges or beams)
     - Slab tendons with flat ducts are generally used for thin structural elements (e.g. slabs)

2. **Structural design**
   - Taking account of structural design requirements
     - An internal or external post-tensioning system - or a combination of both - is adopted for multistrand tendons
     - For slab tendons, a bonded or unbonded post-tensioning system may be chosen

3. **Required protection level**
   - The tendon encapsulation is chosen depending on the required protection level (PL).

<table>
<thead>
<tr>
<th>Protection Level</th>
<th>PL 1</th>
<th>PL 2</th>
<th>PL 3</th>
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</thead>
<tbody>
<tr>
<td>External Bonded</td>
<td></td>
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<tr>
<td>External Unbonded</td>
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<tr>
<td>Internal Bonded</td>
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<td></td>
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</tr>
<tr>
<td>Internal Unbonded</td>
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</table>

Notes:
* All anchorages use 0.6” strand, except the Sc anchorage, which uses 0.5” strand. The E, H and P anchorage may be used with 0.6” or 0.5” strand. Whenever possible 0.6” and not 0.5” strand should be used, as it is more economical.

1. Internal unbonded slabs tendons are detailed with protection level PL 2, in order to provide a permanent encapsulation for the grease.
2. For special applications, E, K and L anchorages are available with protection level PL 3.
3. For strengthening works and special applications, the VSL E anchorage may be used for external tendons.
4. Specific consideration needs to be given to structural redundancy when using internal unbonded tendons for the prestressing of slabs. Fire may result in localised loss of the tendon’s cross-section, or future modifications/additions to the slabs may interfere with the tendons.
VSL BONDED AND UNBONDED SLAB POST-TENSIONING SYSTEM

VSL MONOSTRAND UNBONDED SLAB POST-TENSIONING SYSTEM

The VSL Monostrand unbonded slab post-tensioning system uses 0.6" strands, which are given a coating of permanent corrosion-preventing grease and are enclosed in extruded plastic sheathing. The grease and plastic provide double corrosion protection, and prevent any bonding between the strands and the surrounding concrete. The monostrands are installed either singly or in bundles of up to four strands, assembled in a row next to each other. Each strand is individually anchored, stressed and locked-off.

VSL BONDED SLAB POST-TENSIONING SYSTEM

The VSL bonded post-tensioning slab system has been used in many prestigious buildings, bridges and other structures. The system uses up to five 0.6" strands contained in flat-shaped ducting and anchored in a single anchorage. Strands are individually stressed and locked-off. After stressing, the duct is filled with a cement grout that fully bonds the strands to the surrounding concrete.

Live (stressing) anchorages
(also used as dead-end anchorages)

- Standard stressing anchorage for slab tendons
  - Single anchor in cast iron and a plastic trumpet
  - Used for bonded tendons
  - Unit: 6-2 to 6-5

- Standard stressing anchorage for slab tendons
  - Anchor body in cast iron and a plastic trumpet
  - Used for bonded tendons
  - Unit: 6-1

6-1 Plus:
- Standard stressing anchorage for slab tendons
- Anchor body in cast iron and a plastic trumpet
- Used for bonded tendons
- Unit: 6-1

Live (stressing) anchorages
(also used as dead-end anchorages)

- Standard stressing anchorage for slab tendons
  - Single anchor in cast iron and a plastic trumpet
  - Used for bonded tendons
  - Unit: 6-2 to 6-5

- Standard stressing anchorage for slab tendons
  - Anchor body in cast iron and a plastic trumpet
  - Used for bonded tendons
  - Unit: 6-1

H anchorage
- Standard dead-end anchorage for slab tendons
- Prestressing force is transferred to the concrete partially by bond and partially by end bearing (bulb)
- Units ranging from 6-1 to 6-5
- Strands anchored by compression fittings bearing on a bearing plate
- Units ranging from 6-1 to 6-5

For slabs with large volumes that need to be poured in several stages, VSL usually recommends a solution with overlapping of passive anchorages or splicing with passive reinforcement.

For special requirements, VSL can offer a coupler or an intermediate stressing anchorage for slab tendons. For further information please contact your local VSL representative.

Bare strand
The standard strand used for bonded slab tendons is bare strand (diameter 0.6") protected by a duct filled with cementitious grout.

Safe access
VSL requires safe access to working areas for all operations related to post-tensioning.

Pocket recess

Row 1

Live End

Grout inlet/outlet
→ refer to Working Procedures (5. Grouting) Page 18

Local anchorage-zone reinforcement
→ refer to corresponding Data Sheet Technical Section

Diameter: 1m

Row 2

Live End

Grout inlet/outlet
→ refer to Working Procedures (5. Grouting) Page 18

Local anchorage-zone reinforcement
→ refer to corresponding Data Sheet Technical Section

Lmin – straight length behind the anchorage
The trumpet length of the anchorage is sufficient for the required straight length behind the anchorage.

Stressing jack
Stressing jacks for slab tendons can be carried and placed by a single worker
→ for dimensions refer to the Technical section Chapter 6 - Page T 57

Tendon supports
Spacing between supports should not exceed 1m for large radii of curvature (≥10m) and 0.5m for small radii of curvature.

R1 = minimum radius of tendon curvature

Bonded slab system:
- Elevation: Rmin ≥ 2.5m
- Plane: Rmin ≥ 6.0m

Double curvature in plane (S-shape) has to be avoided, since the strands will be clamped when stressed individually.

Unbonded monostrand system:
- Plane/elevation: Rmin ≥ 2.5 m

General zone reinforcement, refer to note below

Local anchorage-zone reinforcement for H and P anchorages
For slab tendons with units up to 6-5, passive anchorages H and P do not require local anchorage-zone reinforcement (primary prism reinforcement).

However, the general zone must be reinforced in order to withstand the distribution of forces within the slab (secondary prism reinforcement).

→ refer to Data sheets for H and P anchorages
→ refer to Chapter 4.4.2 Page T 54
VSL INTERNAL MULTISTRAND POST- TENSIONING SYSTEM

Internal bonded tendons – the most commonly used solution
Most applications of the internal VSL Multistrand system are bonded tendons, where bare strands are protected with cementitious grout, providing a bond to the structure. Such tendons are extensively used in bridges and transportation structures as well as being successfully implemented in building construction.

Special applications:
VSL also provides solutions with unbonded multistrand tendons, where bare strands are used in combination with a soft filling material (vax or grease) or where sheathed and grease had strands are used in combination with cementitious grout. This type of tendon may, for example, be used for nuclear power plants. For specific details please contact your local VSL representative.

Live (stressing) anchorages
(also used as dead-end anchorages)
GC anchorage
- The most economical VSL anchorage for multistrand applications
- Compact and easy to handle anchorage system
- Units ranging from 6-3 to 6-55

Sc anchorage
- Used exclusively with 0.5" strands
- Units ranging from 5-4 to 5-55
Note: use of 0.5" strands is no longer recommended.

Dead-end anchorages
H anchorage
- The prestressing force is transferred to the concrete partially by bond and partially by end bearing (bulk)
- Units ranging from 6-3 to 6-37

Couplers
K coupler
- Fixed coupler used for connection to a cable that has already been stressed
- Can be combined with GC and E anchorages
- Coupled strands are anchored using compression fittings positioned on the coupling head
- Units ranging from 6-3 to 6-37

The intermediate anchorage, Zc, is used for tendons where the ends cannot be fitted using normal stressing anchorages (e.g. in circular pressure shafts-pressure tunnels and in e.go-shaped ducts).

Drain at low point of tendon
Only required for drainage in special cases, in particular if tendons are left ungrouted during the winter season

Local anchorage-zone reinforcement
- refer to corresponding Data Sheet

Rmin – minimum radius of tendon curvature

\[ R_{min} = \frac{2.8}{\sqrt{R_{pc} \cdot \rho \cdot \delta}} \geq 2.5 \text{ m} \]

Fpc = tendon breaking load (kN)

The value for Rmin should be considered in the plane of the tendon (taking into account curvature in elevation and plan):

\[ R_{min} = \frac{1}{R_{pc}} \cdot \frac{1}{R_{\delta}} \]

Note:
The indicated values of Rmin apply for corrugated steel ducts and for PT-PLUS® polymer ducts. Exceptions below these values may be made in special cases such as loops and pre-bent smooth steel pipes. For further details please contact your VSL representative.

Live End

Groat inlet/outline and vents
- refer to Working Procedures (5. Grouting) Page 18

Stressing jack
Stressing jacks for multistrand tendons are handled by tower crane or auxiliary mobile scaffolding equipped with a hoist
- for dimensions refer to the Technical section
Chapter 6 - Page T 57

Typical elevation of an internal bonded VSL multistrand post-tensioning tendon

Tendon supports
Spacing between supports is given as a function of the duct diameter: is less than or equal to 10-12 times the internal duct diameter (≤ 10 to 12 x D6duct) Plastic half-shells are used to prevent PT-PLUS® ducts from being tensed when installed in curved sections where \( R < 2 \times \) Rmin

Safe access
VSL requires safe access to working areas for all operations related to post-tensioning.

Stressing jack
Stressing jacks for multistrand tendons are handled by tower crane or auxiliary mobile scaffolding equipped with a hoist
- for dimensions refer to the Technical section
Chapter 6 - Page T 57

Live board
minimum 100mm

Clearance for operations
- required clearance for stressing operations and installation of jacks
- refer to the Technical section Chapter 6 - Page T 57

Block-out dimensions
- refer to the Technical section
Local anchorage-zone reinforcement
- refer to corresponding Data Sheet Chapter 6 - Page T 57

Lmin – minimum straight length behind the anchorage

\[ L_{min} = 0.8 \text{m} \text{ for units up to 6-7} = 1.0 \text{m} \text{ for 6-12 to 6-22 units} = 1.5 \text{m} \text{ for 6-27 units and larger} \]
The free length of external multistrand post-tensioning tendons runs outside of the concrete section and the tendons are anchored in buttoresses or diaphragms that form part of the structure.

Reasons that can lead to the decision to implement a solution using external tendons are:
- **Reduction of thickness of cross-sectional members**
  - The fact that the tendon runs outside of the concrete section means that the thickness of cross-sectional members does not need to be sized to accommodate the tendon ducts. This may lead to economies in costs of the permanent works.

- **Construction efficiency and quality**
  - With the tendon running outside of the concrete section, concreting of the cross-sectional members can be carried out more efficiently and with increased quality. This helps improve the durability.

- **Provision for spare tendons**
  - Use of external tendons allows for the possibility of installing additional future tendons by adding spare anchorages and-deviators.

- **Strengthening of existing structures**
  - External tendons are ideal for the strengthening of existing structures.

- **Possibility of visual inspection**
  - External tendons make it easy to inspect the free length of the tendons during the service life.

**Applications**

Applications are not restricted to concrete, but also include structural steel, composite steel-concrete bridges, timber and masonry structures.

The following points should be considered:
- The VSL external post-tensioning system provides the ability to replace tendons, since they are not physically enclosed by surrounding concrete. This is of course only possible, if designer ensures that there is enough clearance behind the anchorages in the completed structure to allow for replacement of the tendons.
- External tendons require regular visual inspection to verify that the integrity of the corrosion protection is still intact, since they lack the physical protection of surrounding concrete.
- Due to the fact that the tendon is not bonded to the structure, it is generally not possible to make full use of the tendon’s tensile capacity for ultimate limit state verifications.

**Special applications:**
- VSL also provides solutions with external tendons featuring unbonded (greased and sheathed) monostands and cementious grout. This type of application is typically used for strengthening works. VSL can offer special anchorage and tendon features to permit tendon force verification and adjustment if required. For specific details please contact your local VSL representative.

**Components of external tendons**

VSL external multistrand post-tensioning tendons feature a double sleeve in the anchorage zone. The PE duct runs continuously through the deviator, hence the tendons are not bonded to the structure.

External tendons consist of:
- GC anchorage (alternatively E anchorage)
- PE duct
- Internal trumpet in the anchorage zone, which is connected to the PE duct
- External trumpet in the anchorage zone
- Bare strand and wedges
- Cementious grout

**Type GC anchorage:**

- Cross-sectional dimensions as for the corresponding Data Sheet
- The value for Rmin should be considered in the plane of the tendon (taking into account curvature in elevation and plan).

**Profiles of external tendons**

In order to allow replacement, the profile of an external tendon is required to be a polyline, consisting of only straight sections and, at deviation points, curved sections with constant radii of curvature.

The construction of the profile is most easily carried out by definition of:
- the fix points (FP) at anchorages and low and high points.
- the curved sections (with constant radii of curvature) at low and high points (deviator locations).
- the working points (WP) at low and high points by connecting tangents to curves at high and low points and to anchorages respectively.

**Typical elevation of an external VSL multistrand post-tensioning tendon**

- Grout inlet/outlet and vents → refer to Working Procedures (5. Grouting) Page 18
- Access to box girder → refer to corresponding Data Sheet
- Local anchorage-zone reinforcement → refer to corresponding Data Sheet
- Rmin – minimum radius of tendon curvature
- Lmin – straight length behind the anchorage
- PE duct
- Strands
- Grout
- DRAADIE
- Access is required for the passage of materials and equipment
- Minimum dimensions d1, d2 and d3 for the installation of stressing jack, the stressing operation and the replacement of the tendon. Contact local VSL representative for advise on these dimensions.
VSL ELECTRICALLY ISOLATED TENDONS (EIT)

Enhanced durability featuring protection level PL 3:
VSL electrically isolated tendons (EIT) feature protection level PL 3, incorporating full encapsulation for the tendon and corrosion protection against aggressive environments outside the tendon. EIT tendons allow monitoring of the encapsulation during the service life.

Electically isolated tendons are chosen to suit specific project requirements, to allow monitoring of the tendon encapsulation or for tendons that are exposed to a highly aggressive environment and need extra protection.

VSL electrically isolated tendons can be used as either internal or external tendons. The details in this section are based on internal bonded tendons. Details of the external EIT tendons are similar to those of standard external tendons but include additional elements for the electrical isolation of the tendon and for the monitoring of the encapsulation.

Advantages of EIT tendons
Prestressed structures benefit from the use of EIT tendons in many ways. Some specific characteristics and related advantages are summarised as follows:
- Full encapsulation of the tendon
- Durability
- Electrical isolation of the tendon
- Monitoring and confirmation of the protection provided
- Quality control during installation
- Stray current protection
- Durability
- Enhanced fatigue strength
- Durability

Special applications:
For strengthening works that require EIT tendons, the VSL EIT anchorage may be used (units ranging from 6-1 to 65-5). In addition, the K coupler and the L (loop) anchorage are also available to PL 3.

For specific details please contact your local VSL representative.

Components of EIT tendons
The VSL EIT tendons consist of a combination of the GC anchorage and the PT-PLUS duct, featuring additional elements for the electrical isolation of the tendon and for the monitoring of the encapsulation.

In detail, they consist of:
- GC anchorage (casting and anchor head)
- Insulation plate
- Plastic tube
- PT-PLUS duct with couplers
- Protection cap with electrical connection
- Bare strand and wedges
- Cementitious grout

Detailing of EIT tendons
The requirements for EIT tendons concerning local anchorage-zone reinforcement, tendon layout and clearance requirements for jack installation are as for the VSL multstrand post-tensioning system. Special requirements for detailing EIT tendons are described below.

Electrical connections
A group of EIT tendons requires the following electrical connections:
- Terminal block (measuring cabinet, centralised for a group of tendons)
- Cable connecting the anchor head and the terminal block: VSL strongly recommends connecting cables to the anchorages at both ends of each tendon, in order to provide the most reliable detection of the location of any defects.
- Cable connecting the passive reinforcement and the terminal block.

Working procedures
Installation of anchorages and ducts, threading of strands, stressing and grouting operations are carried out in the same way as for VSL multstrand tendons (for refer to Working Procedures). Particular attention should be given to the special elements such as the insulation plate and the electrical connections. Early involvement of VSL to coordinate works for the installation of the post-tensioning system is highly recommended and allows discussion of special considerations for electrically isolated tendons.

Checking for leak-tight installation
After installing the anchorages and ducts and prior to concreteing, the leak-tightness of the EIT tendon is confirmed. This may be carried out by visual inspection of the complete installation or a leak-tightness check using compressed air as a leak-tightness check with dry ice (CO

Monitoring the integrity of the encapsulation
The use of EIT tendons allows the electrical isolation and the integrity of the duct to be checked after construction and enables monitoring of the corrosion protection of the steel strands throughout the service life. By connecting an LCR meter to the terminal block, simple AC impedance measurements can be performed. The instrument measures the impedance (Z), which includes (over the tendon length) the grout in the duct, the duct (together with couplers, vents and any defects) and the concrete surrounding the duct. Based on the impedance, the instrument calculates and displays the following parameters:
- Ohmic resistance R (Ω)
- Capacitance C (nF)
- Loss factor D

The measured parameters depend on:
- Length of tendon and duct diameter (the ohmic resistance, R, for a given tendon decreases with its length)
- Type of anchorage
- Detailing of the duct (couplers, mirror welded joints)
- Number and type of grout vents
- Specific electric resistance of the concrete and grout, which itself depends on the water-cement ratio, the grade of hydration and on climatic parameters such as temperature and humidity.

The ohmic resistance is standardised in length-independent values to allow comparison and in order to set limiting values for acceptance criteria:
- Standardised ohmic resistance R = R x L [kΩ], where L is the length of the tendon

As indicated, the measured ohmic resistance depends strongly on the environment (temperature and humidity) and in consequence the acceptance criteria should be defined in a project-specific monitoring plan. If available, reference should be made to local standards and recommendations, e.g. the Swiss guideline ‘Measures to ensure durability of post-tensioning tendons in RC concrete structures’, published by the Swiss Federal Highway Agency (AITSRA) and Swiss Railways (SBB) in 2007.

The potential of EIT tendons can only be fully achieved if all involved parties are aware of the special considerations needed during all project stages (design, preparation of the works, steel-fixing works, installation of the PT system, concreting, stressing and grouting). The specific installations required for impedance measurement during erection and the service life of the structure must be planned in advance and detailed in the project specifications.

The results of the monitoring must be interpreted by a specialist and any requirements for special measures should be evaluated accordingly.

Field results – long-term monitoring
Above figures show the results of long-term monitoring of the Preis du Mariage Bridge in Switzerland, where six VSL EIT tendons were installed. The AC impedance of each tendon has been measured at frequent intervals since the time of grouting. As can be seen, the six individual tendons show a certain scatter, however the overall trend is an increase of the resistance with time, which can be explained by the hydration of the grout and the surrounding concrete and the subsequent drying out. In the ‘9σ Resistance vs. log Time’ plot a straight line can be observed. This indicates that the increase in resistance is very rapid at the beginning but slows down after some months, becoming asymptotic after several years. It should be noted that the primary focus of long-term monitoring is to check for the stability or increase of resistance with time and that the absolute value of the resistance itself is only of secondary importance.

EIT allows detection of the ingress of water at a very early stage. If (chloride-containing) water reaches a defect in the duct, the concrete and the grout become wet and the electrical resistance of this tendon will decrease significantly and rapidly (a sudden drop). In consequence, the measurement of the electrical impedance at the normal inspection intervals represents a simple but very effective early warning system to detect a corrosion-risk situation. Hence, appropriate steps (inspection and repair if required) can be taken before any significant damage occurs.
VSL – WORKING PROCEDURES - KEY FOR QUALITY

As an experienced specialist contractor, VSL carries out high-quality installation using trained personnel and reliable equipment, in accordance with well-proven procedures. This section gives a general overview of working procedures for slab tendons, and for internal and external multistrand tendons.

1. Placing of anchorages, ducts and local anchorage-zone reinforcement

The first step for installation of a post-tensioning system is the installation of the anchorages, the ducts and the local anchorage-zone reinforcement.

**Anchorage (stressing anchorages):**
- are fixed to the formwork by bolts
- must be oriented perpendicularly to the cable axis
- the formwork must have a suitable hole on the cable axis, if strands are to be installed before concreting or if prefabricated cables are being placed
- Ducts:
  - are supported on tendon supports
  - must be installed without kinks
  - are provided with grout vents

Local anchorage-zone reinforcement:
- must be positioned behind the anchorage in accordance with VSL data sheets

2. Threading of strands

Three options are available for the installation of post-tensioning cables:

2.1 Pushing-through of individual strands (before or after concreting for internal PT, after concreting for external PT)

2.2 Pulling-through of an entire strand bundle (after concreting for both internal and external PT)

2.3 Installation of prefabricated cables (before concreting, for internal PT only)

3. Stressing of the tendons

The stressing operation can be carried out once the concrete has reached the minimal specified strength in accordance with the VSL data sheets and the formwork has been removed from the anchorage.

Stressing consists of the following steps:

- Step 1: Placing of the anchor head and wedges: It is important for this operation to be carried out after concreting in order to avoid the surfares of the anchorage or wedges being contaminated by concrete laitance.
- Step 2: Positioning of the jack
- Step 3: Stressing: During stressing, the pressure displayed on the manometer and the measured elongation of the tendons are recorded on the stressing report. As an alternative to manual record-keeping, VSL can provide automatic data acquisition during stressing
- Step 4: Load transfer: By releasing the pressure in the jack, the load is transferred from the stressing jack to the anchorage
- Step 5: Cutting of strands: Overlength strands are cut once the stressing operation has been completed and approved.

4. Capping of anchorages

In preparation for the grouting operation, the anchor heads are sealed by installing grout caps. The grout caps are fixed to the anchorage and equipped with vents, in order to fill the cavities around the wedges. Capping arrangements will depend on the required level of protection level (see page 10). As a result, grout caps can be either temporary or permanent.

The use of temporary or permanent grout caps is required for all applications, in order to ensure that the cavities in the anchorages have been completely filled, with proper cement grout.

### SLAB TENDONS

**Bonded tendons:**
- The VSL bar anchorage series features a pocket recess, which allows fixing of the tendon to the formwork. The tendon is connected to the anchorage, from which the grout inlet/outlet is connected.

- The duct (bonded tendons) or the sheathed strands (unbonded tendons) are supported on tendon supports. Distances between supports must not exceed 1m for large radii of curvature (+10m) and 0.5m for small radii of curvature. Ducts must be tied down to the rebars.

**Unbonded tendons:**
- The S 6:1 Mono anchorages feature a plastic pocket recess, for fixing the anchorage to the formwork. The tendon is connected to the anchorage and provides a seal.

### INTERNAL MULTISTRAND TENDONS

Stressing anchorages of the VSL multistrand system are fixed to the formwork using bolts. The duct is installed and connected to the anchorage. The grout inlet/outlet is integrated into the anchorage.

- The duct is supported on tendon supports; distances between supports must not exceed 10 to 12 times the internal diameter of the duct.
- For PT-PLUS® ducts, it is recommended that protection sheath are fixed on the duct at tendon supports or at horizontal tendon deviation for tendon radii less than twice the minimum radius (R < 2 Rmm). The ducts must be tied down to the rebars.

For installation of the strands of internal and external multistrand tendons, the following procedures are used:

**Pushing-through** of individual strands (2.1) - The strands are pulled from a coil and pushed into the duct. For long cables, strand-pushing equipment is used. Pushing-through may be carried out either before or after concreting for internal PT and is always carried out after concreting and removal of the inner form in the case of external PT.

An alternative, the entire strand bundle may be pulled through the duct after concreting (2.2). This is carried out using a winch and a pulling rope.

The stressing operation is identical for internal and external multistrand tendons. All strands are stressed simultaneously by using a VSL centre-hole multistrand jack and a hydraulic pump. The equipment is positioned and relocated by crane or by auxiliary mobile scaffolding equipped with a hoist.

VSL's multistrand jacks are compact and short in order to minimise strand protrusion for stressing and the space required behind the anchorages for installation.

### EXTERNAL MULTISTRAND TENDONS

Before concreting: In the anchorage zone, the stressing anchorage and an external sleeve are installed. Reusable void formers are used to create the voids for the tendons in deviators and the bellmouth at the exit of the tendons at anchorage diaphragms.

After concreting: the PE pipe and the internal trumpet are installed. Mirror welding of the duct elements is performed prior to installation. A duct coupler is used for specific connections, in order to provide tolerance in installation. Temporary supports for the duct are required during installation. The external tendons may also need permanent supports, if the distance between the deviators and/or anchorages exceeds 15m for road bridges or 12m for railway bridges.
5. GROUTING

Objectives of grouting
The objectives in grouting tendons are:
1. To provide an effective corrosion protection system, by filling the free space in the tendon with a stable grout that passesivate the prestressing steel by providing an alkaline encapsulation, and
2. To achieve an effective bond between the tendon and the surrounding concrete (for internal bonded prestressing only).

The quality of the grouting is of prime importance for the durability of post-tensioned tendons in any kind of application. High-quality grouting is achieved through:
- Careful selection of the constituent materials
- Continuous quality control to ensure consistent material properties
- Selection of suitable mixing equipment
- Selection of a mix design and mixing procedures adapted to the selected materials, environment and equipment
- Effective cable encapsulation
- Execution of grouting on site by qualified personnel following approved method statements
- Correct detailing of the tendon layout to ensure optimum flow of the grout

Steps in grouting
Grouting of PT tendons is carried out in the following steps:
1. Prior to grouting:
   - Blowing through of the ducts. Note that the use of water to flush ducts prior to grouting is prohibited, since it is impossible to completely remove the flush water from the duct.
   - Installation of temporary or permanent grout caps at all anchorage points.
   - Air testing to detect any leaks in the assembled duct system.
2. Grouting:
   - Preparation of the grout
   - Uninterrupted grouting of the tendon
   - Subsequent closure of the vents (in the grouting direction), only once the grout coming out has the same consistency and viscosity as that in the mixer.
   - When the entire cable is filled, the pressure must be held for at least one minute, in order to ensure that the tendon is leak-tight.
   - One day after grouting, all air and outlet points and the grout caps must be checked for complete filling and topped up if required.

VSL policy on grouting
It is the policy of VSL that all entities of the group must carry out grouting in accordance with the following European standards:
- EN445: Grout for prestressing tendons – Test methods
- EN446: Grout for prestressing tendons – Grouting procedures
- EN447: Grout for prestressing tendons – Basic requirements

For countries outside Europe, reference is made to ISO 14128, Part 1-3.

GROUT specification
Grout is composed of cement, water and admixtures. These components have a complex interaction, which strongly affects the grout characteristics.
- Cement: Portland cement is recommended for grouting. The cement must be free of chlorides (below 0.1%) or other aggressive elements. In addition, it must be compatible with the admixtures and must maintain uniform properties throughout different batches.
- Water: Water must be free of all impurities that could influence the hardening of the grout and must not contain any substances that attack the prestressing steel. In general, drinking water satisfies these requirements.
- Admixtures: Admixtures of admixtures, to reduce viscosity and improve workability/ Placing admixture, to limit settlement/ segregation and to ensure that the grout remains homogeneous.

VSL-HPI Grout
Thanks to its many years of experience, VSL knows the importance of high-quality grouting to ensure the long-term durability of post-tensioned tendons. Under the trademark VSL-HPI (High-Precision Injection), VSL has developed a complete process dedicated to improving the quality of grouting activities on site.

Generally, VSL develops an individual HPI-Grout mix for each profit centre or independent project. This uses the locally available grout constituents, which are checked for their compatibility and performance. The grout mix is designed and optimised for stable, low-bled grouts so as to ensure the complete filling of ducts in order to provide a fully alkaline environment for the prestressing steel.

Grouting tests
VSL-HPI grout satisfies or even exceeds all the standard test requirements as prescribed in EN 445, 446 and 447 (as well as ISO 14128, Part 1-3). The test requirements are as follows:

1. Standard test for viscosity
   Aim: assure proper viscosity (flow time) of grout for injection
   Test set-up: 1 litre of grout has to pass through a standardised siphon within a set time
   Requirements: Flow time limit of 25 seconds. It must also exhibit stability of flow time over an extended period of at least 30 minutes.

2. Standard test for compressive strength
   Aim: Record compressive strength, usually after 7 and 28 days.
   Test set-up: standard compressive strength test for a prism specimen of 40 x 40 x 160 mm
   Requirements: The compressive strength of the grout must be less than 30 MPa at 28 days or 27MPa at 7 days.

3. Mud balance test
   Aim: Verification of fluid grout density (weight/volume) to confirm the water content of the grout mix in situ.
   Test set-up: Mud balance test
   Requirements: VSL-HPI grouts feature a high density of about 2600 kg/m³ because of their low water content and low porosity.

4. Wick-induced bleed test
   Aim: Verification of bleed and volume change including the filtering effect of a strand
   Test set-up: A transparent 1m vertical tube with a single 0.6 mm stand at its centre. Grout is poured to a defined height, the bleed and volume changes are measured at specified intervals up to 24 hours.
   Requirements: The bleeding must not exceed 0.3% of the initial volume after 3 hours kept at rest and the volume change of the grout at rest for 24 hours must be within the range of ±1% and ±5%.

5. Inclined tube test
   Aim: Verification of bleed and stability
   Test set-up: Inclined transparent tubes of 5m length, each with 12 strands of 0.6 mm. The tubes are filled with grout, bleed and volume changes are measured at regular intervals up to 24 hours. This test is the only test available at present that gives a realistic representation of the environment of the grout inside the cable and enables analysis of the stability of the grout against segregation.
   Requirements: The bleeding shall not exceed 0.3% of the initial volume after 3 hours kept at rest.

The above tests are in general carried out daily when tendons are being grouted, except for the inclined tube test, which is performed to obtain approval for a specific grout mix.

Special considerations
For internal prestressing in match-cast precast segmental structures, all joints need to be epoxy grouted. If tendons are running in a deck slab, the application of a waterproofing membrane is highly recommended and is absolutely mandatory where de-icing salt may be used.

Alternatively, VSL can supply and install PT-PLUS duct segmental couplers specifically designed and detailed for this type of application (see Technical section).

Reference
For further information on grouting, see the VSL Report ‘GROUTING OF POST – TENSIONING TENDONS’ (VSL Report Series No. 5, issued in 2002).

6. FINISHING WORKS AFTER GROUTING

After grouting, the following finishing works must be performed:
- In the case of External PT, the duct coupler must be covered with heat-shrink sleeves.
- In the case of anchorages within a block-out recess, the pocket recess is filled with concrete after grouting.

Vents for VSL slab tendons
No vents are required at the tendon high points for slab tendons that are relatively short (i.e. below or within the acceptable range given above for the maximum vent distance) and that have a relatively small drop of more than 0.5m - 0.8m.

Vacuum-assisted grouting
In vacuum-assisted grouting, the tendon is subjected to a vacuum before grouting and most of the enclosed air is removed. This significantly reduces the risk of leaving voids in the grouted tendon due to entrapped air. It can be of particular use for the grouting of:
- Long horizontal tendons without defined high points
- External tendons, where the provision of vents at high points at deviations or pier segments is not possible

Vacuum-assisted grouting is only feasible if the entire duct system, including the anchorages, is sealed airtight. In addition, special equipment is required and special connection details have to be provided.
Void control with the VSL Grout Void Sensor

The VSL Grout Void Sensor is used to reduce the risk of undetected defects by monitoring that the tendon has been properly filled with grout and by confirming the grout properties. The sensor is installed prior to concreting at potentially critical points of the tendon and detects if there is insufficient alkalinity or if there is chloride contamination of the grout during the filling process. Moreover, it allows the detection of bleed water. As a result, it confirms the presence of grout with sufficient alkaline properties at all critical sections of the tendon, providing maximum quality control during installation. The VSL Grout Void Sensor is patent protected and was developed in 2010, drawing on successful results from laboratory tests and tests on a full-scale mock-up.

Electrically isolated tendons (EIT) - long-term monitoring of tendon encapsulation and detection of the location of any possible defects

Knowing the location of any possible defect is essential in order to estimate its consequences for durability, and also to repair the defect. In order to locate the defect, an AC electric field is imposed between the post-tensioning tendon and the passive reinforcement, using the electrical connections provided for the impedance measurements. Measuring the magnetic flux of the resulting AC current makes it possible to determine the areas with current flow and to locate points where the current is exiting the tendon. The figure below shows the presence of a magnetic field in sector B, while in sector A, no magnetic field is measured. Reliable pinpointing of the defect is possible if the tendons are electrically connected from both ends.

In-service monitoring for special structures - guaranteeing performance over the years

VSL provides in-service monitoring for special structures such as nuclear power plants. Applicable regulations often mandate surveillance strategies to monitor containment structures, due to the fact that external factors, as well as changes in the mechanical properties of the concrete and steel as they age, have a direct impact on nuclear safety.

VSL is able to provide different techniques for monitoring the post-tensioning tendons and stresses and deformations in the structure. Examples include extensometers for strain measurement along the tendons using Fibre Bragg Technology. Temperature and strain are measured along selected tendons, allowing monitoring of tendon forces at any moment during service life.

For further information on structural monitoring please contact your local VSL representative.

DESIGNING WITH POST-TENSIONING TENDONS

When designing a structure with post-tensioning tendons, different structural and geometrical parameters have to be accounted for, in order to be in line with applicable codes and regulations. This page shall give an overview on the different parameters and show main dependencies between them:

1. TENDON PROPERTIES:

<table>
<thead>
<tr>
<th>Type of tendon</th>
<th>Internal multistrand</th>
</tr>
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<tbody>
<tr>
<td>required Tendon Force</td>
<td>Preliminary design by engineer</td>
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<tr>
<td>No. of strands</td>
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<td>Unit</td>
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<tr>
<td>Pk, Breaking Load Tendon</td>
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<td>Stressing force Pk</td>
<td>75% Pk</td>
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<td>Tendon Force P</td>
<td>Pk = Pmax + 0.01</td>
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<td>Wedge draw in</td>
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<td>Protection Level</td>
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</table>

2. CONCRETE PROPERTIES:

| Concrete quality | C 30 / 37 |
| concrete strength at time of stressing (m3/3) | 28 N/mm² |

3. TENDON GEOMETRY:

Parameters to take into account for definition of tendon geometry:

- min. radius of curvature
- min. straight length behind anchorage
- spacing between ducts
- concrete cover and actual tendon axis
- min. centre spacing between anchorages
- min. required edge distance

4. DETAILING OF LOCAL ANCHORAGE ZONE:

- Local anchorage zone reinforcement

5. EQUIPMENT FOR STRESSING:

| Chosen equipment | Technical Block 6. |
| Stressing Jack | ZPE 580 |

Notes:
1. Values in blue (italic) are indicated for example only
2. The example is made for a typical internal bonded multistrand tendon. However, the flow chart may be implemented for the design of other type of tendons.
3. Indications in gray (italic) are references to corresponding chapters of this brochure

6. GEOMETRY REQUIREMENTS FOR STRESSING:

- Block out dimensions
- Clearance requirements for stressing operation

7. DETAILING OF GENERAL ZONE:

- Load introduction of prestressing forces (anchorage, deviator) into structure
- Diaphragm, deviator and blister dimension (if required)
- Rebar arrangement compatible with PT hardware and local anchorage zone
1. TENDONS

1.1 Strand Properties 15 mm (0.6")

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<th>Unit Strands numbers</th>
<th>Breaking load</th>
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<th>Y170ST7 (pEN)</th>
<th>Grade 270 (ASTM)</th>
<th>Steel duct* recommended</th>
<th>Plastic duct VSL PT-PLUS*</th>
<th>FE pipe</th>
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<td>220</td>
<td>235</td>
<td>5</td>
<td>7</td>
<td>5</td>
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</tbody>
</table>

1. Flat ducts possible as well (width = 75 mm, height = 21 mm)
2. Flat duct PT-PLUS for use with VSL anchorages: see 2.2.3
3. Soldered only for short cables with D180. For other cases contact local VSL representative.
4. Given values may slightly vary depending on local availability of ducts. In any case the filling ratio (cross-section steel / duct) must not exceed 0.5 (EN623)
5. $d$ refers to outer pipe diameter. For $d_b$ diameter refer to section 2.2.3 (Page 73)
2. DUCTING

2.1 Ducts featuring protection level PL 1

For internal tendons that require protection level PL 1, corrugated steel ducts are used:

2.1.1 Galvanised corrugated steel ducts
The most commonly used sheaths are made from rolled galvanised steel strips. For internal multistrand post-tensioning applications, the ducts are round, while for internal slab post-tensioning tendons the VSL flat duct is generally chosen (up to 5 strands), in order to minimise the eccentricity of the tendon in the duct and to maximise the static height of the post-tensioning tendon.

Galvanised steel ducts are corrugated and gout-light (once embedded in concrete) and must have sufficient strength to withstand different types of mechanical loading. The corrugated shape provides bond between the tendon (grout) and the surrounding concrete. For additional information refer to EN252 or applicable local standards.

2.1.2 Bare corrugated steel ducts
In countries that do not accept galvanised ducts, bright corrugated steel ducts may be used.

When using corrugated steel ducts, VSL recommends implementation whenever possible of galvanised ducts to avoid any effects of corrosion of the duct on the friction coefficient of the tendon.

For dimensions refer to Chapter 1.2 and 1.4 and to the Table below.

2.1.3 Couplers for corrugated steel ducts
Couplers for corrugated steel ducts have a slightly larger diameter than the duct, to allow the coupler to be threaded over the duct. It should have a minimum length of 200mm or three times the duct diameter.

2.2 Ducts featuring protection level PL 2 and PL 3

2.2.1 The VSL PT-PLUS® duct system
The VSL PT-PLUS® duct system is used for internal bonded tendons. By providing a leak-tight barrier, it meets the requirements for enhanced corrosion protection (PL 2). In addition, the PT-PLUS® system can be fitted with additional details at the anchorage to provide electrically isolated tendons (EIT) and a protection level PL 3. The PT-PLUS® ducts are made of polypropylene.

The corrugated shape of the duct provides bond between the tendon (grout) and the surrounding concrete. Compared to the corrugated steel duct, the use of PT-PLUS® duct features improved structural behaviour of the post-tensioned tendon under fatigue loading (EN 1992-1-1, Section 6.8).

For internal slab post-tensioning tendons or transverse tendons in bridge deck slabs, the PT-PLUS® flat duct is used. This allows the eccentricity of the tendon in the duct to be minimised and maximises the static height of the post-tensioning tendon.

The standard core area of PT-PLUS® ducts is black. In hot countries, the use of white ducts is recommended.

2.2.2 PT-PLUS® duct coupler
PT-PLUS® ducts are fabricated in lengths of 6m and are connected by PT-PLUS® duct couplers. The PT-PLUS® duct coupler consists of two half-shells, which are fixed by clamps.

Alternatively, heat-shrinkable sleeves may be used for coupling of ducts or individual duct elements may be joined by ‘mirror welding’ (refer to point 2.2.5 on the right-hand side).

2.2.3 Dimensions of the PT-PLUS® duct system

Round PT-PLUS® ducts

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Wall Thickness</th>
<th>Protection Width</th>
<th>Protection Height</th>
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</thead>
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<td>22 mm</td>
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<tr>
<td>41.5 mm</td>
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Flat PT-PLUS® ducts

<table>
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<tr>
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2.4 Smooth polymer ducts

Smooth polymer ducts are predominantly used for external tendons. They are made of UV-resistant, polyethylene (PE) material (virgin granulate) in accordance with EN 12201, ASTM D3035 or ASTM F714 or equivalent standards. Material recycled from previously used PE components must not be used. Ducts normally have a diameter/wall thickness (RD5) of 17 and a filling ratio not higher than 0.5. The filling ratio is the ratio between the section of the prestressing steel and the duct section. For dimensions refer to Chapter 1.2.

Smooth plastic ducts are usually delivered in elements of 6m or 12m. The duct of an external tendon is built up of several elements, which are joined by ‘mirror welding’, a heat fusion process that heats the two surfaces and then fuses them together, resulting in a permanent, monolithic fusion joint.

2.5 VSL PT-PLUS duct segmental coupler

The VSL PT-PLUS duct segmental coupler is implemented for internal prestressing in match-cast precast segmental structures. Providing encapsulation at segment joints. It consists of a face seal ring that is compressed during the joining of segments against well-defined bearing surfaces on both segments.

2.6 Influence of the choice of duct on fatigue resistance of tendons

The fatigue resistance of post-tensioned tendons depends as well on the type of duct used. When using a corrugated steel duct the contact surface between the strand and steel duct is very limited. In consequence, the contact pressure on the strand in debonded zones is very high. In contrast, PT-PLUS® ducts feature a larger contact surface and lower contact pressure between strand and polymer.

The figure below shows the results of fatigue tests of post-tensioned beams performed at ETH Zürich. The results indicate fatigue resistance under cyclic loading with a nominal stress range in the prestressing steel. The X-axis shows the number of cycles, while the Y-axis shows the stress amplitude in the post-tensioning steel.

Tests with polymer ducts showed a significantly better fatigue performance than tests with corrugated steel ducts.

In order to avoid wire breakage, VSL recommends limiting the equivalent stress range under fatigue loading to the resisting stress range of the prestressing steel for 1 Ms cycles: 150MPa for polymer ducts

120MPa for corrugated steel ducts

For fatigue load combination and further details refer to EN 1992-1-1, Section 6.8.
3. ANCHORAGES

This section includes technical data of VSL anchorages, such as anchorage geometry, local anchorage zone reinforcement and minimum centre spacing. Below an overview of available Data Sheets.

The information on the following data sheets of local anchorage zone reinforcement and required concrete strength at the time of stressing is VSL’s recommended detailing. Details under particular local regulations may vary from the indicated content. Please contact VSL for clarification.

How to find the corresponding Data Sheet:

1. Choose anchorage

The choice of anchorage can be carried out in function of the type of structural element, design considerations as well as the required protection level:

-> refer to Page 7: The VSL strand post-tensioning systems – solutions for any application

2. Choose type of strand and grade of local anchorage zone reinforcement

Choose the required strand type:

• Fpk = 279 kN
• Fpk = 265 kN / 260.4 kN
(or Fpk = 186 kN / 177 kN in case 0.5” strand)
-> refer to Page T1 & T2 for strand characteristics

Choose required grade of passive reinforcement for local anchorage zone:

• fy = 600 MPa
• fy = 460 MPa
• fy = 395 MPa

3. Choose Data Sheet

Choose Data Sheet based on tables on this double page:

VSL SLAB Post-Tensioning System

<table>
<thead>
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<th>Anchorage</th>
<th>Data Sheet Type</th>
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<th>Rebar fy (MPa)</th>
<th>Data Sheet No.</th>
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VSL MULTISTRAND Post-Tensioning System - Internal Bonded Tendons

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VSL SLAB Post-Tensioning System - Electrically Isolated Tendons

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### Slab Post-Tensioning System

**Internal Bonded Post-Tensioning**

**ANCHORAGE TYPE VSLab S**

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CONCRETE 20/25 MPa

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Notes
- All dimensions in [mm]
- Strain A_y = 150N/mm², f_y = 1770N/mm² (GUTS), f_p = 265 kN
- Concrete: minimum required strength f_c, cylinder / f_c, cube in N/mm² at stressing
- For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
- Local zone reinforcement bent and anchored in accordance with BS EN 1992
- Reinforcement, edge distance and center spacing may be modified, contact VSL

Min. yield strength for local zone reinforcement f_y = 460N/mm²

1) Depending on slab thickness and required concrete cover U_n, min ≤ U
2) X = anchorage spacing. Minimum edge distance: X/2 + concrete cover t
3) Transverse bars to be anchored according to general detailing rules

CONCRETE 20/25 MPa

<table>
<thead>
<tr>
<th>Local Zone Reinforcement</th>
<th>Spacing</th>
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Notes
- All dimensions in [mm]
- Strain A_y = 150N/mm², f_y = 1770N/mm² (GUTS), f_p = 265 kN
- Concrete: minimum required strength f_c, cylinder / f_c, cube in N/mm² at stressing
- For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
- Local zone reinforcement bent and anchored in accordance with BS EN 1992
- Reinforcement, edge distance and center spacing may be modified, contact VSL
CONCRETE 20/25 MPa

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**Notes**
- All dimensions in [mm]
- Strand Ap = 150 mm², fpy = 1770 N/mm² (GUTS), Fpk = 265 kN
- For calculation of minimum edge distance refer to 4.1.1
- Local zone reinforcement bent and anchored in accordance with BS EN 1992
- Reinforcement, edge distance and center spacing may be modified, contact VSL.
- For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.

Min. yield strength for local zone reinforcement fpy = 390 N/mm²

ANCHORAGE TYPE VS-Lab S (Strand Fpk = 265 kN)
LOCAL ZONE REINFORCEMENT fpy = 390 N/mm²

**Notes**
- All dimensions in [mm]
- System applicable to strands with Ap = 140 mm² or Ap = 150 mm²

**Unit A B C D ØE F**
- 6-1 122 94 70 90 22-25 32
Slab Post-Tensioning System
Internal Unbonded Post-Tensioning
ANCHORAGE TYPE S 6-1 Mono

Slab Post-Tensioning System
Internal Bonded and Unbonded Post-Tensioning
ANCHORAGE TYPE S 6-1 PLUS and S 6-1 MONO (Strand $F_{pa} = 260 / 265.5 / 279$ kN)
LOCAL ZONE REINFORCEMENT $f_y = 460 / 500$ N/mm²
CONCRETE 16/20 MPa

Notes
All dimensions in [mm]
System applicable to strands with $A_p = 140$ mm² or $A_p = 150$ mm²

<table>
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<tr>
<th>Unit</th>
<th>A</th>
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Notes
All dimensions in [mm]
Min. required concrete strength $f_{c,min} / f_{c,max} = 16/20$ MPa at stressing.
For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
$X =$ anchorage spacing.
$X1 =$ min spacing between last and first anchorage of grouped anchorages.

Minimum edge distance: 120mm + concrete cover
Minimum edge distance: $X/2 +$ concrete cover

Nom. strand breaking load
$F_p = 265.4 / 265.5$ kN
$F_{pa} = 279$ kN

Min. yield strength for local zone reinforcement
$f_y = 460$ N/mm²
$f_y = 500$ N/mm²
Slab Post-Tensioning System
Internal Bonded Post-Tensioning
DEAD END ANCHORAGE TYPE H (Slab)

Grout Connection
End-Piece with Clip
Crimped Strand Tails Bulb
Strands
Spacer Bar

Notes
All dimensions in [mm]
System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
System can be used with corrugated steel duct or with PT-Plus duct

Nom. strand breaking load
Min. concrete strength at stressing
Max. tendon force after lock-off

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Fₚₚ₀ = 260.4 / 265.5 / 279 kN
20 / 25 fc,cyl / fc,cube in MPa
80% of Fₚₚ₀

Slab Post-Tensioning System
Internal Bonded Post-Tensioning
DEAD END ANCHORAGE TYPE P (Slab)

Compressed Fittings
Grout Connection
PT-Plus® Duct
Strands
End-Piece with
Anchor Plate
Retainer Plate

Notes
All dimensions in [mm]
System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
System can be used with corrugated steel duct or with PT-Plus duct

Nom. strand breaking load
Min. concrete strength at stressing

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Fₚₚ₀ = 260.4 / 265.5 / 279 kN
20 / 25 fc,cyl / fc,cube in MPa
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning
ANCHORAGE TYPE GC

PT-Plus
Duct

Notes
All dimensions in [mm]
System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
(1) J-spacing of bolts for fixation to formwork
(2) ØH-Inner dia of the trumpet
System can be used with corrugated steel duct or with PT-Plus® duct

Reinforcement consists of a combination of spiral and stirrups

ANCHORAGE TYPE GC (Strand Fpk = 279 kN)
LOCAL ZONE REINFORCEMENT f_p = 500 N/mm²

System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
Strand Ap = 150 mm², fpk = 1860 N/mm² (GUTS), Fpk = 279 kN
Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 25/30 MPa

CONCRETE 28/35 MPa

CONCRETE 32/40 MPa

CONCRETE 36/45 MPa

CONCRETE 40/50 MPa

Notes
All dimension in [mm]
Min. yield strength for local zone reinforcement fy = 500 N/mm²
Min. required concrete strength fc,cylinder / fc,cube in MPa at stressing
n = number of spiral turns including first and last required as anchorage length
System can be used with corrugated steel duct or with PT-Plus® duct

X = minimal center spacing between anchorages
For calculation of minimum edge distance refer to 4.4.1
Reinforcement, edge distance, center spacing may be modified, contact VSL
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning

ANCHORAGE TYPE GC (Strand F_p = 260 / 265 kN)
LOCAL ZONE REINFORCEMENT f_p = 460 N/mm²

OPTION A - SPIRAL REINFORCEMENT

CONCRETE 20/25 MPa

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CONCRETE 24/30 MPa

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CONCRETE 28/35 MPa

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CONCRETE 32/40 MPa

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CONCRETE 36/45 MPa

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Notes
All dimension in [mm]
Min. yield strength for local zone reinforcement f_y = 460N/mm²
Min. required concrete strength f_c,m, min./ f_c,m, min. at stressing Strand A_p = 150mm², f_p, min. = 1770N/mm² (GUTS), f_p, min. = 285.6kN
Strand A_p = 140mm², f_p, min. = 1860N/mm² (GUTS), f_p, min. = 260.4kN

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
X = minimal center spacing between anchorages
For calculation of maximum edge distance refer to 4.4.1
n = number of spiral turns including first and last required as anchorage length
Reinforcement, edge distance, center spacing may be modified, contact VSL
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning
ANCHORAGE TYPE E 0.6

Anchor Head
Protection Cap
Tape
Strands
Gripped Connection
Wedges
Bearng Plate
Duct
Trumpet

Concrete 23/28 & 26/35 MPa

Concrete 32/40 & 36/45 MPa

Concrete 43/53 MPa

Notes
All dimensions in [mm]
System applicable to strands with Ap = 140 mm² or Ap = 155 mm²
Concrete strength is defined as minimum required f'c,cm in MPa at time of stressing
(1) Δ-spacing of bolts for fixation to framework
(2) ØH-inner dia of the trumpet
System can be used with corrugated steel duct or with PT-Plus® duct

Reinforcement consists of a combination of spiral and stirrups

Notes
All dimensions in [mm]
Min. yield strength for local zone reinforcement f_y,cm = 500 N/mm²
Min. required concrete strength f'c,cm, in MPa at stressing
Strand A_p = 150mm², L_p = 1500mm (GUTS), A_P = 275mm²
For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
**Multistrand Post-Tensioning System**

**Internal Bonded Post-Tensioning**

**ANCHORAGE TYPE E 0.6 (strand 260 or 265 kN)**

**LOCAL ZONE REINFORCEMENT** $f_y = 460$ N/mm$^2$

---

**OPTION A - SPIRAL REINFORCEMENT**

**OPTION B - STIRRUP REINFORCEMENT**

---

**CONCRETE 24/30 MPa**

**CONCRETE 28/35 MPa**

---

**CONCRETE 32/40 MPa**

**CONCRETE 36/45 MPa**

---

**CONCRETE 40/50 MPa**

---

**Notes**

- All dimension in [mm]
- Min. yield strength for local zone reinforcement $f_y = 460$ N/mm$^2$
- Min. required concrete strength $f_{c,min} = 1770$ N/mm$^2$ at stressing
- Strand $A_p = 150$ mm$^2$, $f_{pk} = 1770$ N/mm$^2$ (GUTS), $F_{pk} = 265.5$ kN
- Strand $A_p = 140$ mm$^2$, $f_{pk} = 1860$ N/mm$^2$ (GUTS), $F_{pk} = 260.4$ kN
- Min. yield strength for local zone reinforcement $f_y = 390$ N/mm$^2$
- Min. required concrete strength $f_{c,min} = 1900$ N/mm$^2$ at stressing
- Strand $A_p = 150$ mm$^2$, $f_{pk} = 1770$ N/mm$^2$ (GUTS), $F_{pk} = 265.5$ kN
- Strand $A_p = 140$ mm$^2$, $f_{pk} = 1860$ N/mm$^2$ (GUTS), $F_{pk} = 260.4$ kN

---

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.

- X = minimal center spacing between anchorages
- For calculation of minimum edge distance refer to 4.4.1
- $n$ = number of spiral turns including first and last required as anchorage length
- Reinforcement, edge distance and center spacing may be modified, contact VSL.
### Multistrand Post-Tensioning System
#### Internal Bonded Post-Tensioning

**DEAD END ANCHORAGE TYPE H 0.6 and H 0.5**

- **Spacer Bars**
- **Crimped Strand Tail Bulb**
- **Grout Connection**
- **Duct**
- **Tension Ring**

#### Anchorages

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#### Notes
1. Min. concrete strength at stressing: 20 to 25 % of $f_{ck}$ in MPa
2. X/Y: Minimum center spacing = Max (minimum center spacing stressing anchorage; dimension A respectively B of H anchorage + 20mm)
3. Minimum edge distance: X/2 resp Y/2 + concrete cover

### Multistrand and Slab Post-Tensioning System
#### Internal Bonded Post-Tensioning

**ANCHORAGE TYPE H 0.6 and H 0.5 (Strand $F_{pk} = 186 / 260 / 265 / 279$ kN)**

**LOCAL ZONE REINFORCEMENT $f_y = 460$ N/mm²**

#### Anchorages

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<td>310</td>
<td>2</td>
<td>360</td>
<td>400</td>
</tr>
</tbody>
</table>

#### Notes
1. Nom. strand breaking load: 20 / 25 % of $f_{ck}$ in MPa
2. $f_{pk} = 260.4 / 265.5 / 279$ kN
3. $20 / 25 \text{fc, cyl} / \text{fc, cube}$ in MPa
4. 80% of $f_{pk}$
5. System applicable to strands with $A_p = 100$ mm² or $A_p = 140$ mm² or $A_p = 150$ mm²
6. Strands (bulbs) can be arranged either in rectangular (Arr. 1) or square (Arr. 2)

---

All dimension in [mm]

**Max. tendon force**

- Nom. breaking load: 70% of $F_{pk}$
- $F_{pk} = 260.4 / 265.5 / 279$ kN

**Nom. concrete strength at stressing**

- 20 / 25 % of $f_{ck}$ in MPa
- 80% of $f_{pk}$

---

**Notes**

- All dimension in [mm]
- System applicable to strands with $A_p = 100$ mm² or $A_p = 140$ mm² or $A_p = 150$ mm²
- Strands (bulbs) can be arranged either rectangular (Arr. 1) or square (Arr. 2)
- System can be used with corrugated steel duct or PT-Plus duct
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning
DEAD END ANCHORAGE TYPE P

Compression Fittings
Grout Connection
Retainer Plates

Tension Ring
Strands
Anchor Plate
Duct

Multistrand and Slab Post-Tensioning System
Internal Bonded Post-Tensioning
ANCHORAGE TYPE P (Strand $F_{pk} = 260 / 265 / 279$ kN)
LOCAL ZONE REINFORCEMENT $f_y = 500$ N/mm$^2$

Notes
All dimensions in [mm]
Min. yield strength for local zone reinforcement $f_y = 500$ N/mm$^2$
1) X/Y = Center spacing of anchorage. Minimum edge distance: X/2 resp Y/2 + concrete cover
Detailing of minimum clearance to edge shall be according to corresponding stressing anchorage

Slab Post-Tensioning

Notes
All dimension in [mm]
Min. yield strength for local zone reinforcement $f_y = 500$ N/mm$^2$
1) X = center spacing of anchorage depending on nom. strand breaking load. Minimum edge distance: X/2 + concrete cover
General zone reinforcement (secondary prism) not shown. In slabs there is always need to reinforce vertical secondary prism.

Multistrand Post-Tensioning

Unit Arrangement A B C

<table>
<thead>
<tr>
<th>Unit</th>
<th>A B C</th>
<th>X Y</th>
<th>A B C</th>
<th>X Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-2</td>
<td>180 20</td>
<td>280</td>
<td>150 30</td>
<td>200</td>
</tr>
<tr>
<td>6-3</td>
<td>230 20</td>
<td>330</td>
<td>200 30</td>
<td>250</td>
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<td>6-4</td>
<td>260 20</td>
<td>430</td>
<td>250 30</td>
<td>300</td>
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<td>6-7</td>
<td>270 25</td>
<td>430</td>
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<td>300</td>
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<td>430</td>
</tr>
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<td>6-19</td>
<td>370 27</td>
<td>630</td>
<td>360 30</td>
<td>430</td>
</tr>
<tr>
<td>6-22</td>
<td>420 27</td>
<td>730</td>
<td>360 30</td>
<td>430</td>
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<td>6-31</td>
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</tr>
<tr>
<td>6-37</td>
<td>540 27</td>
<td>120</td>
<td>530 36</td>
<td>430</td>
</tr>
</tbody>
</table>

Notes
All dimensions in [mm]
System applicable to strands with $A_p = 140$ mm$^2$ or $A_p = 150$ mm$^2$
System can be used with corrugated steel duct or PT-Plus duct
The anchor plate with the compression fittings can be arranged either in rectangular format (Arr. 1) or in square format (Arr. 2)
## Multistrand Post-Tensioning System
### Internal Bonded Post-Tensioning

#### COUPLER TYPE K

![Diagram of Coupler Type K](image)

<table>
<thead>
<tr>
<th>Unit</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>ØD</th>
<th>ØF</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-3</td>
<td>430</td>
<td>160</td>
<td>210</td>
<td>150</td>
<td>76</td>
<td>118</td>
</tr>
<tr>
<td>6-4</td>
<td>440</td>
<td>160</td>
<td>220</td>
<td>160</td>
<td>83</td>
<td>118</td>
</tr>
<tr>
<td>6-7</td>
<td>560</td>
<td>160</td>
<td>320</td>
<td>190</td>
<td>95</td>
<td>128</td>
</tr>
<tr>
<td>6-10</td>
<td>660</td>
<td>160</td>
<td>420</td>
<td>240</td>
<td>121</td>
<td>128</td>
</tr>
<tr>
<td>6-15</td>
<td>770</td>
<td>160</td>
<td>530</td>
<td>270</td>
<td>133</td>
<td>128</td>
</tr>
<tr>
<td>6-16</td>
<td>770</td>
<td>160</td>
<td>530</td>
<td>280</td>
<td>146</td>
<td>128</td>
</tr>
<tr>
<td>6-22</td>
<td>910</td>
<td>190</td>
<td>250</td>
<td>145</td>
<td>159</td>
<td>128</td>
</tr>
<tr>
<td>6-31</td>
<td>970</td>
<td>190</td>
<td>260</td>
<td>165</td>
<td>188</td>
<td>150</td>
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<tr>
<td>6-37</td>
<td>1200</td>
<td>200</td>
<td>360</td>
<td>178</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

### Notes
- All dimensions in [mm]
- System applicable to strands with $A_p = 140 \text{ mm}^2$ or $A_p = 150 \text{ mm}^2$
- System can be used with Type GC or E bearing plate
- System can be used with corrugated steel duct or PT-Plus duct

#### COUPLER TYPE Z

![Diagram of Coupler Type Z](image)

<table>
<thead>
<tr>
<th>Unit</th>
<th>A</th>
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<th>C</th>
<th>D</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<tr>
<td>6-2</td>
<td>140</td>
<td>70</td>
<td>90</td>
<td>65</td>
<td>450</td>
<td>620</td>
<td>180</td>
</tr>
<tr>
<td>6-4</td>
<td>170</td>
<td>80</td>
<td>100</td>
<td>70</td>
<td>900</td>
<td>1130</td>
<td>210</td>
</tr>
<tr>
<td>6-6</td>
<td>210</td>
<td>100</td>
<td>140</td>
<td>90</td>
<td>1400</td>
<td>1200</td>
<td>250</td>
</tr>
<tr>
<td>6-12</td>
<td>300</td>
<td>160</td>
<td>160</td>
<td>100</td>
<td>1350</td>
<td>1910</td>
<td>340</td>
</tr>
<tr>
<td>6-22</td>
<td>400</td>
<td>190</td>
<td>250</td>
<td>145</td>
<td>1100</td>
<td>2280</td>
<td>440</td>
</tr>
</tbody>
</table>

### Notes
- All dimensions in [mm]
- System applicable to strands with $A_p = 140 \text{ mm}^2$ or $A_p = 150 \text{ mm}^2$
- System can be used with corrugated steel duct or with PT-Plus duct
- $\Delta L$: movement of coupling head due to tendon extensions
**Multistrand Post-Tensioning System**  
Internal Bonded Post-Tensioning

**DEAD END ANCHORAGE TYPE AF**

---

**Anchorage Body (Casting)**

**High strength Grout in-fill**

**Strands with Compression Fittings**

**Base Plate**

---

**2nd Injection**  
(Tendon Grout)

**1st Injection**  
(High Strength Grout)

---

**Notes**

- All dimensions in [mm]
- System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
- Minimum in-fill grout strength at time of stressing fₜₐₐₚ = 100 MPa
- System can be used with corrugated steel duct or PT-Plus® duct

---

**OPTION A - SPIRAL REINFORCEMENT**

**OPTION B - STIRRUP REINFORCEMENT**

---

### Strand Fₚₖ = 265 kN

- Min. yield strength for local zone reinforcement fₑₖ = 390 N/mm²

### Strand Fₚₖ = 279 kN

- Min. yield strength for local zone reinforcement fₑₖ = 500 N/mm²

---

### System applicable to strands with Ap = 140 mm² or Ap = 150 mm²

### Minimum in-fill grout strength at time of stressing fₜₐₚ = 100 MPa

### X = minimal center spacing between anchorages

### For maximum tendon force refer to 4.2.8

---

### All dimension in [mm] Strand Ap = 150mm², fpk = 1770N/mm² (GUTS), Fpk = 265.5 kN

### Min. required concrete strength fc, cylinder / fc, cube = 28/35 MPa at stressing

### Strand Ap = 150mm², fpk = 1860N/mm² (GUTS), Fpk = 279 kN

### For calculation of minimum edge distance refer to 4.4.1

### Reinforcement, edge distance, center spacing may be modified, contact VSL
Required cross-sectional area of hairpin bars if anchorage is an intermediate anchorage (~1/4 of 2 x P_0 anchored behind tendon at ~ 50% · f_y):

\[ A_{n} = \frac{P_{0}}{n} \]

- \( A_{n} \) (mm²) cross-sectional area of one hairpin bar
- \( n \) (-) number of hairpin bars
- \( P_{0} \) (kN) Prestressing force in the tendon
- \( f_{A_{ext}} \) (mm) External diameter of duct
- \( T \) (mm) Concrete thickness
- \( X \) (mm) Required anchoring length according to applicable standard
- \( f_{y} \) (N/mm²) Yield strength of hairpin bars: min. 390 N/mm²

Min. required concrete strength \( f_{c,m} \), \( f_{c,15d} \geq 23.28 \) MPa at time of stressing

Concrete cover to ducts shall not be less than the external diameter of the ducts

Arrangement of multiple L anchorages depending on available concrete thickness

<table>
<thead>
<tr>
<th>Unit</th>
<th>( \Omega_{A} ) internal/external</th>
<th>( \Omega_{B} ) internal/external</th>
<th>( R ) min</th>
<th>( \Omega_{A} ) internal/external</th>
<th>( \Omega_{B} ) internal/external</th>
<th>( R ) min</th>
</tr>
</thead>
<tbody>
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<td>45/50</td>
<td>600</td>
<td>50/55</td>
<td>45/50</td>
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<td>600</td>
<td>50/55</td>
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<td>600</td>
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<tr>
<td>6-4</td>
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<td>75/82</td>
<td>70/82</td>
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<td>750</td>
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<td>80/97</td>
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<td>95/102</td>
<td>1500</td>
<td>120/127</td>
<td>110/117</td>
<td>1500</td>
</tr>
</tbody>
</table>

Notes
- All dimensions in [mm]
- System applicable to strands with \( A_{p} = 140 \text{ mm}^2 \) or \( A_{p} = 150 \text{ mm}^2 \)
- System can be used with corrugated steel duct or with PT-Plus duct
- For larger units contact VSL
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning
ANCHORAGE TYPE E 0.5

Anchor Head
Grout Connection
Tape
Strands
Wedges
Bear Plate

Notes
All dimensions in [mm]
System applicable to strands with Ap = 100 mm²
Concrete strength is defined as minimum required f_y,local/ f_y,fc, cube in MPa at time of stressing
(1) J- spacing of bolts for fixation to formwork
(2) ØH-inner dia of the trumpet

CONCRETE 28/35 MPa

<table>
<thead>
<tr>
<th>Unit</th>
<th>ØC</th>
<th>ØD</th>
<th>ØH</th>
<th>ØH(inner dia trumpet)</th>
<th>J(ØH)</th>
<th>P</th>
<th>ØK</th>
<th>ØL</th>
<th>A</th>
<th>B</th>
<th>F</th>
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<tbody>
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<td>45</td>
<td>25</td>
<td>70</td>
<td>65</td>
<td>15</td>
<td>85</td>
<td>65</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>5-2</td>
<td>55</td>
<td>90</td>
<td>50</td>
<td>40</td>
<td>110</td>
<td>M10</td>
<td>15</td>
<td>270</td>
<td>175</td>
<td>15</td>
<td>270</td>
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<tr>
<td>5-3</td>
<td>74</td>
<td>110</td>
<td>65</td>
<td>50</td>
<td>125</td>
<td>M10</td>
<td>20</td>
<td>215</td>
<td>125</td>
<td>20</td>
<td>215</td>
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<tr>
<td>5-4</td>
<td>104</td>
<td>150</td>
<td>80</td>
<td>65</td>
<td>210</td>
<td>M10</td>
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<td>410</td>
</tr>
<tr>
<td>5-5</td>
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<td>M16</td>
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<td>45</td>
<td>520</td>
</tr>
<tr>
<td>5-6</td>
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<td>85</td>
<td>260</td>
<td>M16</td>
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<td>525</td>
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<tr>
<td>5-7</td>
<td>172</td>
<td>230</td>
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<td>100</td>
<td>310</td>
<td>M16</td>
<td>60</td>
<td>610</td>
<td>340</td>
<td>50</td>
<td>605</td>
</tr>
<tr>
<td>5-8</td>
<td>198</td>
<td>240</td>
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<td>320</td>
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<td>750</td>
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</tbody>
</table>

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.

OPTION A - SPIRAL REINFORCEMENT

OPTION B - STIRRUP REINFORCEMENT

All dimensions in [mm]
Min. yield strength for local zone reinforcement f_y,local/ f_y,fc, cube in MPa at stressing
Concrete: minimum required local zone reinforcement f_y,local at stressing
Strand Ap = 100 mm², f_y,local = 1860 N/mm² (GUTS), f_p,k = 186kN
n = number of spiral turns including first and last required as anchorage length
Reinforcement, edge distance, center spacing may be modified, contact VSL.
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning
ANCHORAGE TYPE E 0.5 (strand 186 kN)
LOCAL ZONE REINFORCEMENT $f_p = 390$ N/mm²

OPTION A - SPIRAL REINFORCEMENT

OPTION B - STIRRUP REINFORCEMENT

CONCRETE 28/35 MPa

CONCRETE 32/40 MPa

CONCRETE 36/45 MPa

CONCRETE 40/50 MPa

Notes

All dimensions in [mm]

Min. yield strength for local zone reinforcement $f_p = 350$ N/mm²

Min. required concrete strength $f_{c,min}$ in MPa at stressing

For calculation of minimum edge distance refer to 4.4.1

Reinforcement, edge distance, center spacing may be modified, contact VSL

Notes

All dimensions in [mm]

System applicable to strands with $A_p = 100$ mm²

(1) J = spacing of bolts for fixation to formwork

(2) ØH = Inner exit diameter of casting
OPTION A - SPIRAL REINFORCEMENT

CONCRETE 20/25 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 24/30 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 28/35 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 32/40 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 36/45 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 40/50 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

Notes

All dimensions in [mm]

Min. yield strength for local zone reinforcement $f_y = 460\,\text{N/mm}^2$

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

For max. tendon force and temporary over stressing refer to 4.1 and 4.2 resp.

$\sigma_{\text{max}} = 1860\,\text{N/mm}^2$ (GUTS), $F_p = 186\,\text{kN}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

OPTION B - STIRRUP REINFORCEMENT

CONCRETE 20/25 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 24/30 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 28/35 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 32/40 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 36/45 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

CONCRETE 40/50 MPa

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL

Notes

All dimensions in [mm]

Min. yield strength for local zone reinforcement $f_y = 460\,\text{N/mm}^2$

Min. required concrete strength $f_{c,\text{cyl}} / f_{c,\text{cube}}$ in MPa at stressing $X = \text{minimal center spacing between anchorages}$

For calculation of minimum edge distance refer to 4.4.1

$n = \text{number of spiral turns including first and last required as anchorage length}$

Reinforcement, edge distance, center spacing may be modified, contact VSL
Multistrand Post-Tensioning System
External Grouted Post-Tensioning
ANCHORAGE TYPE GC

**OPTION B - STIRRUP REINFORCEMENT**

**Notes**
- All dimensions in [mm]
- System applicable to strands with Ap = 140 mm² or Ap = 150 mm²
- (1) J-spacing of bolts for fixation to formwork
- (2) ØH-Inner diameter of external duct.

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**Notes**
- All dimensions in [mm]
- X = minimal center spacing between anchorages
- For calculation of minimum edge distance refer to 4.4.1
- Min. required concrete strength f'c,cylinder /fc, cube in MPa at stressing
- Strand Aₚ = 150 mm², L₁ = 1660 kN/mm² (GUTS), f_p = 1860 N/mm²
- For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
### OPTION A - SPIRAL REINFORCEMENT

**CONCRETE 24/30 MPa**

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**CONCRETE 28/35 MPa**

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**CONCRETE 32/40 MPa**

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**CONCRETE 36/45 MPa**

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**CONCRETE 40/50 MPa**

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**CONCRETE 50/62.5 MPa**

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### OPTION B - STIRRUP REINFORCEMENT

**CONCRETE 24/30 MPa**

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**CONCRETE 28/35 MPa**

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**CONCRETE 32/40 MPa**

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**CONCRETE 36/45 MPa**

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**CONCRETE 40/50 MPa**

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**CONCRETE 50/62.5 MPa**

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### Notes

- All dimensions in [mm]
- Min. yield strength for local zone reinforcement $f_y = 400$N/mm²
- Min. required concrete strength $f_{c,min}/f_{c,calc}$ in MPa at stressing Strand $A_s = 150$mm²; $f_y = 1770$N/mm² (GUTS), $f_{c,min} = 205.5$N
- Strand $A_s = 140$mm²; $f_y = 1900$N/mm² (GUTS), $f_{c,min} = 200.4$N

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.

- **X** = minimal center spacing between anchorages

For calculation of minimum edge distance refer to 4.4.1

- $n$ = number of spiral turns including first and last required as anchorage length

Reinforcement, edge distance, center spacing may be modified, contact VSL.

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.

- **X** = minimal center spacing between anchorages

For calculation of minimum edge distance refer to 4.4.1

- $n$ = number of spiral turns including first and last required as anchorage length

Reinforcement, edge distance, center spacing may be modified, contact VSL.
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning EIT (Electrically Isolated Tendon)

ANCHORAGE TYPE GC

Option A - Spiral Reinforcement

Option B - Stirrup Reinforcement

CONCRETE 25/30 MPa

CONCRETE 32/40 MPa

CONCRETE 40/50 MPa

CONCRETE 24/35 MPa

CONCRETE 36/45 MPa

CONCRETE 46/55 MPa

Notes

All dimensions in [mm]

System applicable to strands with Ap = 140 mm² or Ap = 150 mm²

(1) J-spacing of bolts for fixation to formwork

(2) ØH inner dia of the trumpet

Electrical connections for monitoring not shown
Multistrand Post-Tensioning System
Internal Bonded Post-Tensioning EIT
ANCHORAGE TYPE GC (Strand F_p = 260 / 265 kN)
LOCAL ZONE REINFORCEMENT f_y = 460 N/mm²

OPTION A - SPIRAL REINFORCEMENT

CONCRETE 24/30 MPa

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CONCRETE 26/35 MPa

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CONCRETE 30/40 MPa

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CONCRETE 36/45 MPa

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CONCRETE 50/62.5 MPa

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Notes
All dimension in [mm]
Min. yield strength for local zone reinforcement f_y = 460 N/mm²
Min. required concrete strength f_{c,avg} in MPa at stressing
Strand A_0 = 150mm², f_{y strand} = 1770 N/mm² (GUTS), F_{pk} = 265.5 kN
n = number of spiral turns including first and last required as anchorage length
Reinforcement, edge distance, center spacing may be modified, contact VSL

For max. tendon force and temporary over stressing refer to 4.1 and 4.2.8 resp.
X = minimal center spacing between anchorages
For calculation of minimum edge distance refer to 4.4.1

Min. yield strength for local zone reinforcement f_y = 260 N/mm²
Min. required concrete strength f_{c,avg} in MPa at stressing
Strand A_0 = 140mm², f_{y strand} = 1860 N/mm² (GUTS), F_{pk} = 260.4 kN
4. DESIGN considerations

4.1 STRESSING FORCE OF POST-TENSIONING TENDONS

International standards and codes define the maximum tension force in a post-tensioned tendon, which should generally not be exceeded. The table below gives an overview of different standards. Distinction is made between the forces before and after the transfer of the prestressing force to the concrete, in order to allow a partial compensation for friction losses by temporary ‘overstressing’ (refer to 4.2).

<table>
<thead>
<tr>
<th>STANDARD</th>
<th>Max. force AFTER transfer of prestressing force to the concrete</th>
<th>Max. force BEFORE transfer of prestressing force to the concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIB Model Code 2010</td>
<td>Min (0.75 ( \sigma_p ), 0.85 ( \sigma_{y2} ))</td>
<td>Min (0.80 ( \sigma_p ), 0.90 ( \sigma_{y2} ))</td>
</tr>
<tr>
<td>EC2 (EN-1993-1-1)</td>
<td>Min (0.75 ( \sigma_p ), 0.85 ( \sigma_{y2} ))</td>
<td>Min (0.80 ( \sigma_p ), 0.90 ( \sigma_{y2} ))</td>
</tr>
<tr>
<td>AASHTO LRFD Bridge Design Specification 2010</td>
<td>0.70 ( \sigma_p )(on anchorage) / 0.74 ( \sigma_p )(on tendon)</td>
<td>0.75 ( \sigma_p )</td>
</tr>
</tbody>
</table>

Where:
- \( \sigma_p \) = characteristic tensile strength
- \( \sigma_{y2} \) = characteristic 0.1% proof stress

Most applicable codes and standards allow temporary overstressing of the tendon (refer to 4.2.8).

EN-1992-1-1 specifies maximum tendon forces in national annexes; indicated values are recommended values.

The stressing of a post-tensioning tendon can only be carried out once the concrete in the vicinity of the anchorage has reached the required mechanical strength \( f_{ck} \) (for the tendon it is the on-site measured concrete strength at the time of stressing and should meet or exceed \( f_{ck} \) as specified in the corresponding VSL data sheets or the value specified by the project engineer. For partial stressing at lower forces than \( f_{ck} \), refer to section 4.4.1 of this brochure.

4.2 POST-TENSIONING FORCE IN TENDONS – LOSSES OF TENDON FORCE

The initial post-tensioning force applied at the stressing end of a tendon decreases along the tendon as a result of various factors. The losses of post-tensioning force are described in this chapter. In general, immediate and long-term losses are considered separately:

- Immediate losses:
  - Losses due to friction along the tendon and in the anchorage
  - Losses due to draw-in of the wedges
  - Elastic shortening of the concrete

- Long-term losses:
  - Losses due to relaxation of the prestressing steel
  - Losses due to creep and shrinkage of the concrete

4.2.1 Losses due to friction along the tendon

Losses due to friction along the tendon can be calculated by Coulomb’s formula:

\[
P_{fr} = P_0 \cdot e^{-\mu \cdot e^{k \cdot x}}
\]

Where:
- \( P_{fr} \) = Post-tensioning force at a distance \( x \) from the stressing anchorage
- \( P_0 \) = Post-tensioning force at the stressing anchorage
- \( e \) = base of Napierian logarithms

Values for coefficients \( \mu \) and \( k \):

- Type of tendon and duct
  - Range
  - Recommended value
  - Internal bonded tendon with corrugated steel duct (bare strand) \( \mu = 0.16 - 0.22 \)
    \( k = 0.004 - 0.008 \)
    \( \mu = 0.16 \)
    \( k = 0.005 \) (\( \sigma_p = 9 \times 10^3 \) MPa)
  - Internal bonded tendon with PT-PLUS® polymer duct (bare strand) \( \mu = 0.10 - 0.15 \)
    \( k = 0.004 - 0.010 \)
    \( \mu = 0.12 \)
    \( k = 0.005 \) (\( \sigma_p = 6 \times 10^3 \) MPa)
  - External tendon with PE pipe (bare strand) \( \mu = 0.10 - 0.14 \)
    \( k = 0.0 \)
    \( \mu = 0.12 \)
    \( k = 0 \) (\( \sigma_p = 0 \) MPa)
  - Internal unbonded tendon with individually greased and shawled strands \( \mu = 0.04 - 0.07 \)
    \( k = 0.004 - 0.008 \)
    \( \mu = 0.05 \)
    \( k = 0.005 \) (\( \sigma_p = 2.5 \times 10^3 \) MPa)
  - Special application: External tendon with greased and shawled strands \( \mu = 0.04 - 0.07 \)
    \( k = 0.0 \)
    \( \mu = 0.06 \)
    \( k = 0 \) (\( \sigma_p = 0 \) MPa)

Notes:
1. The internal limit values encompass both lubricated and non-lubricated strands
2. Values of wobble factor \( k \) are zero for tendons outside the concrete section

It should be noted that, in addition to the losses of friction along the tendon, losses occur in the jack and due to friction of the strands in the anchorage. These losses vary with the type of tendon unit, type of anchorage and type of jack used. These losses are taken into account by VSL and so the jacking force of the jack and the pump pressure are calculated accordingly. As a consequence, the project design engineer does not need to consider these losses.

4.2.2 Losses due to draw-in of wedges

When the strands are locked off in the anchorage, the wedges move through a fixed distance of about 6mm. This value is independent of the tendon unit, the nominal diameter of the strand and its grade. By assuming a linear loss of tension due to friction (a valid hypothesis for most cases) the loss in tension and the affected zone of the wedge draw-in may be calculated as follows:

\[
W = \frac{M \cdot E \cdot A}{\Delta P} \cdot \lambda
\]

where:
- \( W \) = Distance affected by the draw-in of wedges
- \( \Delta P \) = loss of force at the anchorage due to draw-in of wedges
- \( E \) = Module of elasticity of post-tensioning steel in [kN/mm]
- \( A \) = steel cross section in [\( \text{mm}^2 \)]
- \( \lambda \) = loss of pressure per m in [kN/mm]

\[
\Delta P = \frac{P_0 - P}{L}
\]

The losses due to relaxation of the prestressing steel depend significantly on the temperature.

If relaxation losses are important for the performance of the structure or member, it is strongly recommended that relaxation tests be performed at the particular temperature whenever the temperature is expected to be significantly above 20°C over extended periods of time.

The relaxation loss after infinite time may be assumed to two to three times the value at 1,000 hours.

As a consequence, for preliminary design the losses due to relaxation of post-tensioning strands with normal initial stress level and temperatures around 20°C can be considered to be 6% to 7%.

This estimate can be considered as an upper value. It should be noted that there is a significant variation between different codes and regulations, thus for detailed calculation reference should be made to applicable codes and regulations, e.g. Ab Model Code 2010.

4.2.3 Losses due to elastic shortening of concrete

The loss in tendon force corresponding to the instantaneous deformation of the concrete should be considered by taking into account the order in which the tendons are stressed. For standard cases, such as slabs or bridge girders, this shortening is insignificant in terms of losses. However, it should be considered for beams that are highly stressed with only a few cables.

4.2.4 Losses due to relaxation of the prestressing steel

Relaxation is the loss of force, measured as a function of time, in a tendon that is stressed and maintained at constant length. It represents a physical property of the material, which varies according to the quality of the steel and the method by which it was produced.

For a given steel, the relaxation depends essentially upon the initial force and the ambient temperature.

Strands used by VSL are low-relaxation strands, with a maximum relaxation at 1,000 hours of 2.5% (for an initial force of 70% UTS (ultimate tensile strength) and ambient temperature of 20°C).

The graph below allows the estimation of the relaxation of a low-relaxation strand at 1,000 hours, for a temperature of 20°C and as a function of the initial stress of the tendon (mean initial stress in % of \( f_{ck} \) considering immediate losses).

In the majority of cases this loss does not have any practical influence since the force required in the tendon is determined by the governing moment, which is usually affected at a point unaffected by the distance \( w \). However, for short tendons with small curvature, or where the controlling force is located in the vicinity of the anchorage, it may be advisable to compensate for the loss caused by draw-in of the wedges by shimming between the anchor block and bearing plate (2-stage stressing operation).
4.2.5 Losses due to creep and shrinkage of concrete

The calculation of losses due to creep and shrinkage of the concrete should be carried out based on applicable codes and standards or according to FIB Model Code 2010.

For bonded tendons, the local deformation at the level of the tendon has to be considered, while for unbonded tendons (e.g., external tendons, which are unbonded to the structure), the deformation of the whole structure between the anchorages of the tendon has to be taken into account.

The following equations are based upon the data from the FIB model code and allow to determine the final losses due to creep and shrinkage under constant stress. As indicated, for detailed calculation references should be made to applicable codes and standards.

\[
\Delta \sigma_{cr, fs} = \frac{E_1}{E_2} \cdot \frac{E_2}{E_3} \cdot \frac{1}{\sigma_{cr, max}} \cdot \frac{\sigma_{cr, max}}{\sigma_{cr, max}}
\]

where:
- \( \Delta \sigma_{cr, max} \) = final post-tensioning losses due to creep and shrinkage [%]
- \( \sigma_{cr, max} \) = variation in the stress in the post-tensioning steel due to creep and shrinkage (MPa)
- \( \sigma_{cr, max} \) = stress in the concrete due to post-tensioning (at the level of the post-tensioning steel) (MPa)
- \( \sigma_{cr, max} \) = initial stress in the concrete due to at a distance \( w \) from

As previously indicated, the losses due to creep and shrinkage depend strongly on geometrical, atmospheric and time factors and also vary in relation to different codes and regulations.

The table below provides an estimate of losses due to creep and shrinkage for three different cases. These values may only be used for preliminary analysis for detailed calculation reference should be made to applicable codes and regulations, e.g., FIB Model Code 2010.

### Case I: Cast-in-situ element with early stress of tendons in dry atmospheric conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab tendons</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>Bridges and Beams</td>
<td>12%</td>
<td>9%</td>
</tr>
</tbody>
</table>

### Case II: Cast-in-situ element with standard stressing of tendons in humid atmospheric conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab tendons</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>Bridges and Beams</td>
<td>12%</td>
<td>9%</td>
</tr>
</tbody>
</table>

### Case III: Precast element with late stressing of tendons

<table>
<thead>
<tr>
<th>Case</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab tendons</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>Bridges and Beams</td>
<td>12%</td>
<td>9%</td>
</tr>
</tbody>
</table>

4.2.6 Total time-dependent losses

Typical values for the total time-dependent losses for post-tensioned tendons due to relaxation of the prestressing steel and creep and shrinkage of the concrete can be calculated by adding the losses due to relaxation to the values of the table above.

- e.g. Case I:
  - for slab tendons ~ 15%
  - for bridges and beams ~ 20%

These values are approximate and for detailed calculation reference should be made to applicable codes and regulations, e.g., FIB Model Code 2010.

4.2.7 Example for determination of post-tensioning force along the tendon

This paragraph shows an example for the determination of the post-tensioning force along the tendon, considering losses due to friction and due to wedge draw-in of the tendon.

VSL tendon 6-12, 12 strands, nominal diameter (Ø) 15.7mm (0.6")

Length of tendon L = 50m

Section of one strand \( A_t = 150 \text{mm}^2 \)

Characteristic tensile strength \( \sigma_t = 1,860 \text{MPa} \)

Characteristic breaking load of tendon \( F_{pt} = 3,348 \text{kN} \)

Modulus of elasticity of post-tensioning steel = 195,000MPa

Tendon equipped with GC 6-12 anchorages and PT-PLUS duct

Initial stress force = 15% \( F_{pt} = 2,521 \text{kN} \)

Tendon geometry:

\[
\text{Influence of wedge draw-in:}
\]

\[
\Delta \sigma_{fs} = \frac{2,511 - 2,195}{50} = 6.32 \text{ kN/m}
\]

\[
W = \frac{6}{0.19500} - \frac{12}{150} = 6.32 \text{ at } 18 \text{m}
\]

\[
\Delta F_p = \Delta \sigma_{fs} \cdot W = 6.32 \times 228 \text{kN}
\]

### Case 2: Detailed calculation with variable \( \Delta p \):

Detailed calculation is carried out by specialised software which takes into account that \( \Delta p \) varies along the tendon. Results are shown below.

The following observations can be made:
- The detailed calculation shows that the losses are not strictly linear along the tendon, but depend on the distribution of the tendon deviation over the tendon length.
- The zone that is affected by the losses due to wedge draw-in (W) is effectively about 15.9m long.
- The post-tensioning force at the passive anchorage is for both cases equal to 0.65\%.
- The difference between Case I and Case II only occurs because of the assumption for Case I that the total stress is distributed linearly over the tendon length.

4.2.8 Over stressing of post-tensioning tendons

Most applicable codes and standards allow a temporary over stressing of the tendon, giving the following advantages:
- A significant increase in the post-tensioning force throughout the length of the tendon partially compensates for the loss of force resulting from friction. This results in a saving in the quantity of post-tensioning steel required.
- Allotment of the maximum admissible force \( P_{adm} \) at a distance \( w \) from the anchorage. For most structures the bending moment governing the magnitude of post-tensioning force is not at the anchorage position.

The value of the over stress is fixed in applicable codes and standards. In addition it should be verified that the post-tensioning force in the tendon after transfer to the concrete remains below the allowable value: e.g. Eurocode 2 (EN 1992-1-1):
- Maximum force AFTER transfer of prestressing force to the concrete: \( \text{Mmin} = (0.75 \sigma_s \cdot 0.85 \sigma_{pt} \cdot e) \cdot \text{max} \)
- Refer to section 4.1 of this brochure.

Alternatively the wedge draw-in can be fully compensated for by adding 6mm shims between the anchor block and the bearing plate.
4.2.9 Stressing of tendons: 1 end stressing or 2 end stressing

The decision, whether to stress a tendon from one end or from both ends depends on the tendon length, its trajectory and the type of duct which is used.

For each particular case it shall be analyzed if there is an interest to stress the tendon from the end or from both ends. If stressing from both ends is required, the stressing is done from the two ends sequentially and not simultaneously.

As general rules, the following can be retained:
- short slab tendons are stressed from one side only
- long tendons with significant change of stress are stressed from both ends.

This section includes 3 examples, which shall serve as guide when defining the stressing ends and dead ends of tendons. The losses include immediate losses, time dependent losses are not considered.

Short slab tendon:
Tendon of ~3m length over two spans with small drape (Slab thickness 3cm)

Tendon elevation:

Stress in prestressing steel (σ₁ / fₚ) when stressing from one end:

Stress in prestressing steel (σ₁ / fₚ) when stressing from both ends:

Stressing from both ends leads to:
- small gain (~1% Δₚ) near left anchorage
- small loss (~2% Δₚ) near right anchorage due to wedge draw-in of 2nd stressing
- overall: no benefit due to stressing from both ends, but basically just a reversal of force diagram because the wedge draw effects the force diagram over half the tendon length.

Long tendon:
Tendon of ~40m length in webs of box girder with 2.5m height over 3 spans:

The above equations of tendon elongation imply that the following parameters, which effect the elongation directly linearly, need to be accurate:
- Applied stressing force (use of calibrated jacks and pressure gauges)
- length of tendon
- as built tendon profile in line with profile defined on shop drawings and used for extension calculations.

4.4 Considerations for the anchorage zone of tendons

The transfer of the prestressing forces from the anchorage into the concrete produces stress which exceed the concrete strength and which must be resisted by the anchorage. Furthermore, anchors must be positioned at an adequate distance from the edge of the concrete and spaced at a minimum center-to-center distance, in order to prevent the anchorage zone from increasing the anchorage zone and the required strength of the anchorage zone depend strongly on the concrete strength at the time of stressing, fₚ.

4.4.1 Required centre spacing and edge distance for PT anchorage

The required centre spacing, X, is indicated in the corresponding data sheets for VSL anchorage. An increase in the concrete strength at the time of stressing, fₚ, leads to a decrease in the required centre distance, X. The data sheets for VSL anchoreages are presented in Section 2 of this technical section.

The VSL SLAB post-tensioning system features local anchorage zones with a rectangular shape (X by Y), designed to minimize the slab thickness.

The VSL MULTISTRAND post-tensioning systems (internal and external) feature local anchorage zones with a square shape (X by X). In situations with particular geometrical requirements, the local anchorage zones may be adapted to a rectangular shape. For specific details including information about corresponding local anchorage zone reinforcement, please contact your local VSL representative.

The minimum required edge distance, e, is calculated as follows:

\[ e = \frac{c}{2} + 10\text{mm} + 0.05f_{\text{ch}} \]

where c is the required concrete cover for passive reinforcement and \( \phi \) is the diameter of the prestressed member’s outer bar layer/s.

For load transfer testing in accordance with EN 12381 (Guideline for European Technical Approval), the concrete cover is 100mm; this can be deducted for the calculation of the minimum required edge distance.

It is recommended to use specialized software for the calculation of the tendon elongation. Calculation may be carried out without a software. However, for some irregular tendon profiles it may be necessary to vary \( \Delta_L \) (force loss per m) along length of tendon instead of using a \( \Delta_L \) averaged over full tendon length.

Using extension measurements to verify whether the theoretical force diagram has been achieved in the field is not a very exact method, since tendon elongation depends on many factors which may significantly vary in magnitude. E.g. modulus of elasticity is not a physical property guaranteed by the strand manufacturer. Results of measurements taken of samples from the same batch of strands may be different by up to 3 to 5%. It is therefore recommended to physically calibrate extension measurements at the beginning of a project by equipping a cable with stressing anchorages at both ends so that the stressing force at the second anchorage can be directly measured by a simple lift off test.

4.5 Shear resistance of post-tensioned members

For the verification of the shear resistance of post-tensioned members the following must be considered:
- the vertical component of a post-tensioning tendon may be considered to increase the shear resistance, if favourable:

\[ \Delta L_{\text{v}} = \frac{\gamma}{\sin \beta} \]

- in the case of tendons with duct diameters \( D \geq b_0 / 8 \), the ultimate resistance of the compression strut should be calculated on the basis of the nominal value of the web using:

\[ A_{\text{nom}} = A_{\phi} \sum L_{\phi} \]

where \( b_0 = \) 0.5 for grouted corrugated steel ducts
0.8 for grouted PTF and PTF/EP polymer ducts
1.2 for ungrouted ducts

- The shear strength of the concrete depends on the opening width of the critical shear crack. The normal force induced by post-tensioning tendons reduces the opening width of the critical shear crack and therefore leads to an increase in shear resistance. This is the case for shear in beams as well as for punching analysis of post-tensioned slabs.

For further information, reference should be made to applicable codes and standards.
5. DETAILING CONSIDERATIONS

This section gives an overview of geometrical constraints for the detailing of the tendon layout of post-tensioning tendons.

5.1 Detailing of tendon layout for INTERNAL tendons

5.1.1 Minimum centre spacing of anchorages

For spacing requirements of post-tensioning anchorages and required edge distances, refer to 4.4.1.

5.1.2 Minimum radii of curvature

VSL recommends limiting the radii of cable curvature to the following values in order for the behaviour in the deviated zone to be acceptable and for the ducts and tendons to be easily installed and handled and for the friction loss values to be met. The values are in line with the fib Model Code 2010.

- Slab post-tensioning system (values for tendon units 6-1 to 6-5):
  - Bonded slab system: in elevation: $R_{slab} \geq 2.5 \text{m}$; in plan: $R_{slab} \geq 0.6 \text{m}$

Double curvature in plane (S-shape) has to be avoided, since the strands will be clamped when stressed individually.

- Unbonded monostrand system:
  - Planelevatie: $R_{slab} \geq 2.5 \text{m}$

- Internal strand post-tensioning system:
  - $R_{slab} = 2.8 \sqrt{F_{pk}} \geq 2.5 \text{ m}$

The value for $R_{min}$ should be considered in the plane of the tendon (taking into account combined tendon curvature in elevation and plan):

$$R = \left( \frac{1}{R_{slab}} + \frac{1}{R_{plan}} \right)^{-1}$$

Note:
The indicated values of $R_{min}$ apply for corroded steel ducts and for PT-PLUS® polymer ducts. Exceptions below these values may be made in special cases such as loops (see below), and pre-bent smooth steel pipes. For further details please contact your VSL representative.

- special application: L (loop) anchorage
  - $R_{slab} = 0.6 \sqrt{F_{pk}} \geq 0.6 \text{ m}$

5.1.3 Straight length behind the anchorage

It is recommended to lay out a rectilinear tendon segment at the back of the anchorage so that the strands do not display excessive deviation at the internal exit point of the anchorage. This straight length in an axial alignment varies with the size of the pre stressing unit.

- Slab post-tensioning system:
  - The straight length of the anchorage is sufficient for the required straight length behind the anchorage.

- Internal strand post-tensioning system:
  - $L_{min} = 0.8 \text{ m}$ for units up to 6-7
  - $1.0 \text{ m}$ for units sized 6-12 to 6-22
  - $1.5 \text{ m}$ for units 6-27 and larger

5.1.4. Distances between ducts

Distances between ducts should be determined in accordance with applicable codes and regulations. Based on the fib Model Code 2010, VSL recommends the following:

- Minimum spacing between ducts is the outer duct diameter
- Ducts for groups of curved tendons should be spaced and reinforcement provided such that the deviation forces from the curved tendons can be safely transferred around the adjacent duct on the inside of the curve. (This can always be checked directly with a local strut and tie model)
- Ducts for groups of tendons should have a minimum spacing that permits adequate placement and compaction of the concretes.
- Tendon ducts may be closely spaced (if they cross approximately perpendicularly, or if they touch only over a small length longitudinally).
- Special attention is drawn to situations where an entire group of parallel tendons is deviated in a concrete element (for instance in the deck slab of a free cantilever bridge). Such cases need to be designed by using local strut and tie models, which will then also allow the designer to size the passive reinforcement required between the ducts.

5.1.5 Required concrete cover

Required concrete cover for post-tensioning tendons should be determined in accordance with applicable codes and regulations. The cover is chosen as a function of the class of exposure, bond and fire resistance.

5.1.6 Tendon supports

- Slab post-tensioning system:
  - Spacing between supports should not exceed 1m for large radii of curvature (+10m) and 0.5m for small radii of curvature.

- Internal strand post-tensioning system:
  - Spacing between supports is given as a function of the duct diameter: $s \leq 10 \times 1.5 \theta_{max}$
  - Plastic half-shells are used to prevent PT-PLUS® ducts from being dened when installed in curved sections where $R < 2 \times R_{slab}$

5.2 Detailing of tendon layout for EXTERNAL tendons

5.2.1 Minimum centre spacing of anchorages

For spacing requirements of post-tensioning anchorages and required edge distances, refer to 4.4.1.

5.2.2 Minimum radii of curvature

VSL recommends limiting the radii of cable curvature to the following values in order for the behaviour in the deviated zone to be acceptable and for the ducts and tendons to be easily installed and handled and for the friction loss values to be met. The values are in line with the fib Model Code 2010.

The minimum radii of curvature should be considered for the deviator zone and the anchorage zone.

- The value for $R_{min}$ should be considered in the plane of the tendon (taking into account combined tendon curvature in elevation and plan):

$$R = \left( \frac{1}{R_{deviation}} + \frac{1}{R_{plan}} \right)^{-1}$$

5.2.3 Straight length behind the anchorage

The straight length of the anchorage is sufficient to serve as the required straight length behind the anchorage provided curvature of tendon behind the anchorage has a minimum radius as given in table 5.2.2 and respective steel pipe has been pre bent to this anchorage zone radius in a steel workshop ensuring tight tolerances.

5.2.4 Distance between ducts

For external tendons, the required distance between ducts is generally governed by the spacing of anchorages in the anchorage zone and the deviator’s diabolo dimension respectively and by the load introduced to deviators in the deviator zone. Besides these structural constraints, VSL recommends provision of at least one duct diameter as minimum spacing between ducts.

5.2.5 Tendon supports

During installation, temporary support of PE pipes is required. During service life, permanent supports may be required if distances between deviators and/or anchorages exceed 15m for road bridges or 12m for railway bridges to avoid cable vibrations due to traffic loads.

5.2.6 Definition of the deviator profile

In order to allow replacement, the trajectory of an external tendon has to be a polynormal, consisting of only straight and curved sections with constant radii of curvature.

The construction of the profile is most easily carried by definition of:

- the fix points (FP) at anchorages and at low and high points
- the curved sections (with constant radii of curvature) at low and high points
- the working points (WP) at low and high points by fitting connecting tangents to curves at high and low point and to anchorage points respectively.

5.2.7 Detailing of ‘Diabolo’ deviator

Detailing of the Diabolo deviator should be carried out based on the following figures:

$\text{where: } \alpha = \text{ angular deviation of tendon (in space)}$

$R_{dev} = \text{ minimum radius of curvature (/> 5.2.2)}$

$L = \text{ length of blaster (function of } \alpha \text{)
6. STRESSING EQUIPMENT AND CLEARANCE REQUIREMENTS

This section gives an overview of VSL stressing equipment. The stressing equipment should be chosen to suit the tendon units being used. Corresponding clearance requirements and block-out dimensions are presented in section 6.2.

6.1 Stressing jack data

The above values may be reduced, if absolutely required.
In such case, the local VSL representative office should be contacted.

6.2 Block-out dimensions and clearance requirements

The above values may be reduced, if absolutely required.
In such case, contact VSL.
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