# VSL POST-TENSIONING SOLUTIONS

CONCEPTUAL DESIGN
ENGINEERING SOLUTIONS
CONSTRUCTION PARTNER
FOR BRIDGES, BUILDINGS
CONTAINMENT
STRUCTURES, SLAB ON
GRADE, SPECIAL
STRUCTURES, REPAIR
AND STRENGTHENING

# A REPUTATION FOR EXCELLENCE SINCE

## VSL's leadership in post-tensioning

VSL is a recognised leader in the field of special construction methods. Well-proven technical systems and sound in-house engineering are the basis of the group's acknowledged reputation for innovative conceptual designs and engineering solutions, for reliability, quality and efficiency.

VSL executes all works using its own staff and equipment.

Gateway, Australia - 2008

## VSL – post-tensioning as the core business

For decades, VSL has designed, manufactured and installed durable, state-of-the art post-tensioning systems complying with international standards and approval guidelines for both new and existing structures. Services and products are all aimed at delivering the optimal solution for the customer.

Deep Bay Link, Hong Kong - 2005

## The VSL Network

VSL operates as a multinational group of companies whose subsidiaries and licensees are organised into closely-cooperating regional units. Customers benefit greatly from the continuing development of VSL's special construction methods and from the exchange of information taking place within the VSL Network.

Dubai Festival City, UAE - 2006

VSL's aim of creating innovative solutions by adapting proven experience is supported by the ability to identify and share immediately the best ideas that have been introduced anywhere within the network. The solutions are developed and tailored for clients worldwide.
VSL subsidiaries execute all work using their own personnel and equipment: technical consultancy and support during planning and all phases of construction are part of VSL's value-added service, which is tailored to suit the client's needs.

## VSL – your construction partner

With offices throughout the world, VSL offers a comprehensive range of professional, high-quality services for all kinds of projects, from feasibility studies and preliminary designs to alternative proposals, contractor consultancy services and field installation. All are aimed at finding the best possible solutions with the best value for money. VSL's involvement seeks to provide fully-customised solutions adapted to the client's requirements. Its worldwide network allows VSL to offer a high degree of competence and flexibility, participating with a spirit of co-operation to find the most appropriate solutions. VSL's goal is to be a privileged partner for engineers and contractors.

CREATING SOLUT

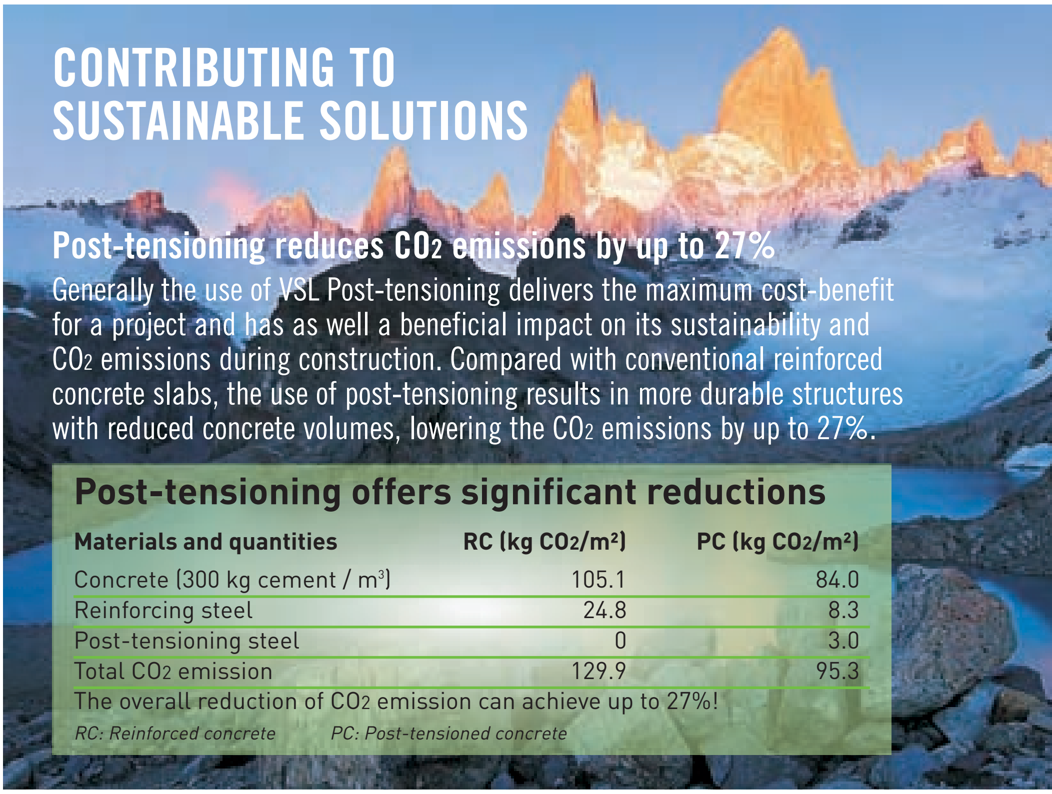
# 1956

## Changing the way we do business

For VSL, sustainable development means striking a balance in its development model between the economic profitability of its businesses and their social and environmental impacts. That commitment is formalised into the VSL Sustainable Development program which focuses on safety, use of fewer scarce materials and less energy and production of less pollution and waste.

## VSL – guided by a strong QSE culture

VSL's leading position is based on a rigorous and committed quality culture. The 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 is committed to maintaining the highest levels of client satisfaction and personnel safety.



# CONTRIBUTING TO SUSTAINABLE SOLUTIONS

## Post-tensioning reduces $CO_2$ emissions by up to 27%

Generally the use of VSL Post-tensioning delivers the maximum cost-benefit for a project and has as well a beneficial impact on its sustainability and $CO_2$ emissions during construction. Compared with conventional reinforced concrete slabs, the use of post-tensioning results in more durable structures with reduced concrete volumes, lowering the $CO_2$ emissions by up to 27%.

### Post-tensioning offers significant reductions

| Materials and quantities | RC (kg $CO_2$/m²) | PC (kg $CO_2$/m²) |
|---|---|---|
| Concrete (300 kg cement / m³) | 105.1 | 84.0 |
| Reinforcing steel | 24.8 | 8.3 |
| Post-tensioning steel | 0 | 3.0 |
| Total $CO_2$ emission | 129.9 | 95.3 |

The overall reduction of $CO_2$ emission can achieve up to 27%!

*RC: Reinforced concrete* *PC: Post-tensioned concrete*

Ras Laffan LNG, Qatar - 1996

## The VSL Academy

Competence is a key factor and VSL adopts a principle of continuous learning and training. Foremen, supervisors and site managers go through centralised training at the VSL Academy, where they learn best practice in all aspects of post-tensioning.

Barcelona New Exhibition Centre, Spain - 2008

## VSL Post-tensioning systems

The VSL Post-tensioning technology includes several systems that are specifically designed for different applications. The following table describes broadly these different systems and their main field of applications, which are thereon developed in this brochure.

| | Monostrand and slab tendons | | Multistrand tendons | | Stressbar | |
|---|---|---|---|---|---|---|
| | Bonded | Unbonded | Internal | External | Internal | External |
| APPLICATIONS | • Slabs on grade<br>• Building slabs<br>• Transverse post-tensioning in bridge decks… | | • Longitudinal post-tensioning in bridges<br>• Building frames<br>• Containments<br>• Special structures… | | • Short tendons, such as transverse post-tensioning for cable-stayed bridge pylons<br>• Precast connections<br>• Structural strengthening… | |

TIONS TOGETHER

# R&D: THE KEY TO QUALITY AND DURABILITY

Research and development are VSL's driving force. The issues of QSE and sustainability have long been priorities together with the efficiency of construction methods and site works. This is also the case for post-tensioning products and services where durability, monitoring and inspection are important to focus on, as too are competence in design and methods.

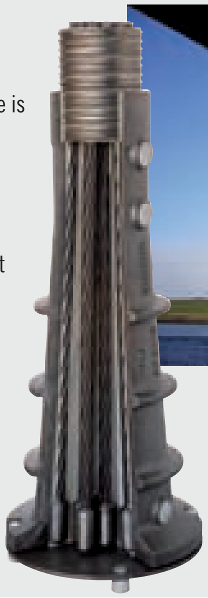
## Traceability and site efficiency

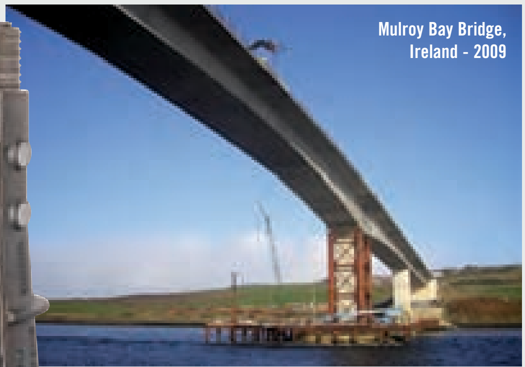
ADAPT, the tool for Automatic Data Acquisition for Post-Tensioning, collects data about tendon forces and elongation during stressing. It uses a personal digital assistant (PDA) to process the information for further use by the client.

PT Observer uses barcode process technology to collect all data throughout the entire post-tensioning process, assuring traceability. VSL's PT Observer and ADAPT systems greatly enhance the quality of the operational process.

## Adaptable and cost-saving solutions

The VSL AF Anchorage is used for vertical tendons, where the prestressing force is transferred to the structure at its lowest end and where there is no access.





Mulroy Bay Bridge, Ireland - 2009

VSL develops custom-made specialised equipment such as movable scaffolding systems, launching girders… for bridge construction and has the in-house capabilities to customise them from one project to the next.

## New solutions for enhanced durability

**Leak-tight encapsulation with PT-PLUS®**

VSL continuously drives durability development and markets its PT-PLUS® plastic duct system for leak-tight encapsulation and higher fatigue resistance.

**Electrical isolation with VSL CS 2000**

Together with the CS 2000 Anchorage, PT-PLUS® ducts produce electrically-isolated tendons (EIT) and allow monitoring of the effectiveness of the corrosion-protective encapsulation. The same principle had already been a success with a VSL world-first, the use of electrically isolated ground anchors on a project in 1985.

**Void control with the VSL Grout void sensor**

The VSL Grout void sensor is installed at potentially critical points on a tendon and checks for the existence of voids after grouting.

**Load control with the VSL Single strand load cell**

The VSL-designed Single strand load cell allows economical and precise measurement of the load on a strand. It is compact and easy to install, fitting onto any VSL Anchor head.

# TRAINING: AT THE HEART OF STRONG PERFORMANCE

VSL is committed to investing in its staff, setting up training schemes and striving for professionalism.

### VSL Academy

VSL has launched the VSL Academy 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 goals of the VSL Academy are to:

- provide a unique training facility and tools within VSL to train our personnel in the skill and techniques required to perform the work to the highest standards specified today;
- provide hands-on practical training on post-tensioning mock-ups designed to cover all operational procedures;
- harmonise working procedures and enhance knowledge.

**VSL Academy: a market leader's initiative**

### PMX – training in project management excellence

The programme's content combines technical topics, planning, organisation, risk management and result orientation with communication topics and leadership. Through this, VSL's managers transfer the fundamentals and culture of the company while promoting exchanges and useful networking throughout the group.

### On site training

As a specialist contractor, VSL aims to maintain and develop its staff's skills on a long-term basis. Senior staff members are in charge of teaching VSL Techniques to new recruits. A well-trained staff is VSL's most valuable asset in providing the best-possible service to clients.

# VSL POST-TENSIONING SOLUTIONS FOR

## Internal tendons – the most commonly-used solution

The VSL systems are based on the method of post-tensioning. Most applications of the multi-strand system are internal and cement grouted, providing bond to the structure. Such tendons are extensively used in bridges and transportation structures as well as being applied successfully in building construction.

**VSL's experience: 150,000 precast segments forming 6.3 million m$^2$ of bridge deck over the last 20 years**

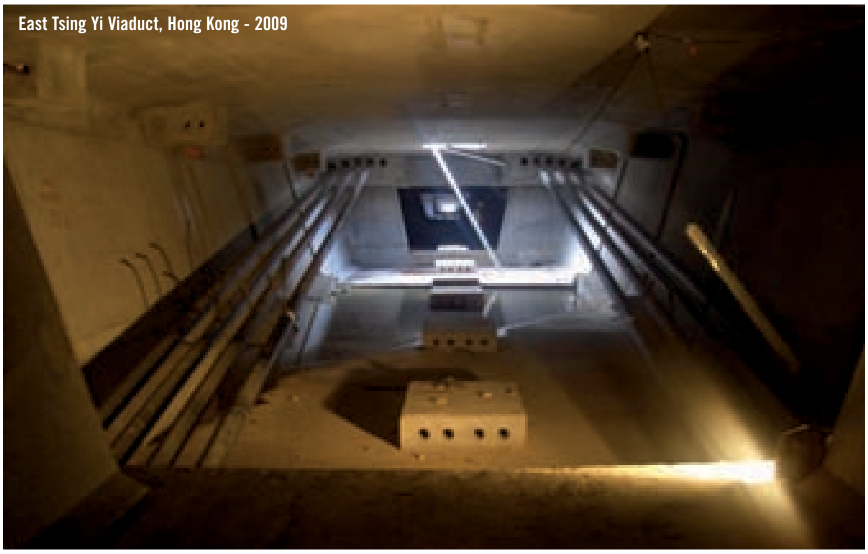
Shenzhen Western Corridor, Hong Kong - 2004

Kingston's Hunt's Bay Bridge, Jamaica - 2006

Gateway Upgrade, Australia - 2009

VSL Post-tensioning systems lead and shape the state-of-the-art in bridge construction. They meet the advanced technical and practical requirements of today's engineers and construction professionals. They are versatile and provide clients with unmatched durability, with a choice of steel or VSL PT-PLUS® plastic duct, as well as the availability of technical and site expertise for fully-encapsulated and electrically-isolated tendons (EIT). The systems comply with national and international standards and are approved by EOTA (European Organisation for Technical Approvals) and by other approval bodies.

# BRIDGES


East Tsing Yi Viaduct, Hong Kong - 2009

## External tendons for more flexibility

External post-tensioning tendons are positioned outside of the concrete section, though anchored into buttresses or diaphragms that form part of the bridge structure. They are therefore not bonded to the structure.
VSL external post-tensioning provides features such as the possibility of replacing tendons if required and easy inspection of the integrity of the corrosion protection. Applications are not restricted to concrete, but also include structural steel, composite steel-concrete bridges, timber and masonry structures. The external tendon technology has been used for bridge superstructures, girders in buildings and roof structures as well as for circular structures such as silos and reservoirs.


Boulonnais Viaduct, France - 1996


Gautrain Rapid Rail Link, South Africa - 2009


Brunswick Head, Australia - 2006


Medway Crossing Bridge, UK - 2001

External post-tensioning tendons can also be installed after completion of a structure if additional load capacity is required. This is done by adding tendons to the structure if the original design and construction were made to accommodate such an addition. Otherwise, a retrofit method can be implemented, although this requires a high level of engineering for structural analysis.

TIONS TOGETHER

# VSL POST-TENSIONING SOLUTIONS FOR BRIDGES

### VSL Post-tensioning – a tool for pushing the limits

Bridge construction without post-tensioning is unthinkable. It is even a prerequisite for most of today's methods and allows the fast bridging of large spans with aesthetically-pleasing results. VSL's competence is outstanding in all known bridge construction methods. It is unrivalled in precast segmental construction, a method particularly suited to building large structures rapidly and economically even and especially into congested urban environments.

### VSL as your "know-how partner"

VSL's post-tensioning know-how originates from thousands of projects and starts with a fundamental understanding of economically-optimised bridge concepts. With its design and methodology teams, VSL provides engineers and contractors with expertise in building cost-effective, durable and tailored structures.

INCREMENTAL LAUNCHING METHOD
Sagarra-Garrigues water channel, Spain - 2008

ERECTION BY LIFTING FRAME
West Tsing Yi Viaduct, Hong Kong - 2004

BALANCED CANTILEVER CAST-IN-SITU
Gateway bridge upgrade, Australia - 2008

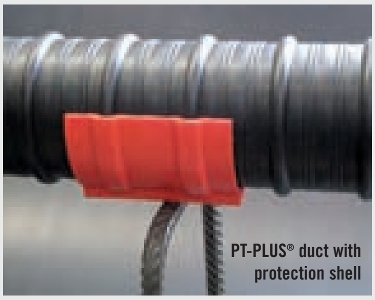
ERECTION BY UNDERSLUNG GANTRY
Windsor Flood Plane Project, Australia - 2006

ERECTION BY OVERHEAD GANTRY
Metro de Santiago, Chile - 2005

# ENHANCING DURABILITY

## Gaining something extra with VSL's PT-PLUS® duct system

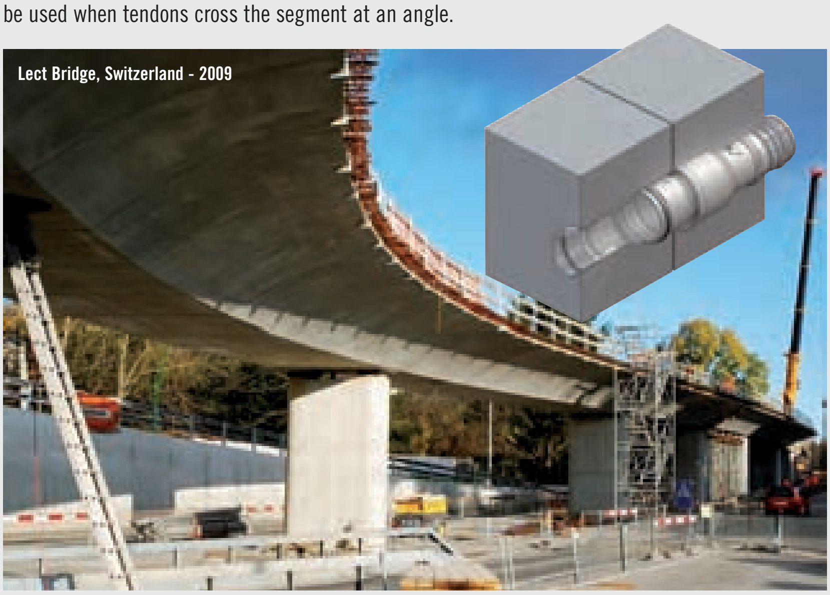
For conventional applications in non-agressive environment, corrugated steel ducts are normally used. However, the corrugated plastic ducts and plastic couplers of the VSL PT-PLUS® system provide important advantages when compared with conventional steel ducts, including tight encapsulation, high fatigue resistance and a low friction coefficient.
*For details see page 22.*



PT-PLUS® duct with protection shell

## A new coupler for EIT in precast structures

A new plastic coupler now permits full tendon encapsulation or EIT protection at the joints of precast segmental structures. The coupler is compact and similar in size to the ducting and can be used when tendons cross the segment at an angle.



Lect Bridge, Switzerland - 2009

## Enhancing durability – VSL's concept for multi-layer protection

**The multi-layer corrosion protection system enhances durability. It combines a careful overall concept and design of the structure's waterproof membranes, low-permeability concrete and leak-tight tendon encapsulation with a cementitious grout or other protection systems.**
**VSL is well qualified to assist decision makers with the adequate service when crucial protection strategies and measures are evaluated and decided.**

Electrically Isolated Tendons (EIT) at the Roeti Bridge, Switzerland - 2007

### The tendon encapsulation - the decisive choice

Bearing in mind *fib*'s bulletin 33 and given the specific characteristics of PT-PLUS®, the following is recommended:

**PL 1:** using corrugated metal duct with special high quality grout (e.g. VSL's HPI Grouting). Cement grout provides excellent protection however grouting is a task for specialists. As an experienced specialist contractor, VSL carries out high-quality grouting using trained personnel and reliable equipment and in accordance with well proven procedures. In addition, VSL recommends the use of vacuum-assisted grouting for the most challenging conditions, such as where high points are not accessible or in other special cases. VSL provides a full service for this state-of-the-art technique.

**PL 2:** using PT-PLUS® ducts as leak tight encapsulation for enhanced protection against corrosion and fatigue, this is particularly suited for transverse tendons in bridge deck slabs and other structures where tendons are close to the concrete surface and subjected to fatigue; generally structures in severe corrosion environment and to bridges and other structures with fatigue loadings.

VSL PT-PLUS® encapsulated tendons (PL 2) for high durability on Abu Dhabi Third Crossing, Dubai - 2008

**PL 3:** allowing monitoring of the integrity of tendon encapsulation including protection against stray currents, applying the Electrical Isolation Tendon (EIT) method with PT-PLUS® ducts and the appropriate VSL Anchorage. VSL's Grout void sensors enhance quality monitoring during grouting of tendons.

***PL = Protection Level***

# VSL POST-TENSIONING IN BUILDINGS - A TOOL TO ACHIEVE SUBSTANTIAL BENE

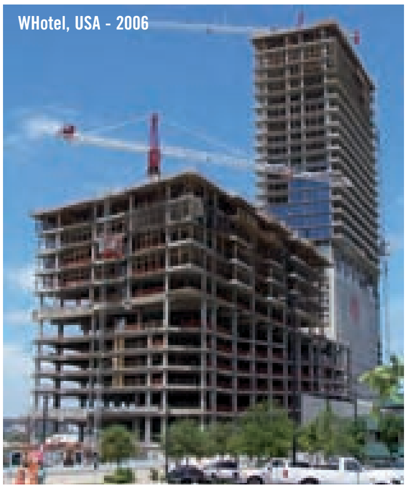
Kens Project, Australia - 2004

## Architects have:

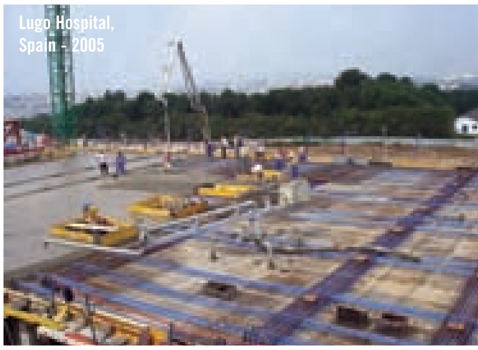
- more aesthetic freedom and larger column-free spaces that generate more flexibility for offices, shopping centres, warehouses, car parks and similar structures.

## Contractors gain through:

- shorter construction time as formwork is often simpler and due to lesser back-propping;
- reduced cycle times as post-tensioning allows the structure to be stripped earlier leading to an overall reduction in the construction programme;
- fast and easy installation of electric, air conditioning and other services for flat slabs;
- less energy consumption.



WHotel, USA - 2006



Lugo Hospital, Spain - 2005

## Considerable savings for all parties

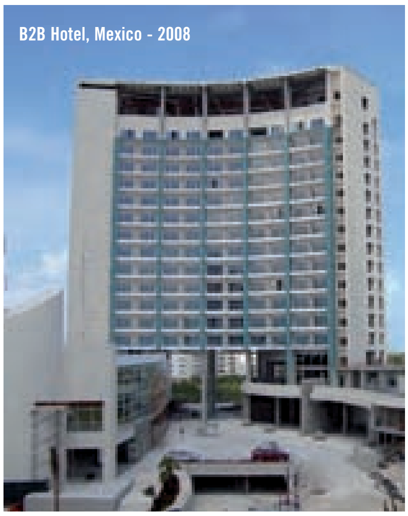
The advantages of using post-tensioning in buildings are being exploited in many countries and acknowledged by all partners in the construction process.

## Owners benefit from:

- savings in materials in structures and foundations, leading to more economical construction;
- reduced financing costs due to shorter construction periods;
- less need for maintenance because of the crack and vibration control;
- more useable space within the available height limits;
- reduced deflection of structures.

## VSL's experience of economical applications:

- post-tensioned slabs for all types of buildings, parking structures and warehouses;
- post-tensioned transfer beams and transfer plates to provide spacious, column-free, architecturally pleasing spaces such as entrance halls, lobbies and convention rooms;
- post-tensioned raft foundations resulting in more economical solutions with improved deflection behaviour and better soil pressure distribution;
- post-tensioned concrete walls such as cores and masonry walls, allowing the architect and engineer to design with more flexibility and pleasing aesthetics;



B2B Hotel, Mexico - 2008

# FITS

- post-tensioning in structural members such as the mega-trusses of high-rise buildings to withstand wind-generated overturning moments.

### VSL Post-tensioning services – providing a solid frame for any structure

VSL's scope of services goes beyond the supply of components and includes:

- design assistance at the conceptual stage to select the best option for the floor system and provide preliminary sizing and quantities;

Burj Residence Dubai, UAE - 2007

- assistance in all detailed design stages with a constant aim of optimising savings in materials, achieving sustainability of the structure and easing construction to reduce the cycle times and the resources required;
- all works for the supply and installation of the post-tensioning materials, including a turnkey service package provided by VSL's site teams.

**VSL's experience: Millions of square metres designed and built throughout the world over the past 50 years**

*Detailed information is given in VSL's "Post-tensioning in building" publication (Report Series 4.1 and 4.2).*

TIONS TOGETHER

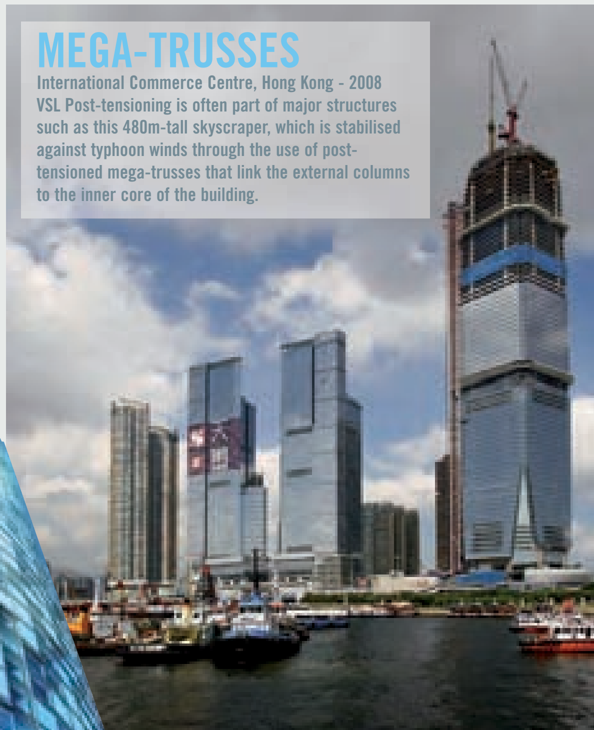
## APPLICATIONS

### FRAME CONSTRUCTION

Venetian Macao Resort Hotel, China - 2007
Frame construction for speed and ease of building with large open spaces or heavy loads.

### SLAB CONSTRUCTION

RCBC Plaza, Philippines - 2000
VSL Post-tensioning allows thinner slabs or larger spans.



### MEGA-TRUSSES

International Commerce Centre, Hong Kong - 2008
VSL Post-tensioning is often part of major structures such as this 480m-tall skyscraper, which is stabilised against typhoon winds through the use of post-tensioned mega-trusses that link the external columns to the inner core of the building.

### TRANSFER PLATE/BEAMS CONSTRUCTION

Liverpool Tower, UK - 2006
Accommodating different floor layouts to ensure proper load transfer.

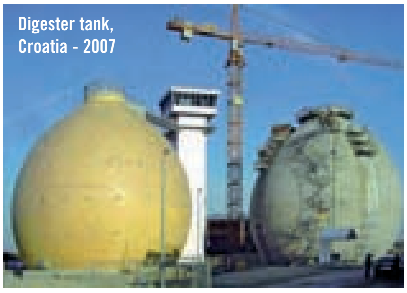
# VSL POST-TENSIONING: IDEALLY SUITED

### Unique VSL Anchorages for economical solutions

The shapes and functions of containment structures make them ideally suited to post-tensioning. Well-designed structures are practically crack-free and, most importantly, they are economical.

Water tank,
Cote d'Ivoire - 2008

Boyer Tank,
Australia - 2008



Digester tank,
Croatia - 2007

AF Anchorages

N'Kossa Barge,
France - 1995

Thanks to the variety of its post-tensioning anchorage systems, VSL offers versatile solutions for engineers and contractors to optimise costs and construction times. Some of the well-known VSL Anchorages are particularly suited for use in containment structures:

- The patented AF Anchorage, which is used as the lower non-stressing anchorage for vertical tendons that are not accessible during strand installation and stressing;
- The L Anchorage, which is used as the lower non-stressing anchorage for vertical tendons and allows the strand bundle to be pushed or pulled through and stressed after the concrete work for the wall has been finished;
- The Z Anchorage, which is normally used for hoop tendons that can be installed within the wall thickness and which therefore do not necessitate buttresses for the stressing operation.

L Anchorage

ICM Corn Silo,
USA - 2008

Z Anchorage

# TO CONTAINMENT STRUCTURES

Uljin Nuclear Power Plant, Korea - 2005

## Meeting stringent requirements with exceptional reliability

Some applications are extraordinary and call for additional measures and special testing:

### Nuclear applications

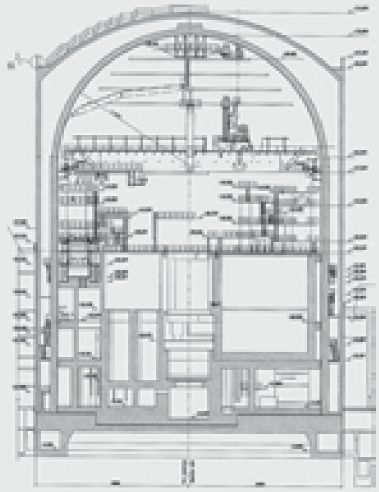
VSL carried out comprehensive tests on a full-scale mock-up of the latest generation of nuclear power plants to verify compliance of its PT systems and methods with new specific requirements. The purpose-built ring structure in Gien, France, has a radius of 24.46m and a height of 2.75m. VSL demonstrated that its systems, equipment and procedures meet the stringent requirements for installation, stressing and grouting operations on various types of tendons forming full 360° circle.

### Liquefied gas applications

The construction of tanks for LNG and LPG (liquefied natural and petroleum gas) requires cryogenic testing of the post-tensioned tendons. During these tests, strands and anchorages are subjected to temperatures down to -196°C and are tested according to ETAG 013 or other international standards. Through its long experience and proven post-tensioning systems, VSL is in a position to supply its post-tensioning systems to any LNG or LPG project worldwide.

### Two units LAES-2 Nuclear Power Station in St Petersburg, Russia.

The VSL System with 55 greased and sheathed 0.6" strands is used for the 67.7m high inner of the two containment shells. 76 hoop tendons anchored in one of the two buttresses, 13 extra tendons in the dome, as well as 50 vertical over-the-dome tendons stressed from a stressing gallery are post-tensioned according to the latest nuclear containment requirements. The system allows checking the residual load, retensioning or replacing the tendons.

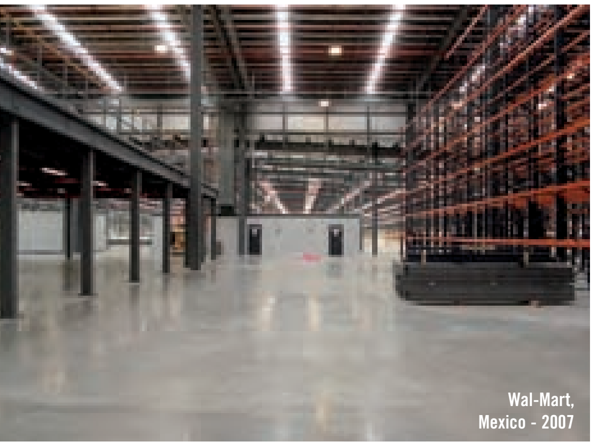


## EXTREME TEMPERATURE TESTING

Anchorages and tendons tested at temperatures down to -196°C

Shanghai LNG Tank, China - 2007-2009

# VSL POST-TENSIONING FOR SLAB ON GRADE CONSTRUCTION: THE COST-EFFECTIVE SOLUTION



Wal-Mart, Mexico - 2007

Hangar Mosnov, Czech Republic - 2007

## Benefits to the owner

**Elimination of joints:** Owners and operators benefit from the elimination of all or most of the costly joints, when using post-tensioned slab on grade.

**Shorter construction time:** Compared with ordinary reinforced concrete slabs, the use of VSL's technologies leads to less excavation, a thinner slab, little or no reinforcement and few if any joints. Large areas in excess of 2,500m$^2$ can be concreted, which results in a shorter construction time and contributes to a very competitive initial cost.

Austrak, Australia - 2003

**"Crack free" performance:** Initial stressing can prevent shrinkage cracking. Post-tensioning compresses the slab and counteracts tensile stresses that would otherwise cause cracking under the worst combinations of loads or in poor soil conditions.

**High impact and abrasion resistance:** The compression resulting from post-tensioning combined with an optimum concrete strength and surface treatment reduces general wear and tear and subsequent maintenance costs.

**Low maintenance:** The significant reduction in the number of joints means that less maintenance is required, giving great improvements in operational efficiency.

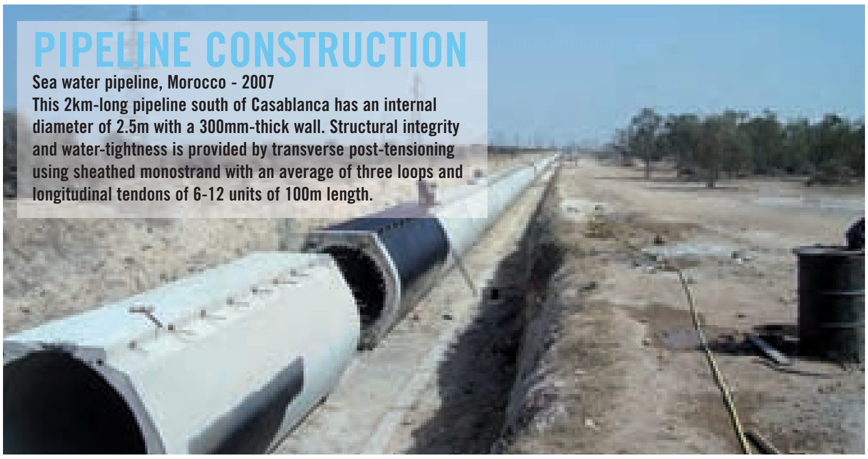
## Large slabs, indoor or outdoor

VSL Post-tensioning is widely used in the construction of pavement areas and in slabs on grade, where a concrete slab foundation is placed directly on the ground. Its advantages provide benefits in many different types of projects including warehouses, distribution centres, container storage terminals, rail and shipping terminals, airports, manufacturing facilities and as floor bases for liquid retaining structures. Post-tensioned slabs are also used for residential purposes and in recreation, such as for tennis courts and skating rinks.
VSL can provide the full range of services from the installation of post-tensioning to the complete design and construction of the concrete slab.

Nestlé Distribution Plant, Chile - 2001

**The 30,000m$^2$ of joint-free slab of the Nestlé Plant constructed by VSL Chile represent the present world record.**

# VSL POST-TENSIONING FOR SPECIAL STRUCTURES: A SMART ALTERNATIVE



## PIPELINE CONSTRUCTION

Sea water pipeline, Morocco - 2007
This 2km-long pipeline south of Casablanca has an internal diameter of 2.5m with a 300mm-thick wall. Structural integrity and water-tightness is provided by transverse post-tensioning using sheathed monostrand with an average of three loops and longitudinal tendons of 6-12 units of 100m length.

### Versatile applications

Without post-tensioning, many special structures could only be built with great effort, if built at all. Over the years, VSL's post-tensioning services have been used for a very wide range of highly prestigious and complex structures including offshore platforms, concrete floating barges, dams and many others. Customers value the experience and versatility they gain by having VSL as a partner from the early planning stages through to construction.

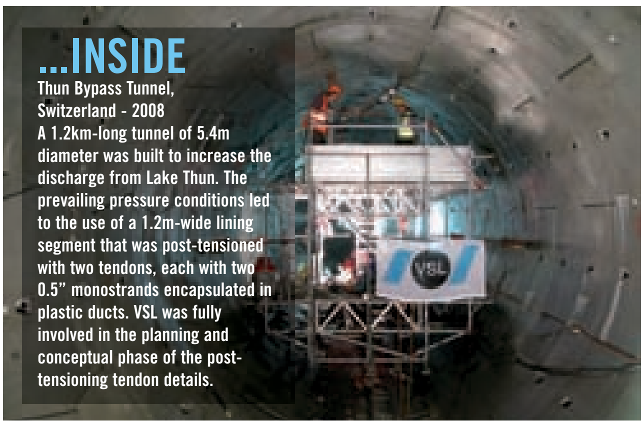
## STADIUM CONSTRUCTION

Sazka Stadium Prague, Czech Republic - 2003
The challenge of building a multifunctional stadium with two halls that are part of irregular and complicated structural elements is an excellent example of a project where clients can benefit from the versatility of VSL as a professional post-tensioning partner.

## SUB-STRUCTURE CONSTRUCTION

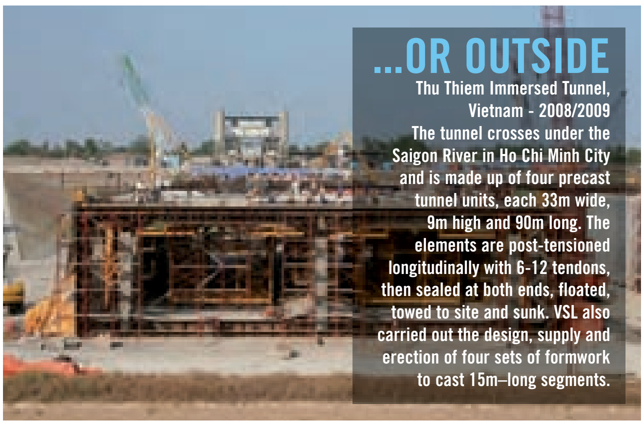
Machang Bridge, Korea - 2006
Post-tensioning tendons with VSL Loop Anchorages were installed for the deck-to-pile footing tie-down system in the piers supporting the bridge's back spans.

## TUNNEL CONSTRUCTION - WHETHER HYDROSTATIC PRESSURE PUSHES FROM...



### ...INSIDE

Thun Bypass Tunnel, Switzerland - 2008
A 1.2km-long tunnel of 5.4m diameter was built to increase the discharge from Lake Thun. The prevailing pressure conditions led to the use of a 1.2m-wide lining segment that was post-tensioned with two tendons, each with two 0.5" monostrands encapsulated in plastic ducts. VSL was fully involved in the planning and conceptual phase of the post-tensioning tendon details.



### ...OR OUTSIDE

Thu Thiem Immersed Tunnel, Vietnam - 2008/2009
The tunnel crosses under the Saigon River in Ho Chi Minh City and is made up of four precast tunnel units, each 33m wide, 9m high and 90m long. The elements are post-tensioned longitudinally with 6-12 tendons, then sealed at both ends, floated, towed to site and sunk. VSL also carried out the design, supply and erection of four sets of formwork to cast 15m–long segments.

T I O N S   T O G E T H E R

# VSL POST-TENSIONING FOR REPAIR WO
# A MUST FOR TAILOR-MADE SOLUTIONS

Structural remedial work requires thorough diagnosis of damage and deterioration followed by full assessment of the causes, risks and consequences involved.
VSL employs state-of-the-art equipment and special inspection techniques to detect defects in reinforced and prestressed concrete structures before any significant damage occurs. Close co-operation with materials testing institutes and structural designers, together with the use of the latest investigation techniques, enables VSL to prepare precise and comprehensive reports.

### Assessment diagnosis of structural conditions includes:

- inspection and surveillance of concrete structures;
- condition evaluation of the same;
- root cause analysis;
- design of repair strategies;
- estimating the order of magnitude for the cost of repairs.

## REPLACEMENT OF EXTERNAL POST-TENSIONING IN BRIDGES

**St Cloud Viaduct, France - 2000**

The external tendons that reinforced the 1974-built 1,102m-long Saint-Cloud Bridge near Paris showed signs of corrosion and the client decided to replace them. As a first precautionary step, shock-absorbers were fitted at each side of the deviators before the tendons were cut and the anchorages removed or adapted. New external tendons were then installed by VSL.

## REPAIR OF BRIDGES

**Figueira de Foz Bridge, Portugal - 2005**

VSL, in partnership with a local contractor, carried out repair works including external post-tensioning, strengthening of the abutments with bars and replacement of expansion joints. There was also retrofitting of structural bearings and seismic devices, including the installation of 4 x 500kN shock-absorbers at the abutments.



C R E A T I N G   S O L U T

# RKS:

## STRENGTHENING OF HISTORICAL BUILDINGS

**Las Arenas Bullfighting Ring, Spain - 2007**

One of the many examples in Barcelona where VSL has assisted with engineering and specialised site works is this former bull ring, built in 1898, which has been transformed into a leisure and entertainment complex. VSL carried out engineering and post-tensioning works in connection with the transfer slab and beams of the Neo-Mudéjar façade. The project involved post-tensioned floors with spans of between 12m and 17m and the supply of other VSL products such a neoprene bearings and studs.

**The Leaning Tower of Pisa, Italy - 1993**

VSL strengthened the world-renowned Leaning Tower of Pisa with 18 specially-developed monostrand hoop tendons. The optimum solution consisted of a marble-coloured PE-sheath and galvanized, non-greased 0.6" strand with a centre stressing anchorage, allowing force adjustment and monitoring during and after the stressing operation.

## STRENGTHENING OF A NUCLEAR POWER PLANT

**Gösgen Nuclear Power Plant, Switzerland - 2005**

A carbon fibre tendon system was used for the seismic upgrade of the emergency feed building at the Gösgen nuclear power plant. The system consists of carbon CFRP plates and head and is well suited for seismic and other strengthening measures where post-tensioning forces are needed in very thin tensile members.

## SILO REPAIR AND STRENGTHENING

**Blue Circle Cement Silo, Singapore - 2001**

The 60m-tall silo was strengthened using a VSL-engineered solution of externally wrapped, bonded tendons each with four strands of 0.6”. The 66 tendons are encapsulated in flat high-density polyethylene ducts and anchored into special stressing brackets.

### VSL’s other repair solutions

VSL also provides other structural solutions for the repair and strengthening of structures including:

- passive strengthening with the design and application of:
  - bonded CFRP (carbon fibre reinforced polymer);
  - bonded SRP (steel reinforced polymer).
- protection with:
  - Ductal®, the ultra-high-strength and ductile blast-resistant solution;
  - dampers for mitigation of vibration induced by earthquake, wind and human activities;
  - cathodic protection for corrosion mitigation.

TIONS TOGETHER

# CREATING SOLUTIONS TOGETHER

## GROUND ENGINEERING

- Ground anchors
- VSoL® walls
- D-walls & Piles
- Ground improvement

## CONSTRUCTION

- Bridges
- Buildings
- Slab on grade
- Containment structures
- Special structures
- Heavy lifting
- Formwork & Equipment

## REPAIR, STRENGTHENING & PRESERVATION

- Structural diagnostics & Monitoring
- Repair & Strengthening
- Protection & Preservation

## SYSTEMS & TECHNOLOGIES

- Post-tensioning strand systems
- Bars & post-tensioning bar systems
- Stay cable systems
- Damping systems (stays & buildings)
- Ductal® UHP concrete
- Bearings & Joints

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# VSL TECHNICAL DATA AND DESIGN CONSIDERATIONS

STRAND AND TENDON PROPERTIES

PT-PLUS® DUCT SYSTEM DATA

TENDON LAYOUT, RADII, FRICTION AND TENDON LOSSES FOR INTERNAL AND EXTERNAL CABLES

BLOCK-OUTS AND EQUIPMENT DATA

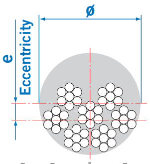
# 1 - STRAND

## 1.1 - STRAND PROPERTIES 13mm (0.5”)

| Strand type | | | prEN 10138 – 3 (2006) Y1860S7 | | ASTM A 416-06 Grade 270 |
|---|---|---|---|---|---|
| Nominal diameter | d | (mm) | 12.5 | 12.9 | 12.7 |
| Nominal cross section | $A_p$ | (mm[2]) | 93 | 100 | 98.7 |
| Nominal mass | M | (kg/m) | 0.726 | 0.781 | 0.775 |
| Nominal yield strength | $f_{p0,1k}$ | (MPa) | 1634[1] | 1640[1] | 1675[2] |
| Nominal tensile strength | $f_{pk}$ | (MPa) | 1860 | 1860 | 1860 |
| Specif./min. breaking load | $F_{pk}$ | (kN) | 173 | 186 | 183.7 |
| Young’s modulus | | (GPa) | approx. 195 | | |
| Relaxation[3] after 1000 h at 20°C and 0.7 x $F_{pk}$ | | (%) | max. 2.5 | | |

*1) Characteristic value measured at 0.1% permanent extension*
*2) Minimum load at 1% extension for low-relaxation strand*
*3) Valid for relaxation class acc. to prEN 10138-3 or low-relaxation grade acc. to ASTM A 416-06*

## 1.2 - TENDON PROPERTIES 13mm (0.5”)

| Unit | Strands numbers | Steel area | | | Breaking load | | | Corrugated steel duct[3] (recommended) | | Corrugated plastic duct VSL PT-PLUS® | | Steel pipes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_p$ acc. to prEN | | ASTM | Y1860S7 (prEN) | | Grade 270 (ASTM) | Øi / Øe | e  | Øi / Øe | e | Ø ext x t |
| | | d=12.5 mm $A_p$=93 mm[2] | d=12.9 mm $A_p$=100 mm[2] | d=12.7 mm $A_p$=100 mm[2] | d=12.5 mm $A_p$=93 mm[2] | d=12.9 mm $A_p$=100 mm[2] | d=12.7 mm $A_p$=98.7 mm[2] | | | | | |
| | | [mm[2]] | [mm[2]] | [mm[2]] | [kN] | [kN] | [kN] | [mm] | [mm] | [mm] | [mm] | [mm] |
| 5-1 | 1 | 93 | 100 | 98.7 | 173 | 186 | 183.7 | 20/25 | 3 | 22/25 | 6 | 25.0 x 2.0 |
| 5-2 | 2 | 186 | 200 | 197 | 346 | 372 | 367 | 35/40 | 8 | 76/25[2] | - | 31.8 x 2.0/2.5/3.0 |
| 5-3 | 3 | 279 | 300 | 296 | 519 | 558 | 551 | 35/40 | 6 | 76/25[2] | - | 33.7 x 2.0/2.5/3.0 |
| 5-4 | 4 | 372 | 400 | 395 | 692 | 744 | 735 | 40/45[1] | 7 | 76/25[2] | - | 42.4 x 2.0/2.5/3.0 |
| 5-7 | 5 | 465 | 500 | 494 | 865 | 930 | 919 | 45/50 | 8 | 58/63 | 14 | 60.3 x 2.0/2.5/3.0 |
| | 6 | 558 | 600 | 592 | 1038 | 1116 | 1102 | 45/50 | 6 | 58/63 | 12 | |
| 5-7 | 7 | 651 | 700 | 691 | 1211 | 1302 | 1286 | 50/57 | 7 | 58/63 | 11 | 60.3 x 2.0/2.5/3.0 |
| 5-12 | 8 | 744 | 800 | 790 | 1384 | 1488 | 1470 | 55/62 | 9 | 58/63 | 10 | 70.0 x 2.0/2.5/3.0 |
| | 9 | 837 | 900 | 888 | 1557 | 1674 | 1653 | 55/62 | 8 | 58/63 | 9 | |
| | 10 | 930 | 1000 | 987 | 1730 | 1860 | 1837 | 60/67 | 10 | 58/63 | 9 | |
| | 11 | 1023 | 1100 | 1086 | 1903 | 2046 | 2021 | 60/67 | 9 | 58/63 | 8 | |
| 5-12 | 12 | 1116 | 1200 | 1184 | 2076 | 2232 | 2204 | 60/67 | 8 | 58/63 | 7 | 70.0 x 2.0/2.5/3.0 |
| 5-15 | 13 | 1209 | 1300 | 1283 | 2249 | 2418 | 2388 | 65/72 | 9 | 76/81 | 14 | 82.5 x 2.0/2.5/3.0 |
| | 14 | 1302 | 1400 | 1382 | 2422 | 2604 | 2572 | 65/72 | 8 | 76/81 | 13 | |
| 5-15 | 15 | 1395 | 1500 | 1481 | 2595 | 2790 | 2756 | 70/77 | 9 | 76/81 | 12 | 82.5 x 2.0/2.5/3.0 |
| 5-19 | 16 | 1488 | 1600 | 1579 | 2768 | 2976 | 2939 | 70/77 | 9 | 76/81 | 12 | 88.9 x 2.5/3.0/3.5 |
| | 17 | 1581 | 1700 | 1678 | 2941 | 3162 | 3123 | 75/82 | 11 | 76/81 | 11 | |
| | 18 | 1674 | 1800 | 1777 | 3114 | 3348 | 3307 | 75/82 | 10 | 76/81 | 10 | |
| 5-19 | 19 | 1767 | 1900 | 1875 | 3287 | 3534 | 3490 | 75/82 | 9 | 76/81 | 9 | 88.9 x 2.5/3.0/3.5 |
| 5-22 | 20 | 1860 | 2000 | 1974 | 3460 | 3720 | 3674 | 80/87 | 10 | 100/106 | 20 | 88.9 x 2.5/3.0/3.5 |
| | 21 | 1953 | 2100 | 2073 | 3633 | 3906 | 3858 | 80/87 | 9 | 100/106 | 19 | |
| 5-22 | 22 | 2046 | 2200 | 2171 | 3806 | 4092 | 4041 | 80/87 | 8 | 100/106 | 18 | 88.9 x 2.5/3.0/3.5 |
| 5-27 | 23 | 2139 | 2300 | 2270 | 3979 | 4278 | 4225 | 85/92 | 12 | 100/106 | 19 | 101.6 x 3.0/4.0/5.0 |
| | 24 | 2232 | 2400 | 2369 | 4152 | 4464 | 4409 | 85/92 | 11 | 100/106 | 18 | |
| | 25 | 2325 | 2500 | 2468 | 4325 | 4650 | 4593 | 90/97 | 14 | 100/106 | 19 | |
| | 26 | 2418 | 2600 | 2566 | 4498 | 4836 | 4776 | 90/97 | 13 | 100/106 | 18 | |
| 5-27 | 27 | 2511 | 2700 | 2665 | 4671 | 5022 | 4960 | 95/102 | 15 | 100/106 | 17 | 101.6 x 3.0/4.0/5.0 |
| 5-31 | 28 | 2604 | 2800 | 2764 | 4844 | 5208 | 5144 | 95/102 | 14 | 100/106 | 16 | 108.0 x 3.0/4.0/5.0 |
| | 29 | 2697 | 2900 | 2862 | 5017 | 5394 | 5327 | 95/102 | 13 | 100/106 | 15 | |
| | 30 | 2790 | 3000 | 2961 | 5190 | 5580 | 5511 | 95/102 | 12 | 100/106 | 14 | |
| 5-31 | 31 | 2883 | 3100 | 3060 | 5363 | 5766 | 5695 | 95/102 | 11 | 100/106 | 13 | 108.0 x 3.0/4.0/5.0 |
| 5-37 | 32 | 2976 | 3200 | 3158 | 5536 | 5952 | 5878 | 100/107 | 13 | 115/121 | 20 | 114.3 x 3.0/4.0/5.0 |
| | 33 | 3069 | 3300 | 3257 | 5709 | 6138 | 6062 | 100/107 | 12 | 115/121 | 19 | |
| | 34 | 3162 | 3400 | 3356 | 5882 | 6324 | 6246 | 100/107 | 12 | 115/121 | 19 | |
| | 35 | 3255 | 3500 | 3455 | 6055 | 6510 | 6430 | 110/117 | 17 | 115/121 | 19 | |
| | 36 | 3348 | 3600 | 3553 | 6228 | 6696 | 6613 | 110/117 | 17 | 115/121 | 19 | |
| 5-37 | 37 | 3441 | 3700 | 3652 | 6401 | 6882 | 6797 | 110/117 | 16 | 115/121 | 18 | 114.3 x 3.0/4.0/5.0 |
| 5-43 | 43 | 3999 | 4300 | 4244 | 7439 | 7998 | 7899 | 120/127 | 18 | 130/136 | 23 | 127.0 x 3.0/4.0/5.0 |
| 5-55 | 55 | 5115 | 5500 | 5429 | 9515 | 10230 | 10104 | 130/137 | 17 | 130/136 | 17 | 139.7 x 3.0/4.0/5.0 |

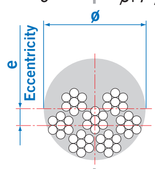
*1) Flat ducts possible as well*
*2) Flat duct PT-PLUS® with rectangular slab anchorages, for PT-PLUS® see also under 3.1.3.*
*3) If flat ducts (steel or PT PLUS®) to be used with square type castings please contact your VSL representative. In plan view, tendons with slab type anchorages must be straight between anchorages or have only unidirectional turns with min. radii of > 6 m. Strands must always be pushed-in prior to concreting. Eccentricity e: negligible*
*4) Given values may slightly vary depending on local availability of ducts. They are minimal for most applications. For special cases (long tendons, many curvatures, small radii etc.) greater size duct is recommended – please verify with VSL. In any case the filling ratio (cross-section steel / duct) must not exceed 0.5 (EN523).*
*5) Please check with the nearest VSL office for the complete anchorage list.*

## 1.3 - STRAND PROPERTIES 15mm (0.6")

| Strand type | | | prEN 10138 – 3 (2006) Y1860S7 | | ASTM A 416-06 Grade 270 |
|---|---|---|---|---|---|
| Nominal diameter | d | (mm) | 15.3 | 15.7 | 15.24 |
| Nominal cross section | $A_p$ | (mm²) | 140 | 150 | 140 |
| Nominal mass | M | (kg/m) | 1.093 | 1.172 | 1.102 |
| Nominal yield strength | $f_{p0,1k}$ | (MPa) | 1636[1] | 1640[1] | 1676[2] |
| Nominal tensile strength | $f_{pk}$ | (MPa) | 1860 | 1860 | 1860 |
| Specif./min. breaking load | $F_{pk}$ | (kN) | 260 | 279 | 260.7 |
| Young's modulus | | (GPa) | approx. 195 | | |
| Relaxation[3] after 1000 h at 20°C and 0.7 x $F_{pk}$ | | (%) | max. 2.5 | | |

*1) Characteristic value measured at 0.1% permanent extension*
*2) Minimum load at 1% extension for low-relaxation strand*
*3) Valid for relaxation class acc. to prEN 10138-3 or low-relaxation grade acc. to ASTM A 416-06*

## 1.4 - TENDON PROPERTIES 15mm (0.6")

| Unit | Strands numbers | Steel area | | | Breaking load | | | Corrugated steel duct[3] (recommended) | | Corrugated plastic duct VSL PT-PLUS® | | Steel pipes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_p$ acc. to prEN | | ASTM | Y1860S7 (prEN) | | Grade 270 (ASTM) | Øi / Øe | e | Øi / Øe | e | Ø ext. x t |
| | | d=15.3 mm $A_p$=140 mm² | d=15.7 mm $A_p$=150 mm² | d=15.24 mm $A_p$=140 mm² | d=15.3 mm $A_p$=140 mm² | d=15.7 mm $A_p$=150 mm² | d=15.24 mm $A_p$=140 mm² | |  | | | |
| | | [mm²] | [mm²] | [mm²] | [kN] | [kN] | [kN] | [mm] | [mm] | [mm] | [mm] | [mm] |
| 6-1 | 1 | 140 | 150 | 140 | 260 | 279 | 260.7 | 25/30 | 5 | 22/25 | 4 | 25.0 x 2.0 |
| 6-2 | 2 | 280 | 300 | 280 | 520 | 558 | 521 | 40/45 | 9 | 76/25[2] | - | 33.7 x 2.0/2.5/3.0 |
| 6-3 | 3 | 420 | 450 | 420 | 780 | 837 | 782 | 40/45 | 6 | 76/25[2] | - | 42.4 x 2.0/2.5/3.0 |
| 6-4 | 4 | 560 | 600 | 560 | 1040 | 1116 | 1043 | 45/50[1] | 7 | 76/25[2] | - | 48.3 x 2.0/2.5/3.0 |
| 6-7 | 5 | 700 | 750 | 700 | 1300 | 1395 | 1304 | 50/57 | 8 | 58/63 | 13 | 76.1 x 2.0/2.5/3.0 |
| │ | 6 | 840 | 900 | 840 | 1560 | 1674 | 1564 | 55/62 | 9 | 58/63 | 11 | │ |
| 6-7 | 7 | 980 | 1050 | 980 | 1820 | 1953 | 1825 | 55/62 | 7 | 58/63 | 9 | 76.1 x 2.0/2.5/3.0 |
| 6-12 | 8 | 1120 | 1200 | 1120 | 2080 | 2232 | 2086 | 65/72 | 11 | 76/81 | 18 | 80.0 x 2.0/.2.5 |
| │ | 9 | 1260 | 1350 | 1260 | 2340 | 2511 | 2346 | 65/72 | 9 | 76/81 | 16 | │ |
| │ | 10 | 1400 | 1500 | 1400 | 2600 | 2790 | 2607 | 70/77 | 11 | 76/81 | 15 | │ |
| │ | 11 | 1540 | 1650 | 1540 | 2860 | 3069 | 2868 | 70/77 | 9 | 76/81 | 13 | │ |
| 6-12 | 12 | 1680 | 1800 | 1680 | 3120 | 3348 | 3128 | 75/82 | 11 | 76/81 | 12 | 80.0 x 2.0/.2.5 |
| 6-15 | 13 | 1820 | 1950 | 1820 | 3380 | 3627 | 3389 | 80/87 | 13 | 100/106 | 25 | 101.6 x 3.0/4.0/5.0 |
| │ | 14 | 1960 | 2100 | 1960 | 3640 | 3906 | 3650 | 80/87 | 11 | 100/106 | 24 | |
| 6-15 | 15 | 2100 | 2250 | 2100 | 3900 | 4185 | 3911 | 80/87 | 10 | 100/106 | 23 | 101.6 x 3.0/4.0/5.0 |
| 6-19 | 16 | 2240 | 2400 | 2240 | 4160 | 4464 | 4171 | 85/92 | 12 | 100/106 | 22 | 101.6 x 3.0/4.0/5.0 |
| │ | 17 | 2380 | 2550 | 2380 | 4420 | 4743 | 4432 | 85/92 | 11 | 100/106 | 20 | │ |
| │ | 18 | 2520 | 2700 | 2520 | 4680 | 5022 | 4693 | 90/97 | 13 | 100/106 | 19 | │ |
| 6-19 | 19 | 2660 | 2850 | 2660 | 4940 | 5301 | 4953 | 90/97 | 12 | 100/106 | 18 | 101.6 x 3.0/4.0/5.0 |
| 6-22 | 20 | 2800 | 3000 | 2800 | 5200 | 5580 | 5214 | 100/107 | 17 | 100/106 | 17 | 108.0 x 3.0/4.0 |
| │ | 21 | 2940 | 3150 | 2940 | 5460 | 5859 | 5475 | 100/107 | 16 | 100/106 | 16 | |
| 6-22 | 22 | 3080 | 3300 | 3080 | 5720 | 6138 | 5735 | 100/107 | 15 | 100/106 | 15 | 114.3 x 3.0/4.0/5.0 |
| 6-27 | 23 | 3220 | 3450 | 3220 | 5980 | 6417 | 5996 | 100/107 | 14 | 115/121 | 22 | 114.3 x 3.0/4.0/5.0 |
| │ | 24 | 3360 | 3600 | 3360 | 6240 | 6696 | 6257 | 100/107 | 13 | 115/121 | 22 | │ |
| │ | 25 | 3500 | 3750 | 3500 | 6500 | 6975 | 6518 | 110/117 | 18 | 115/121 | 21 | │ |
| │ | 26 | 3640 | 3900 | 3640 | 6760 | 7254 | 6778 | 110/117 | 17 | 115/121 | 21 | │ |
| 6-27 | 27 | 3780 | 4050 | 3780 | 7020 | 7533 | 7039 | 110/117 | 16 | 115/121 | 20 | 114.3 x 3.0/4.0/5.0 |
| 6-31 | 28 | 3920 | 4200 | 3920 | 7280 | 7812 | 7300 | 110/117 | 15 | 130/136 | 27 | 127.0 x 3.0/4.0/5.0 |
| │ | 29 | 4060 | 4350 | 4060 | 7540 | 8091 | 7560 | 120/127 | 21 | 130/136 | 27 | │ |
| │ | 30 | 4200 | 4500 | 4200 | 7800 | 8370 | 7821 | 120/127 | 20 | 130/136 | 26 | │ |
| 6-31 | 31 | 4340 | 4650 | 4340 | 8060 | 8649 | 8082 | 120/127 | 19 | 130/136 | 25 | 127.0 x 3.0/4.0/5.0 |
| 6-37 | 32 | 4480 | 4800 | 4480 | 8320 | 8928 | 8342 | 120/127 | 18 | 130/136 | 24 | 139.7 x 3.0/4.0 |
| │ | 33 | 4620 | 4950 | 4620 | 8580 | 9207 | 8603 | 120/127 | 17 | 130/136 | 23 | │ |
| │ | 34 | 4760 | 5100 | 4760 | 8840 | 9486 | 8864 | 120/127 | 16 | 130/136 | 22 | │ |
| │ | 35 | 4900 | 5250 | 4900 | 9100 | 9765 | 9125 | 130/137 | 22 | 130/136 | 22 | │ |
| │ | 36 | 5040 | 5400 | 5040 | 9360 | 10044 | 9385 | 130/137 | 21 | 130/136 | 21 | │ |
| 6-37 | 37 | 5180 | 5550 | 5180 | 9620 | 10323 | 9646 | 130137 | 20 | 130/136 | 20 | 139.7 x 3.0/4.0 |
| 6-43 | 43 | 6020 | 6450 | 6020 | 11180 | 11997 | 11210 | 140/147 | 21 | 150/157 | 27 | 152.4 x 3.0/4.0/5.0 |
| 6-55 | 55 | 7700 | 8250 | 7700 | 14300 | 15345 | 14339 | 160/167 | 26 | 150/157 | 21 | 168.3 x 3.0/4.0 |

*1) Flat ducts possible as well*
*2) Flat duct PT-PLUS® with rectangular slab anchorages, for PT-PLUS® see also under 3.1.3.*
*3) If flat ducts (steel or PT PLUS®) to be used with square type castings please contact your VSL representative. In plan view, tendons with slab type anchorages must be straight between anchorages or have only unidirectional turns with min. radii of > 6 m. Strands must always be pushed-in prior to concreting. Eccentricity e: negligible*
*4) Given values may slightly vary depending on local availability of ducts. They are minimal for most applications. For special cases (long tendons, many curvatures, small radii etc.) greater size duct is recommended – please verify with VSL. In any case the filling ratio (cross-section steel / duct) must not exceed 0.5 (EN523).*
*5) Please check with the nearest VSL office for the complete anchorage list.*

# 2 - ANCHORAGES

For the selection and the dimensions of the most commonly used anchorages, please consult the VSL data sheets on anchorages. For spacing between anchorages and edge distance, refer to individual anchorage data sheet.

# 3 - DUCTING

## 3.1 TYPES

### 3.1.1 Bright corrugated steel ducts

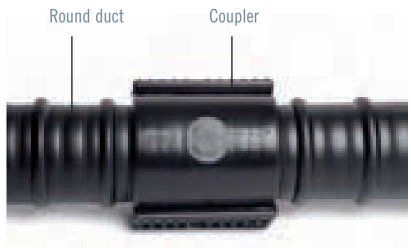
The most commonly used sheaths are made from rolled steel strip. Round and flat (max. 5 strands are available). They are corrugated and leak-tight and must have sufficient strength to withstand varying degrees and types of mechanical loading. For additional information and details, locally valid norms (or for example EN523) can be consulted.

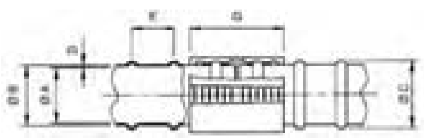
### 3.1.2 Galvanized corrugated steel ducts

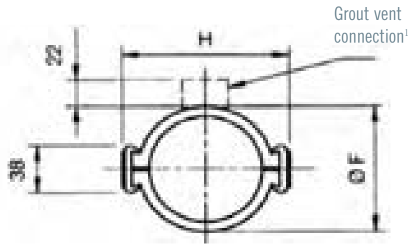
Galvanization is sometimes used to ensure corrosion protection of the metal strip. It can provide lower friction losses when stressing the tendon.
*Please check local code requirements.*

### 3.1.3 Corrugated PT-PLUS® duct system

For enhanced corrosion protection and fatigue resistance of the tendons, use of the VSL PT-PLUS® corrugated plastic duct system is recommended. The PT-PLUS® system is particularly suitable for railroad brides, bridge decks, parking structures and other situations where severe corrosion or high fatigue loading may be expected. In addition, the PT-PLUS® system with additional details at the anchorages allows to provide electrically isolated tendons (EIT) and a protection level of PL3 (*fib* bulletin 33). These EIT tendons permit monitoring of the leak tightness of the tendon encapsulation and protection of the tendon over the entire design life of the structure.




*[1] Couplers are available with/without grout vents for a threaded tube with dia. 23 mm*

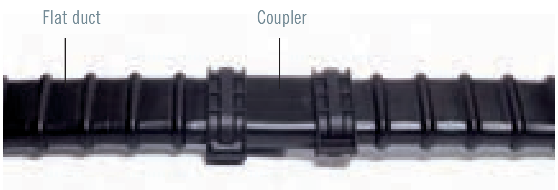
### Dimensions for PT-PLUS® duct system

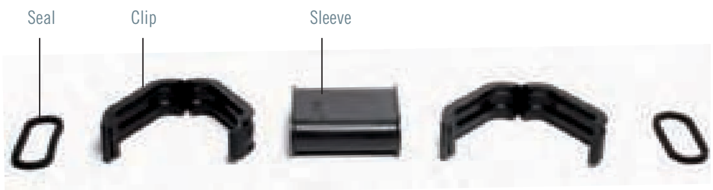
*Dimensions in mm, subject to modifications*

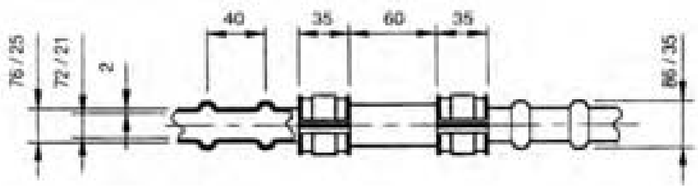
| Type | Tendon unit 0.5" | Tendon unit 0.6" | Ø A | Ø B | Ø C | D | E | Ø F | G | H | Nominal weight Duct kg/m | Nominal weight Coupler kg/unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 5-1 | 6-1 | 22 | 25 | 31 | 1.5 | 55 | 27.5[2] | 80[2] | 27.5[2] | 0.180 | 0.010 |
| 59 | 5-12 | 6-7 | 58 | 63 | 73 | 2.5 | 42 | 82 | 108 | 106 | 0.480 | 0.200 |
| 76 | 5-19 | 6-12 | 76 | 81 | 91 | 2.5 | 52.5 | 100 | 116 | 124 | 0.620 | 0.250 |
| 100 | 5-31 | 6-19/22 | 100 | 106 | 116 | 3.0 | 60 | 123 | 126 | 147 | 0.980 | 0.270 |
| 115 | 5-37 | 6-27 | 115 | 121 | 131 | 3.0 | 60 | 138 | 127 | 162 | 1.120 | 0.320 |
| 130 | 5-43/55 | 6-31/37 | 130 | 136 | 146 | 3.0 | 52 | 153 | 134 | 177 | 1.200 | 0.380 |
| 150 | | 6-55 | 150 | 157 | 167 | 3.5 | 60 | 175 | 126 | 198 | 1.620 | 0.420 |

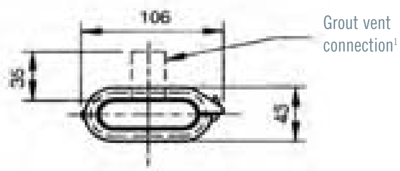
*[2] One-piece sleeve coupler*

*Note: PT-PLUS® ducts come in lengths of approximately 6 m, type 22 ducts are 7 m long*




*Dimensions in mm, subject to modifications*

*[1] Couplers are available with/without grout vents for a smooth tube with dia. 16 / 20 mm.*



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The PT-PLUS® flat duct system and type 22 are often used for slab post-tensioning in buildings, for transversal tendons for bridges and for similar structures where the exploitation of a maximum tendon eccentricity in relatively thin members is important.

### 3.1.4 Smooth plastic ducts

Smooth plastic ducts are predominantly used for external tendons. Occasionally they have been also used for internal tendons when no bonding steel / concrete is required. They are normally made of UV resistant, new high density polyethylene (HDPE) material (virgin granulate) acc. to EN12201 and ASTM D3035 or ASTM F714 or equivalent standards. Material recycled from previously used PE components shall not be used. Ducts normally have a ratio of diameter / wall thickness of 16 to 18, with an internal diameter not smaller than $1.7\sqrt{Ap}$ (Ap = nominal cross section of the steel area in the tendon), suitable to carry internal pressure during grouting (ETAG013 (2002) e.g. specifies 1 MPa / 10 bar design pressure). The following dimensions of external tendon pipes are recommended (see table below).

### 3.1.5 Steel pipes

In certain applications (e.g. cryogenic, nuclear, offshore) where the ducts are subject to high loading when particularly tight tendon curvature is required, or when tendons are in congested parts of structures, steel pipes are used. Tubes are thin (in compliance with EN or equivalent standards) and machine-bendable, (for recommended dimensions, see 1.2 / 1.4).
Steel tubes used externally: dimensions are primarily dictated by the availability of local standardized tubes. The table below can serve as a guideline and is based on an internal diameter of $\geq 1.7\sqrt{Ap}$ where Ap represents the cross section of the prestressing steel.

**Dimensions for smooth plastic ducts**

| Tendon size | External pipe diameter (mm) | | Wall thickness (mm) | |
|---|---|---|---|---|
| | strands | | strands | |
| | bare | PE sheathed | bare | PE sheathed |
| 5-12 / 6-7 | 75 | 90 | 4.3 | 5.1 |
| 5-15/19 / 6-12 | 90 | 110 | 5.4 | 6.0 |
| 5-22/31 / 6-15/19 | 110 | 140 | 6.6 | 6.7 |
| 5-37 / 6-22/27 | 110 | 160 | 6.6 | 7.7 |
| 5-43 / 6-31 | 140 | 160 | 8.3 | 7.7 |
| 5-55 / 6-37 | 160 | 180 | 9.5 | 8.6 |

*Dimensions in mm, subject to modifications*

**Dimensions for steel pipes**

| Strand Nos. | Min inside dia. for strands with | | |
|---|---|---|---|
| | 100 mm² | 140 mm² | 150 mm² |
| 4 | 34 | 40.2 | 41.6 |
| 7 | 45 | 53.2 | 55.1 |
| 12 | 58.9 | 69.7 | 72.1 |
| 15 | 65.8 | 77.9 | 80.6 |
| 19 | 74.1 | 87.7 | 90.8 |
| 22 | 79.7 | 94.3 | 97.7 |
| 27 | 88.3 | 104.5 | 108.2 |
| 31 | 94.7 | 112.0 | 115.9 |
| 37 | 103.4 | 122.4 | 126.6 |
| 43 | 111.5 | 131.9 | 136.5 |
| 55 | 126.1 | 149.2 | 154.4 |

*Dimensions in mm, subject to modifications*

*Wall thickness e ≥ Ø / 50 or minimum 1.5 mm*
*Ø = external diameter*
*Where steel pipes need to be welded, e ≥ 3 mm*

## 3.2 FRICTION COEFFICIENT AND LOSSES DUE TO PRESTRESSING

### 3.2.1 Friction coefficient

The following values may be assumed when using the equation $P_x = P_0\ e^{-(\mu\varphi_x + kx)}$ :

**Equation of loss of post-tensioning force along a tendon**

$P_x$ = Remaining force at distance x from the stressing end
$P_0$ = Stressing force at the stressing end
μ = Friction coefficient
$\varphi_x$ = Accumulated tendon deviation from the stressing end
k = Wobble coefficient
x = Distance from the stressing end

| | Range | Recommended value |
|---|---|---|
| Corrugated steel sheath | $\mu$ = 0.16 - 0.24<br>k = (0.6 - 1.0) x $10^{-3}$ $m^{-1}$ | $\mu$ = 0.20<br>k = 0.8 x $10^{-3}$ $m^{-1}$ |
| PT-PLUS® plastic duct | $\mu$ = 0.12 - 0.14<br>k = (0.8 - 1.2) x $10^{-3}$ $m^{-1}$ | $\mu$ = 0.14<br>k = 1.0 x $10^{-3}$ $m^{-1}$ |
| Steel pipes incl. saddles for external tendons:<br>with clean dry<br>or lubricated strands[1] | $\mu$ = 0.20 - 0.30<br>k = refer to 2 below | $\mu$ = 0.25<br>k = refer to 2 below |
| Saddles for external tendons with internal HDPE tube over saddle:<br>- bare strands<br>- greased and plastic sheathed monostrands | $\mu$ = 0.12 - 0.15<br>$\mu$ = 0.02 - 0.08<br>k = refer to 2 below | $\mu$ = 0.14<br>$\mu$ = 0.06<br>k = refer to 2 below |
| Greased and plastic sheathed monostrands | $\mu$ = 0.04 - 0.07<br>k = (0.4 - 0.6) x $10^{-3}$ $m^{-1}$ | $\mu$ = 0.05<br>k = 0.5 x $10^{-3}$ $m^{-1}$ |

*1. μ-values depend on lubrication*
*2. The wobble factor can normally be neglected*

### 3.2.2 Draw-in of wedge at lock-off: max. 6 mm

This value is independent of the jack or tendon type. If necessary, e.g. for short tendons, compensation can be provided by appropriate procedures.

### 3.2.3 Other tendon force losses

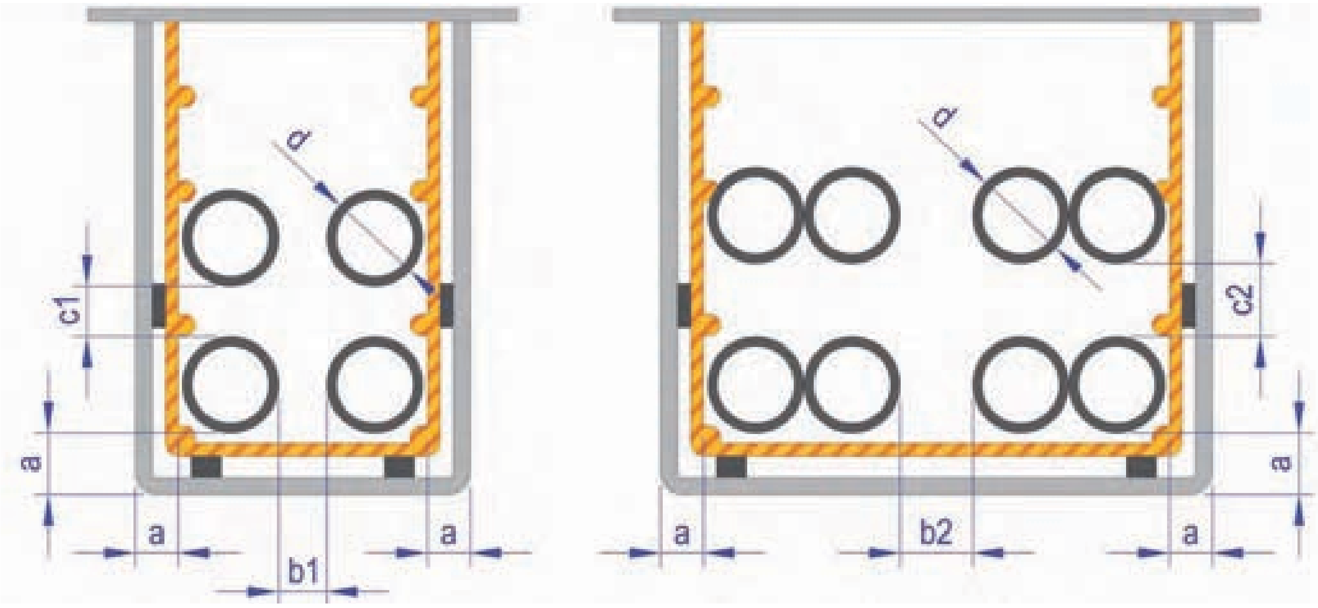
In addition to friction and relaxation losses (see above), also concrete shrinkage and creep as well as a draw-in of the wedge during lock-off must be considered.
To calculate losses due to concrete shrinkage and creep, reference should be made to the technical documents and standards applicable to each project.

## 3.3 DUCT SPACING AND COVER

The cable layout patterns are dictated by the designer.

When detailing that cable layout, it is absolutely essential to consider the spacing of cables from another, required cover, and radii of curvature. Usually the spacing and curvatures are laid down in standards, guidelines or national approvals. If not available, VSL recommends that the following guidance values be observed, these being minimum values:

**Minimum spacing and cover of duct**




*Measurement (a)*

| | |
|---|---|
| *• Precast elements, elements protected from bad weather, soft environmental conditions* | *30* |
| *• In general* | *40* |
| *• Severe environmental conditions* | *50* |

*SPACING*
*b1, c1 = 0.7 times diameter of the duct*
*b2, c2 = 1.0 times diameter of the duct*

## 3.4 SPACING OF THE SUPPORTS AND TOLERANCES

The spacing of the supports underneath the steel and plastic ducts must be 10 to 12 times the internal diameter of the duct. Kinks are not permitted.

The fastening fittings must be sufficiently robust and close enough so that the ducts and tendons will not exhibit displacements or deformations in excess of the allowed tolerances. For tolerances on cable positions reference should be made to applicable standards and recommendations.

Moreover, under all circumstances and in every direction, whenever a cable displays or potentially displays deviation in the vicinity of an edge of concrete which could lead to spalling of concrete cover, an offset with respect to the theoretical axis is only tolerated provided that equilibrium reinforcing bars have been provided over this zone.

Standard steel duct

**In determining minimum spacings and concrete cover requirements for ducts, reference should be made to applicable standards and recommendations, see 3.3.**

PT-PLUS® plastic duct with protection shell

**VSL Protection shells are recommended to be fixed on the duct at tendon supports for tendon radii R < 2 Rmin (see under 4.2), and where ducts risk to be dented by closely placed rebars.**

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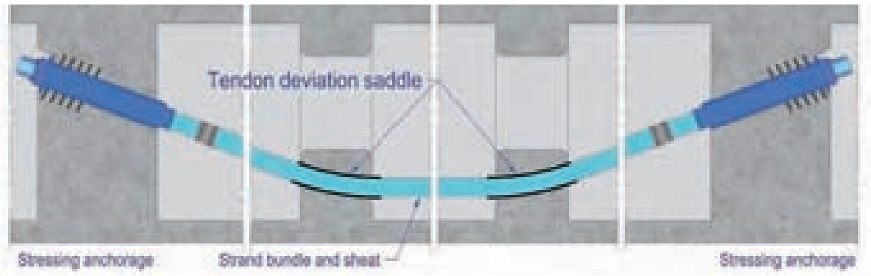
## 3.5 SADDLES FOR EXTERNAL TENDON

### 3.5.1 Saddles

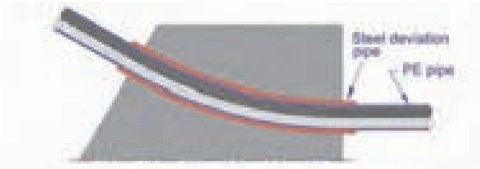
Various solutions are used in practice. In most cases, saddles consist of a pre-bent steel tube cast into the surrounding concrete or attached to a steel structure by stiffening plates. The connection between the free tendon length and the saddle must be carefully detailed in order not to damage the prestressing steel by sharp angular deviations during stressing and in service. It is also important that the protective sheath be properly joined. If tendon replacement is a design requirement, the saddle arrangement must be chosen accordingly.

### 3.5.2 Various saddle arrangements

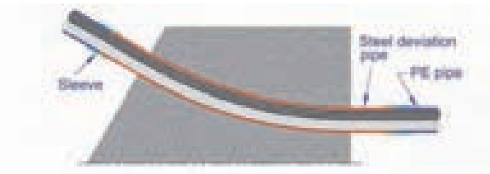




PE pipe through bell-mouth deviator, from anchorage to anchorage *(most common detail)*




PE pipe through deviator pipe, from anchorage to anchorage




Deviation pipe protrudes from concrete at sufficient distance and is coupled to PE pipe

### 3.5.3 Minimum radius of tendon curvature for external tendons

| Tendon unit | | Minimum |
|---|---|---|
| 0.5" | 0.6" | radius |
| up to 5 - 12 | 6 - 7 | 2.00 m |
| up to 5 - 19 | 6 - 12 | 2.50 m |
| up to 5 - 31 | 6 - 22 | 3.00 m |
| up to 5 - 43 | 6 - 31 | 3.50 m |
| up to 5 - 55 | 6 - 37 | 4.00 m |
| up to | 6 - 43 | 4.50 m |
| up to | 6 - 55 | 5.00 m |

- The values are equivalent to approximately $R_{min}$ (m) = (1.5 to 1.3) $\sqrt{F_{pk}\ [MN]}$ $\geq$ 2.0 m
- They apply to smooth steel and HDPE pipe and assume a straight length on either side of the deviation.

Diabolo bell-mouth for deviation points at diaphragm segment

# 4 - DESIGN REQUIREMENTS

## 4.1 ANCHORAGE ZONE REINFORCEMENT

The transfer of the prestressing forces from the anchorage into the concrete produces stresses which exceed the concrete strength and that must be withstood by special reinforcement. A distinction may be made between three types of reinforcement.

**a) Local zone reinforcement in the immediate vicinity of the anchorage**

For this purpose, spirals (helices) or appropriate orthogonal reinforcement are normally used. This reinforcement is considered as an integral component of the anchorage and its design lies within the field of responsibility of VSL. This reinforcement is specified in approvals and it may only be changed upon approval by VSL. *The Anchorage data sheets show the required reinforcement for each anchorage.*

**b) General zone of reinforcement for resisting the spreading of forces in the structure**

This reinforcement is designed by the project designer. *Guidelines for its design can be found in VSL's report "Detailing for post-tensioning".*

**c) Reinforcement for spalling forces near stress free edges**

This reinforcement is designed by the project designer as part of the overall reinforcement of the structure.

## 4.2 MINIMUM RADIUS OF TENDON CURVATURE AND TANGENT LENGTH FOR INTERNAL TENDONS

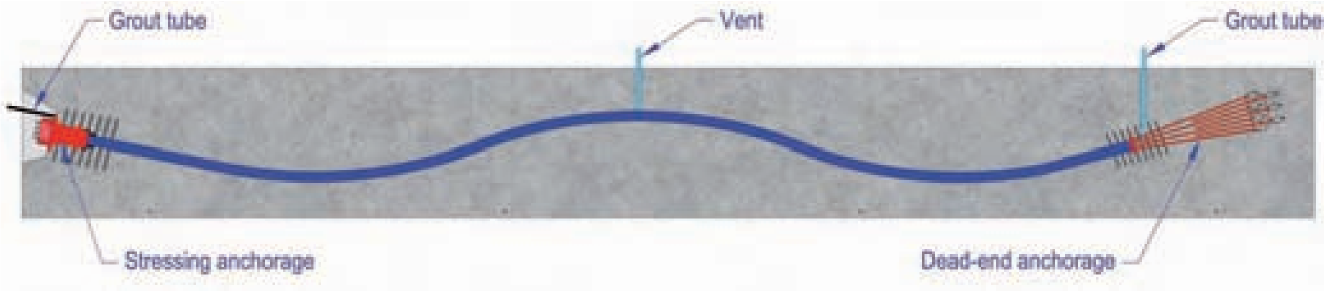

$R_{min\,(m)}$ = 3.0 x $\sqrt{F_{pk}\ [MN]}$ $\geq$ 2.5 m
$L_{min}$ = 0.8 m for $F_{pk} \leq$ 2 MN
= 1.0 m for $F_{pk} \geq$ 2 MN, $\leq$ 7 MN
= 1.5 m for $F_{pk} \geq$ 7 MN
$R_{min\,(m)}$ = 2.50 m for unbonded tendons for 5-1 and 6-1

# 5 - INSTALLATION

## 5.1 ANCHORAGES

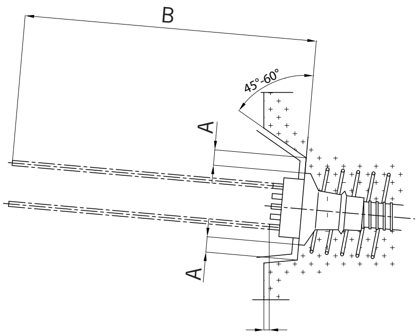
It is a requirement that the bearing plate / casting of anchorages are fixed perpendicular to the tendon axis.
The block-out dimensions and clearance requirement as given under 5.3 should be followed. Departures from these data may be possible. Please contact VSL.

## 5.2 GROUT VENTS




Low point drains should only be foreseen where there is a risk of water freezing inside the duct and hence, drainage is required. As a general rule distance between grout vents should not exceed 100 m. They should have a range of spacing between vents in the order of 30 – 70 m.

## 5.3 BLOCK-OUT DIMENSIONS AND CLEARANCE REQUIREMENTS

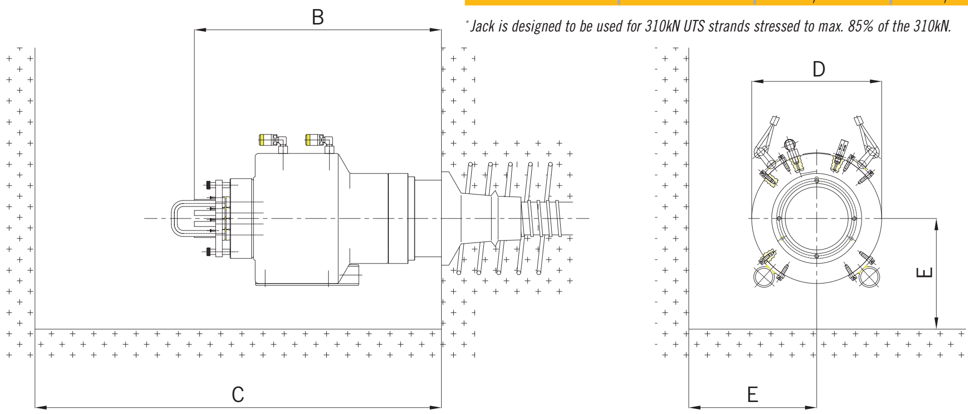



Concrete cover according to applicable standard

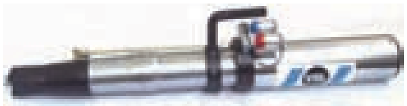
| Jack type | A min. | B | C | D | E |
|---|---|---|---|---|---|
| ZPE-23FJ | – | 300-360 | 1,200 | 116 | 90 |
| ZPE-30 | 30 | 600 | 1,350 | 140 | 100 |
| ZPE-3 | 30 | 500 | 1,000 | 200 | 150 |
| ZPE-60 | 30 | 650 | 1,250 | 180 | 140 |
| ZPE-7/A | 30 | 650 | 1,400 | 300 | 200 |
| ZPE-12/St2 | 50 | 520 | 1,100 | 310 | 200 |
| ZPE-185* | 50 | 620 | 1,220 | 300 | 180 |
| ZPE-200 | 50 | 950 | 2,000 | 330 | 210 |
| ZPE-19 | 50 | 700 | 1,500 | 390 | 250 |
| ZPE-460/31 | 60 | 560 | 1,300 | 485 | 300 |
| ZPE-500 | 80 | 950 | 2,000 | 585 | 330 |
| ZPE-580* | 80 | 860 | 1,620 | 500 | 280 |
| ZPE-750 | 80 | 1,200 | 2,400 | 570 | 365 |
| ZPE-980* | 80 | 950 | 1,760 | 650 | 360 |
| ZPE-1000 | 80 | 1,200 | 2,400 | 790 | 450 |
| ZPE-1250 | 90 | 1,300 | 2,550 | 710 | 375 |
| ZPE-1450* | 90 | 1,010 | 1,850 | 770 | 420 |

** Jack is designed to be used for 310kN UTS strands stressed to max. 85% of the 310kN.*

*Dimensions in mm*



## 5.4 STRESSING JACK DATA



Type I (ZPE-23FJ)

Type II (ZPE-460/31)

Type III (ZPE-1000)

| Designation | ZPE-23FJ | ZPE-30 | ZPE-3 | ZPE-60 | ZPE-7/A | ZPE-12/St2 | ZPE-185* | ZPE-200 | ZPE-19 |
|---|---|---|---|---|---|---|---|---|---|
| Type | I | II | III | III | III | II | II | III | II |
| Length (mm) | 830 | 720 | 475 | 615 | 700 | 610 | 600 | 1,170 | 730 |
| Diameter (mm) | 116 | 140 | 200 | 180 | 280 | 310 | 295 | 315 | 390 |
| Stroke (mm) | 200 | 250 | 160 | 250 | 160 | 100 | 100 | 300 | 100 |
| Piston area (cm²) | 47.10 | 58.32 | 103.6 | 126.4 | 203.6 | 309.4 | 309.3 | 325.7 | 500.3 |
| Capacity (kN)<br>(bar) | 230<br>488 | 320<br>549 | 500<br>483 | 632<br>500 | 1,064<br>523 | 1,850<br>600 | 1,856<br>600 | 2,000<br>614 | 2,900<br>580 |
| Weight (kg) | 23 | 28 | 47 | 74 | 140 | 151 | 120 | 305 | 294 |
| Used for 13mm/ 0.5" tendon types | 5-1 | 5-1 | 5-2<br>5-3 | 5-2<br>to 5-4 | 5-6<br>5-7 | 5-12 | 5-7 | 5-12<br>5-19 | 5-18 |
| Used for 15mm/ 0.6" tendon types | 6-1 | 6-2 | 6-2 | 6-2<br>6-3 | 6-4 | 6-6<br>6-7 | 6-3<br>6-4<br>6-7 | 6-6<br>6-7 | 6-12 |

| Designation | ZPE-460 | ZPE-500 | ZPE-580* | ZPE-750 | ZPE-980* | ZPE-1000 | ZPE-1250 | ZPE-1450* |
|---|---|---|---|---|---|---|---|---|
| Type | II | III | II | II | II | III | II | II |
| Length (mm) | 580 | 1,000 | 760 | 1,185 | 810 | 1,150 | 1,290 | 840 |
| Diameter (mm) | 485 | 550 | 500 | 520 | 645 | 790 | 620 | 765 |
| Stroke (mm) | 100 | 200 | 150 | 150 | 150 | 200 | 150 | 150 |
| Piston area (cm²) | 804.0 | 894.6 | 961.7 | 1,247.0 | 1,652.3 | 1,809.5 | 2,168.0 | 2,436.9 |
| Capacity (kN)<br>(bar) | 4,660<br>580 | 5,000<br>559 | 5,805<br>610 | 7,500<br>601 | 9,750<br>590 | 10,000<br>553 | 12,500<br>577 | 14,500<br>595 |
| Weight (kg) | 435 | 1,064 | 460 | 1,100 | 800 | 2,340 | 1,730 | 1,250 |
| Used for 13mm/ 0.5" tendon types | 5-22<br>5-31 | 5-22<br>5-31 | 5-12<br>to 5-31 | 5-31<br>to 5-55 | | 5-37<br>to 5-55 | 5-37 | |
| Used for 15mm/ 0.6" tendon types | 6-18<br>6-19 | 6-18<br>to 6-22 | 6-12<br>6-19<br>6-22 | 6-31<br>to 6-43 | 6-27<br>6-31<br>6-37 | 6-31<br>to 6-37 | 6-43<br>to 6-55 | 6-43<br>6-48<br>6-55 |

** Jack is designed to be used for 310kN UTS strands stressed to max. 85% of the 310kN.*

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