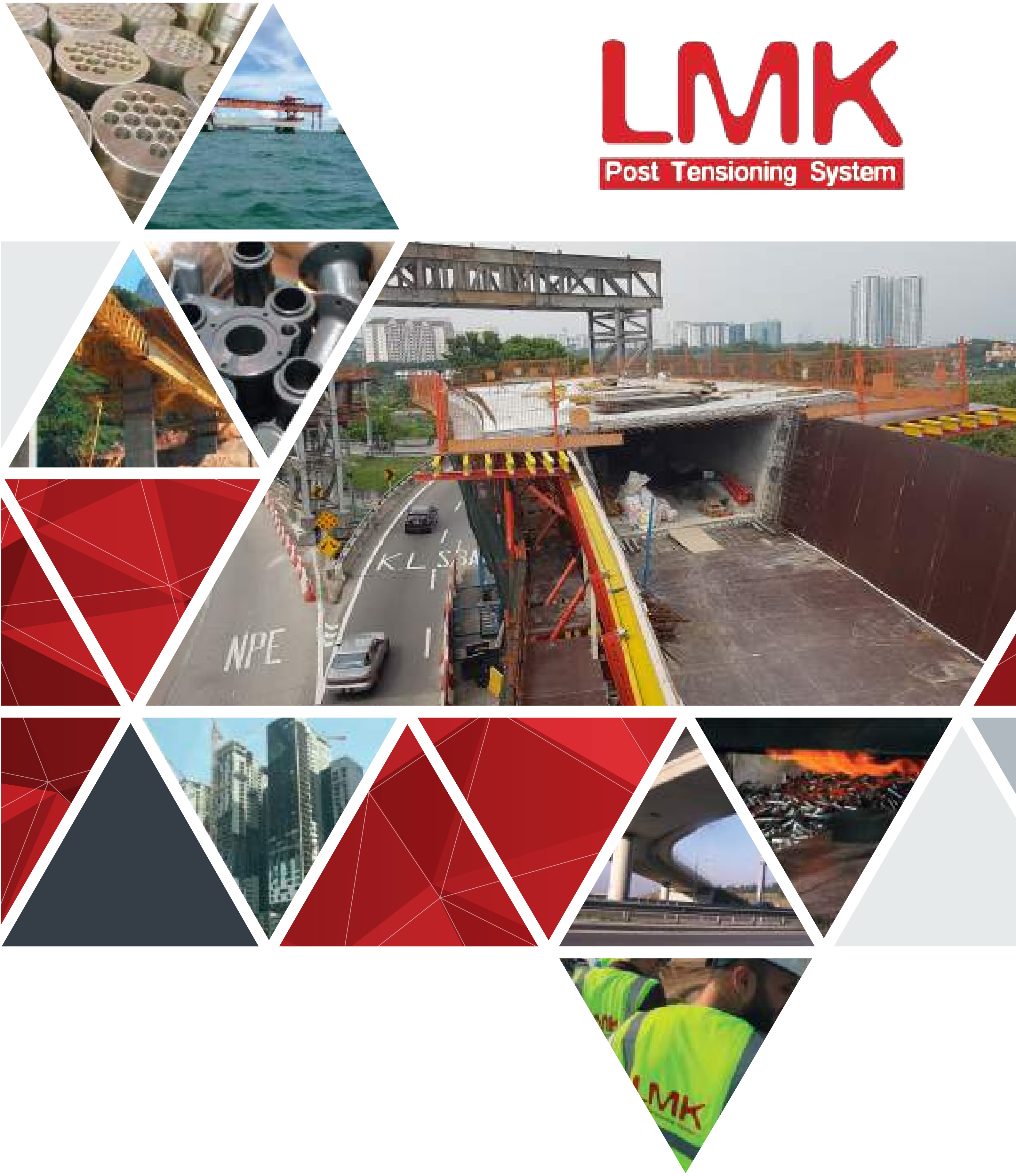
LMK

Post Tensioning System





Contents


LMK System

◗ In Brief

The **LMK** Post Tensioning system has been designed and developed by Engineers of various disciplines with long-standing activity and experience in construction and project management, meeting the requirements of complex PT projects by providing know-how, quality and application consistency.

Its vision has always been focused on applying new technologies contributing to high quality engineering with respect to safety and environmental issues.

LMK PT system responds proactively to the trends of Int'l markets having successfully accomplished numerous projects involving all types of construction methods, from simply supported beams to slabs, cantilevers, incremental launching and segmental structures, demonstrating solid experience in the PT technology.

LMK PT system offers full technical support & assistance through a team of Engineers having participated in prestigious infrastructure projects of building, road and railway industry.

Main Features

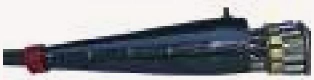
Application

LMK is a Post Tensioning system in which the tensioning force is applied after concreting or after the installation of pre-casted units, through a combination of anchorages and tendons. Adequate bond between LMK system and the structure is provided through grouting. The system can also be implemented in un-bonded (un-grouted) applications.

LMK is widely used at the construction of post-tensioned concrete structures, i.e. bridges, buildings, silos, tanks and other structures for internal and external tensioning as well.

LMK can achieve economic benefits by applying the stressing in phases based on the design and avoiding the need of pre-stressed apparatus, giving to the Consultants/ Designers and Contractors the advantages of a simplified construction.

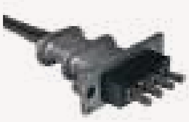
LMK can use a variety of tendons and steel strand sizes by using 0,5" and 0,6" wire-strand covering the majority of designs. If required, special anchorages with various capacities can be designed and manufactured, including special designs for the construction of cable supported structures.

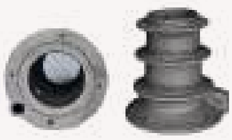


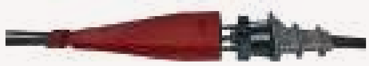
Advantages

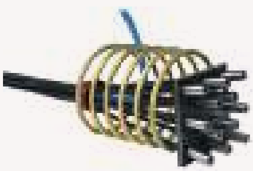
LMK covers Int'l specifications and guidelines such as EN - EAD - ETAG, AASHTO LRFD, F.I.B. (Federation Int'l du Beton) & PTI (Post Tensioning Institute), demonstrating the following advantages:

- Wide selection of compact anchorages with improved load distribution surfaces.
- Easy coupling with standard or enlarged steel or plastic sheaths (flat and round).
- Frontal grouting/connection arrangement.
- Light weight configuration, facilitating the handling and installation.
- Recesses of smaller dimensions.
- Lower losses and smaller tendon's deviations contributing to the economy of the design & construction.







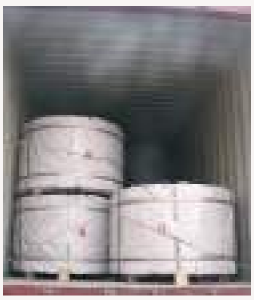


Strands

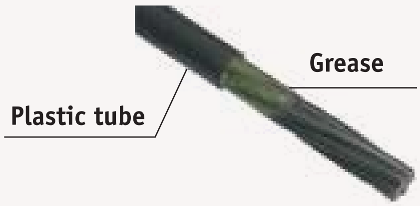
7-wire strands

The strands are made of high tensile strength steel produced by low relaxation process, consisted of 7 steel wires (one central and six helically wrapped) having 13 mm (0.5") or 15 mm (0,6") nominal diameter and characteristics listed in Tables 1.1 & 1.2.
The strands are generally supplied already stabilized (low relaxation) and certified according to standards in testing labs (EN & ASTM). They are usually shipped in coils having the following typical dimensions:

- Outer diameter: 1,2-1,5 m
- Inner diameter: 0,7-0,8 m
- Width: 0,7-0,75 m
- Weight: 3-4 tonns



LMK can use any type of pc strand meeting the project requirements. When needed, oiled, greased or waxed/gelled strands can be applied using plastic sheath (PP or PE), i.e. in case of external post-tensioning or in un-bonded applications. If required, strands can also be supplied galvanized, considering different mechanical properties in comparison with common strand types.



Tendons are consisted of a specific number of wire strands according to the design. The number of strands defines usually the type of anchorage (LMK typical range of production from 1 up to 37 strands).
All types of strands are following the common stress-strain diagram. The yield point of the steel is the reaching of an irreversible plastic strain of 0.1%, defined as $f_{p0,1}$.

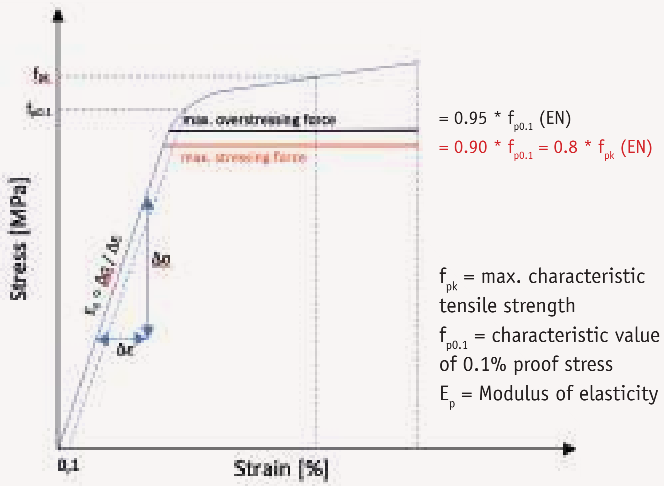


Fig.1 Strands Typical Stress-Strain Graph

Sheaths

◗ General

Strands are threaded through ducts (round or flat) made of steel strips or high-density polyethylene (HDPE) or polypropylene (PP) extruded resin, in corrugated or smooth shape depending on the project's requirements. Ducts must be sufficiently strong and durable for fabrication, transportation, installation, concrete placement, tendon stressing and sufficient leak tight meeting Int'l standards and guidelines (EN, ASTM, FIB and PTI).

To assure a better protection of the strands from corrosion - depending on the level of protection - it is advisable to use galvanized steel ducts or plastic PE/PP ducts. The latter is essential, in cases where structures are exposed to severe corrosion environment, subjected to fatigue loading, as well as in case of electrically isolated tendons (EIT) for railway bridges offering protection against stray currents.

Steel sheaths are flexible, bright, interlocked and grout tight fabricated using the continuous cold rolling and stapling of a flat steel strip (standard steel or galvanized) in widths of about 30-60 mm.
Plastic sheaths are made of polyolefin polymers. HDPE has perfect flexibility and impact strength, handling and weldability in a wide temperature range while PP has a higher shore hardness, better wear and heat resistance. Both PP and PE allow lower and more reliable friction coefficient which is beneficial due to design requirements for longer tendons.

The ducts are normally supplied (for transportation reasons) in lengths of 5,8 m (< 20 ft) or 11,8 m (< 40 ft) and are connected by means of couplers. The coupling system has a minimum typical length of 200-250 mm having a slightly larger diameter so as to be screwed or to be push-fit or even heat-shrunk (case of plastic ducts). Butt welding technique can be also applied in plastic ducts avoiding the use of couplers.

Push to fit coupler

Heat-shrink coupler

Butt welding

Segmental coupler

Installation

The installation of sheaths is taking place in parallel with the placement of reinforcement. Co-ordination between working staff is necessary in order to avoid installation defects and delays.

The proper installation of sheaths at the specified by the design geometry is of utmost importance. It is commonly accepted that the tendon's geometry has priority over reinforcement. The supporting points are made of stirrups located every 0.5 - 1 m as specified by the design and are wire-tight with the reinforcement forming a robust fitting, avoiding steep alignments of ducts beyond the applicable tolerances.

All couplings and connections along the sheath must be carefully tight and sealed, using a PVC tape in case of steel ducts or push to fit/heat shrink couplers and butt welding in case of plastic ducts.

When many tendons are present in a section, it is necessary to foresee adequate spacing for concrete casting and proper vibration avoiding any direct contact with the ducts, protecting them from damages, misalignments and improper compaction.













As a rule of thumb the spacing should follow:

$X \geq \Phi_{external}$

$Y \geq \Phi_{external}$

$k \geq \Phi_{external}$

and k ≥ (concrete cover + rebars nominal diameter)

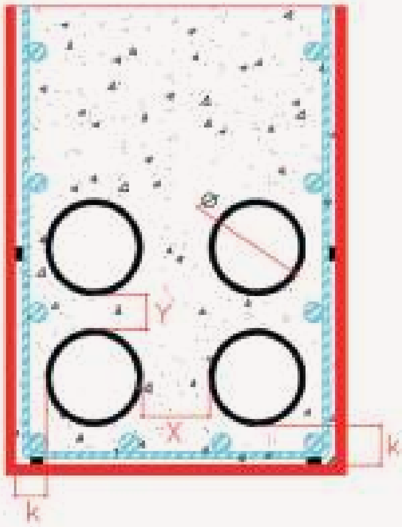


Fig.2 Recommended Ducts Arrangement

Installation of additional reinforcement is always recommended in areas where a tendon's geometry displays vicinity to the edge of the concrete.

In case of external tendons applications, properly designed deviation saddles are being used. These deviators are made of pre-bended tubes casted into concrete or attached to specially designed steel units following a specific geometry. A common solution for segmental pre-casted construction is the use of bell-mouth pathways, formed by re-usable diabolo units flaring at each end within a range of angle in geometry.

External tendons are made of smooth plastic sheaths and filled with grout or grease / wax depending on design requirements.

◗ Threading

Strands are threaded using a strand threading machine prior or after concreting according to the project's requirements (pushing or pulling method). In special cases (i.e. very long tendons and installation after concrete casting), strands can be installed using the pull through method with special sockets/cups/torpedoes and winch.

Depending on the projects requirements (size, length and geometry of tendons), sheaths must have enlarged diameter accommodating a cross section area 2.0-2.5 times larger than the nominal net strand area.

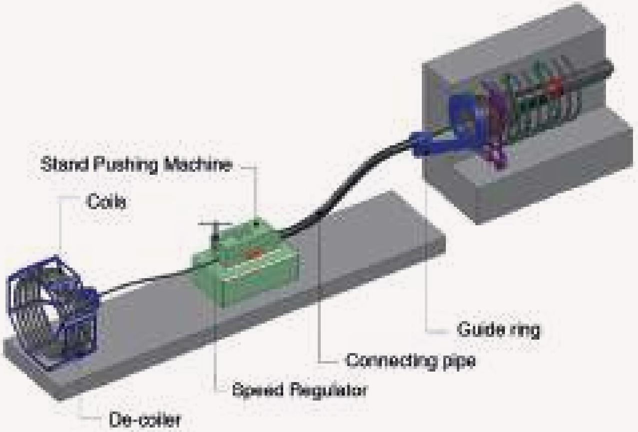


Fig.3 Pushing Method Configuration

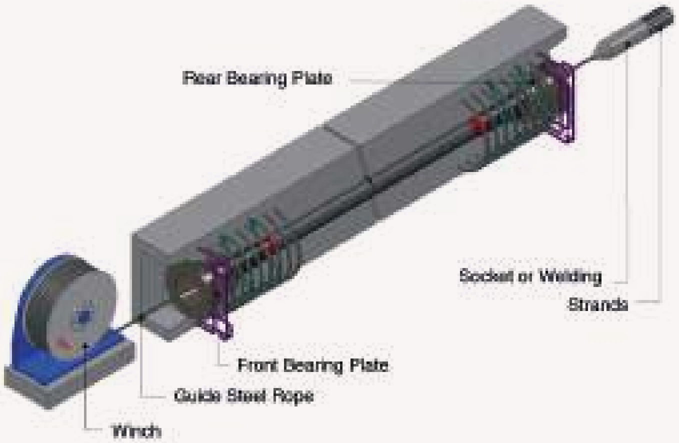


Fig.4 Pulling Method Configuration

Typical Sheath Dimensions

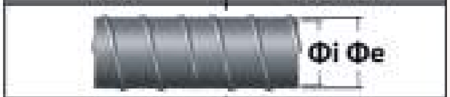


Table 2.1 ROUND STEEL DUCTS (0,6") CORRUGATED	DUCT		COUPLER	
	Φi mm	Φe mm	Φi mm	Φe mm
up to 3 strands	45	50	50	55
4 strands	45	50	50	55
5 strands	50	55	55	60
6-7 strands	60	65	65	70
8-9 strands	75	80	80	85
10-12 strands	80	85	85	90
13-15 strands	85	90	90	95
16-19 strands	100	105	105	110
20-22 strands	106	110	110	115
23-27 strands	115	120	120	125
28-31 strands	125	130	130	135
32-37 strands	135	140	140	145

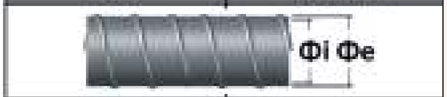


Table 2.2 ROUND STEEL DUCTS (0,5") CORRUGATED	DUCT		COUPLER	
	Φi mm	Φe mm	Φi mm	Φe mm
up to 3 strands	40	45	45	50
4 strands	40	45	45	50
5 strands	40	45	45	50
6-7 strands	50	55	55	60
8-9 strands	55	60	60	65
10-13 strands	65	70	70	75
14-15 strands	70	75	75	80
16-19 strands	80	85	85	90
20-22 strands	85	90	90	95
23-27 strands	90	95	95	100
28-31 strands	100	105	105	110
32-37 strands	110	115	115	120

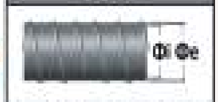


Table 2.3 ROUND PLASTIC DUCTS (0,6") CORRUGATED	DUCT	
	Φi mm	Φe mm
up to 3 strands	40	55
4 strands	40	55
5 strands	50	65
6-7 strands	60	75
8-9 strands	80	96
10-12 strands	80	96
13-15 strands	85	103
16-19 strands	90	108
20-22 strands	100	122
23-27 strands	110	132
28-31 strands	110	132
32-37 strands	120	143

Table 2.4 ROUND PLASTIC DUCTS (0,5") CORRUGATED	DUCT	
	Φi mm	Φe mm
up to 3 strands	30	45
4 strands	40	55
5 strands	40	55
6-7 strands	50	65
8-9 strands	60	75
10-13 strands	70	86
14-15 strands	80	96
16-19 strands	80	96
20-22 strands	80	96
23-27 strands	85	103
28-31 strands	90	108
32-37 strands	100	122

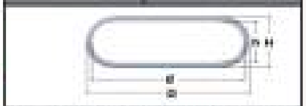


Table 2.5 FLAT STEEL CORRUGATED DUCTS (0,5" & 0,6")	DUCT		COUPLER	
	d x h mm	D x H mm	d x h mm	D x H mm
2 strands	50x22	54x26	54x26	58x30
3 strands	60x22	64x26	64x26	70x30
4 strands	70x22	74x26	74x26	78x30
5 strands	90x22	94x26	94x26	98x30

Table 2.6 FLAT PLASTIC CORRUGATED DUCTS (0,5" & 0,6")	DUCT		COUPLER	
	d x h mm	D x H mm	d x h mm	D x H mm
2 strands	50x22	65x35	65x35	75x48
3 strands	60x22	75x35	75x35	85x48
4 strands	70x22	86x35	86x35	95x48
5 strands	90x22	108x35	108x35	115x48

Table 2.7 ROUND PLASTIC DUCTS (0,6") SMOOTH	DUCT	
	Φi mm	Φe mm
6-7 strands	66,4	75
8-9 strands	79,8	90
10-12 strands	79,8	90
13-15 strands	79,8	90
16-19 strands	97,4	110
20-22 strands	110,8	125
23-27 strands	110,8	125
28-31 strands	124	140
32-37 strands	124	140

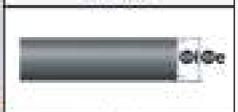


Table 2.8 ROUND PLASTIC DUCTS (0,5") SMOOTH	DUCT	
	Φi mm	Φe mm
8-9 strands	66,4	75
10-13 strands	79,8	90
14-15 strands	79,8	90
16-19 strands	79,8	90
20-22 strands	79,8	90
23-27 strands	79,8	90
28-31 strands	97,4	110
32-37 strands	110,8	125

Dimensions can be modified according to design requirements

Typical Tendons Geometry

Steel/Plastic Round Corrugated Sheaths

Table 3.1

INTERNAL TENDONS 0,5" & 0,6"	Tangent Length Mmin m	Radius of Curvature Rmin m
up to 2 strands	0,8	2,5
3	0,8	3
4	0,8	3,5
5	0,8	4
6	0,8	4
7	0,8	4,5
8	1	4,5
9	1	5
10	1	5,5
11	1	5,5
12	1	5,5
13	1	6
14	1	6
15	1	6,5
16	1	6,5
17	1	7
18	1	7
19	1	7
20	1	7,5
21	1	7,5
22	1	7,5
23	1	8
24	1	8
25	1	8
26	1,5	8,5
27	1,5	8,5
28	1,5	8,5
29	1,5	9
30	1,5	9
31	1,5	9
32	1,5	9
33	1,5	9,5
34	1,5	9,5
35	1,5	9,5
36	1,5	10
37	1,5	10

Recommended Values

Steel/Plastic Flat Corrugated Sheaths

Table 3.2

FLAT TENDONS 0,5" & 0,6"	Tangent Length Mmin m	Radius of Curvature Rmin m
up to 2 strands	0,5	2,5
3	0,5	2,5
4	0,5	2,5
5	0,5	2,5

Recommended Values

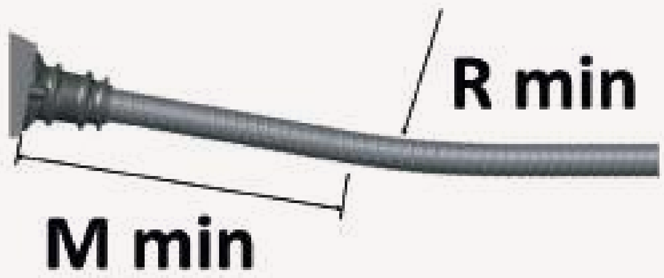


Fig.5 Tendon's Geometry

Plastic Round Smooth Sheaths

Table 3.3

EXTERNAL TENDONS	Radius of Curvature Rmin - (0,5") m	Radius of Curvature Rmin - (0,6") m
up to 6 strands	2	2
up to 7 strands	2	2,5
up to 8 strands	2	2,5
up to 9 strands	2,5	2,5
up to 13 strands	2,5	3
up to 14 strands	3	3
up to 16 strands	3	3,5
up to 17 strands	3	3,5
up to 19 strands	3	3,5
up to 25 strands	3,5	4
up to 32 strands	4	4,5
up to 33 strands	4	5
up to 37 strands	4,5	5

Recommended Values

Anchorages

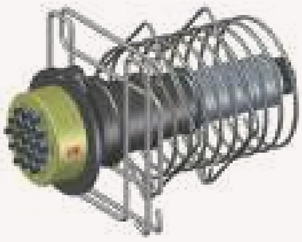
◗ Types

The design of anchorages is in line with Int'l Standards (EN, AASHTO, F.I.B and PTI).

They are formed by cast iron units (bearing plates), steel anchor & coupling heads, couplers, wedges, swages, collars & protective covers, grouting ports, caps, etc. as per EN & ASTM specifications.

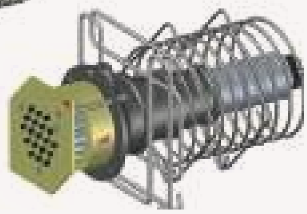
LMK-S stressing anchorages are formed by a steel anchor head where strands are individually gripped by wedges passing through the bearing plate (trump-plate).

LMK-S



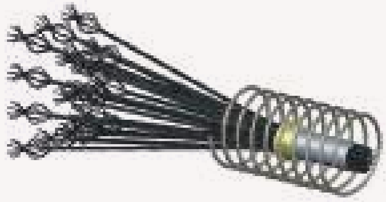
LMK-FS and **LMK-FSB** fixed anchorages are swaged types through a steel plate or through a bearing plate and anchor head with a pressing board that accommodates a better distribution of forces.

LMK-FS



LMK-FSB

LMK-FB is a simplified solution for a fixed type where the bulb-end (known as onion type) of the strand is bonded to the concrete.



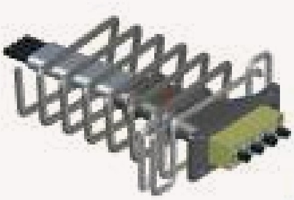
LMK-FB

LMK-FC

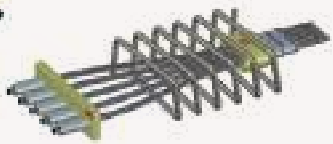
LMK-MC

LMK-FC and **LMK-MC** coupling anchorages are fixed type or movable type, used between adjoined construction members. Couplers are used to give continuity to the tendons, which due to their length or the construction method, cannot be installed or tensioned as one unit. The fixed types are used when stressing of the tendon of the previous member in a construction joint is needed, while movable types allow stressing of the tendon from the adjacent end.

LMK-FC is formed by a coupling head where strands coming from the precedent construction member are individually gripped by wedges passing through a bearing plate forming a stressing anchorage. The strands of the next adjacent member are swaged and gripped in the perimeter of the coupling head. **LMK-MC** is formed by a mono-coupling system gripping through wedges at both sides of the strands. All elements are placed inside a protective cover having a grout port.

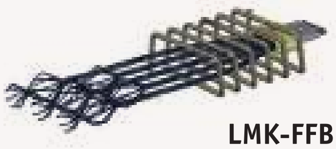


LMK-SFL



LMK-FFL

LMK-FFC



LMK-FFB

LMK-SFL flat anchorages are stressing type, **LMK-FFL** & **LMK-FFB** fixed type and **LMK-FFC** coupling type. Flat anchorages are commonly used in building's thin slabs/ walls and bridge decks. Slab post-tensioning enables deflections and cracks under service conditions to be controlled while permitting larger and thinner spans.

Un-bonded mono-strand system, both for 13 mm (0.5") and 15 mm (0.6") type **LMK-U** can be used in cases where the design specifies un-bonded strands applications (greased and PE coated).

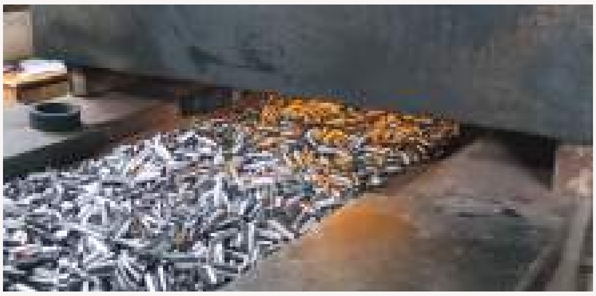
LMK-U

Block-out dimensions & reinforcement

The characteristic spacings X, Y and Z for typical concrete classes, according to the characteristic strength at 28 days, are given in Table 5. For concrete of intermediate strength interpolated data can be utilized.

The minimum recommended distances should not be considered when stressing adjacent anchorages simultaneously. In such case, the recommended distance X_2 must be modified accordingly.

In addition to the reinforcement according to the design, supplementary reinforcement is recommended to be placed in the force distribution zone behind the anchorage.



In cases where the length of a spiral is insufficient, lap splicing is required, considering overlapping length ≥ 52 times of spiral bar diameter (ΦH) (EN 1992-1-1/ section 8).

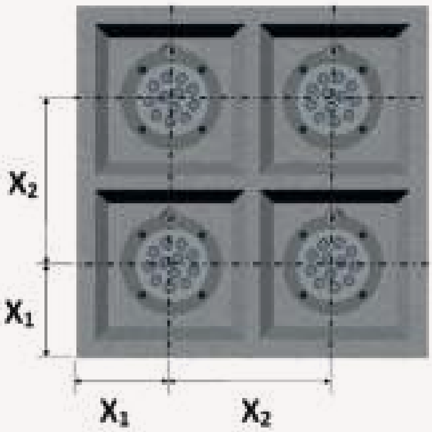


Fig.6 Typical Block-out Configuration Round Anchorages

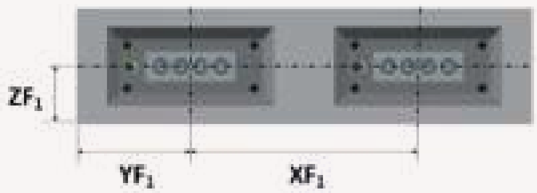


Fig.7 Typical Block-out Configuration Flat Anchorages

The provided values in the following Tables are recommended values and can be modified according to the needs and specifications of each individual project.

Table 4 Recommended Concrete Cover depending on the Environment

Exposure Classes EN 206	Environment	Typical Cases	Cover (mm)
Corrosion induced by carbonation			
XC1	Dry or permanently wet	Buildings	30
XC2	Wet, rarely dry	Foundations	45
XC3	Moderate humidity	Sheltered from rain	45
XC4	Cyclic wet and dry	Water contact	50
Corrosion induced by chlorides excluding sea-water			
XD1	Moderate humidity	Concrete exposed to chlorides	50
XD2	Wet, rarely dry	Swimming pools	55
XD3	Cyclic wet and dry	Pavements & car park slabs	55

LMK-S M15 (0.6") - STRESSING ANCHORAGE

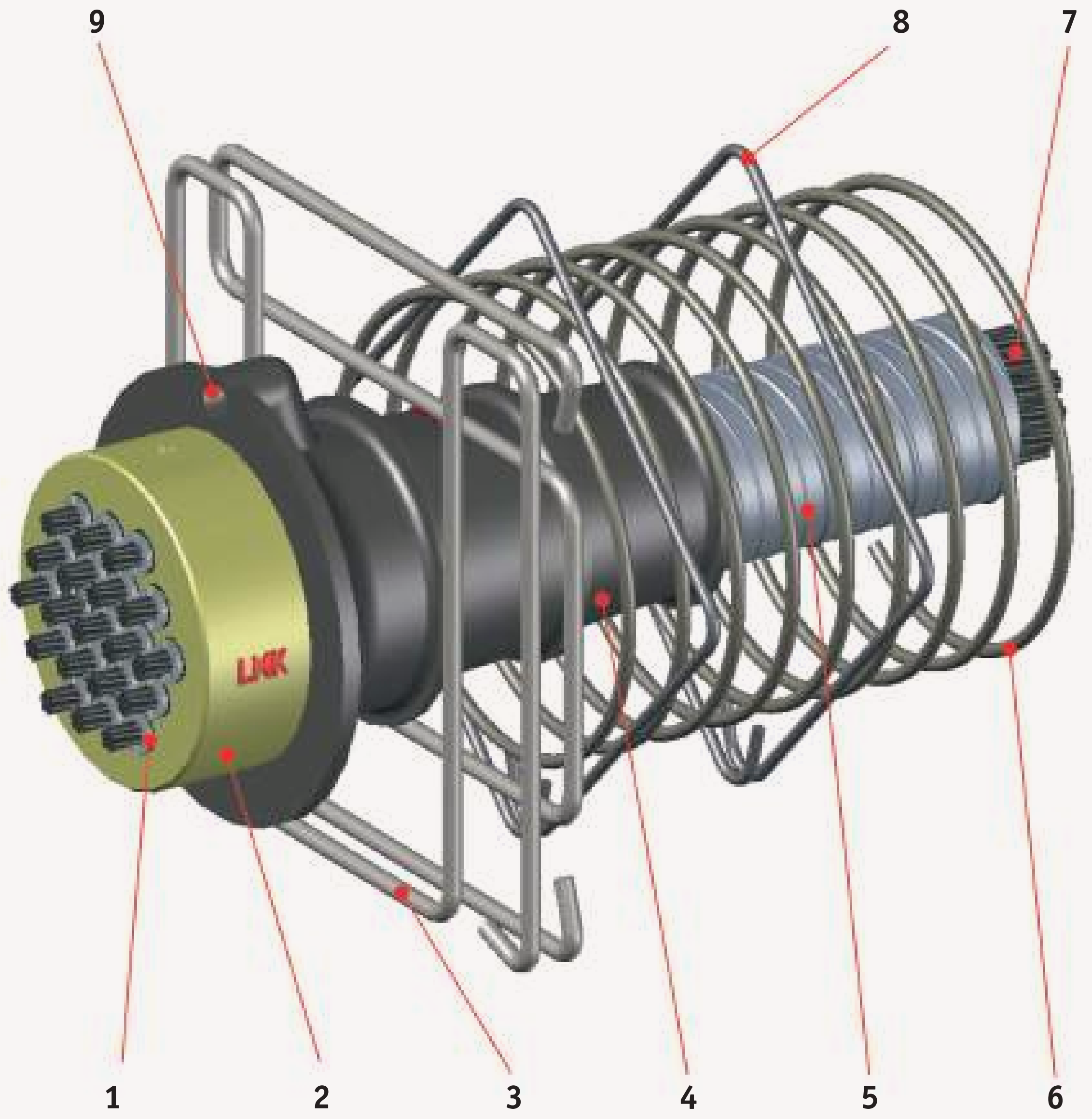


Fig.8.1 Stressing Anchorage Axonometric View

S/N	DESCRIPTION
1	WEDGES
2	ANCHOR HEAD
3	"W" STIRRUPS can be modified according to design requirements
4	BEARING PLATE ensure proper anchorage distance X_2 when simultaneously stressing
5	DUCT Sheath diameter can be modified according to design requirements
6	SPIRAL
7	STRANDS
8	"◊" ADDITIONAL BURSTING REINFORCEMENT distributed along the spiral length
9	GROUT PORT

LMK-S M13 (0.5") - STRESSING ANCHORAGE

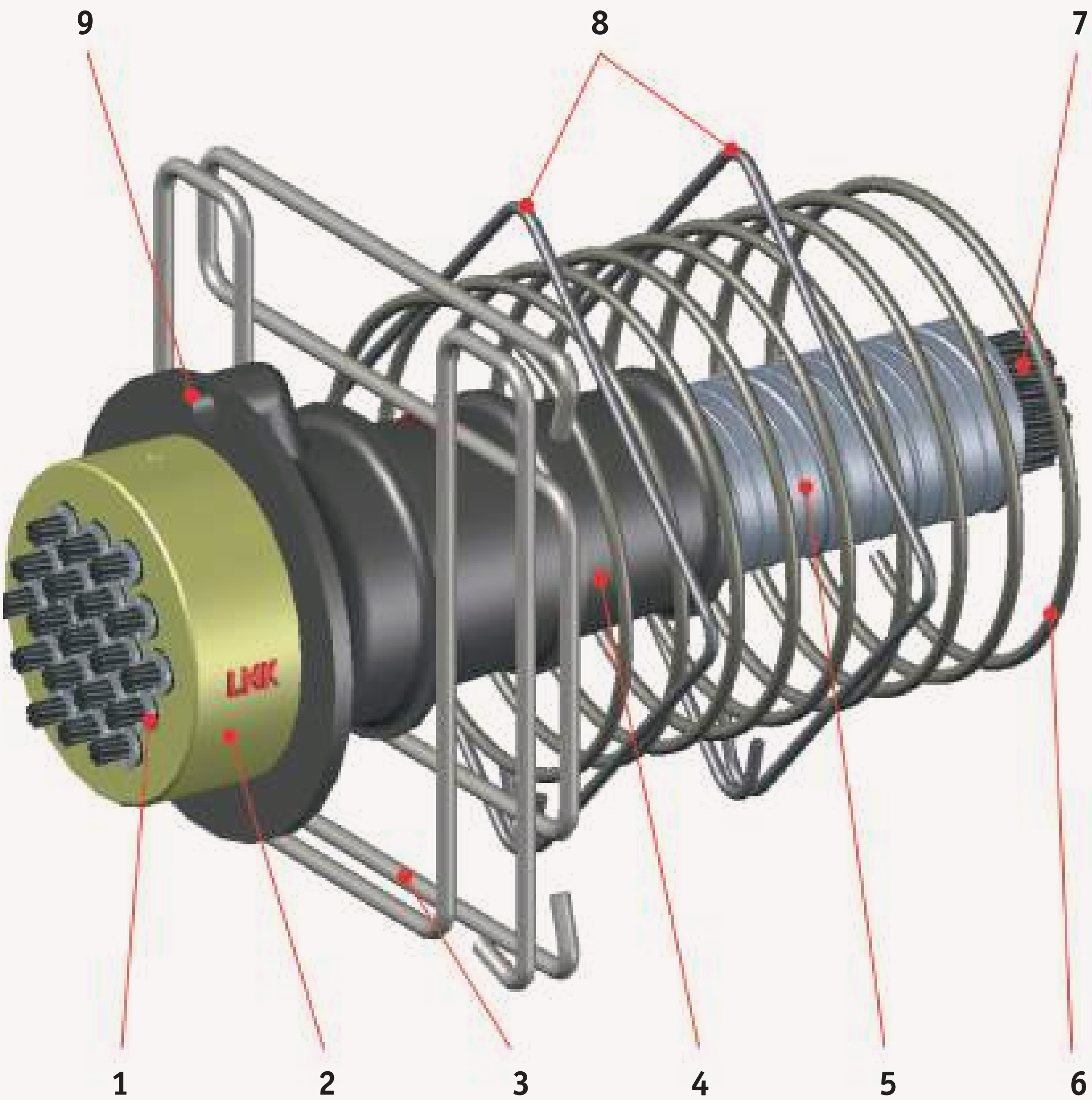


Fig.8.2 Stressing Anchorage Axonometric View

S/N	DESCRIPTION
1	WEDGES
2	ANCHOR HEAD
3	"W" STIRRUPS can be modified according to design requirements
4	BEARING PLATE ensure proper anchorage distance X_2 when simultaneously stressing
5	DUCT Sheath diameter can be modified according to design requirements
6	SPIRAL
7	STRANDS
8	"◊" ADDITIONAL BURSTING REINFORCEMENT distributed along the spiral length
9	GROUT PORT

LMK-FS M15 (0.6") & M13 (0.5") - FIXED SWAGED ANCHORAGE

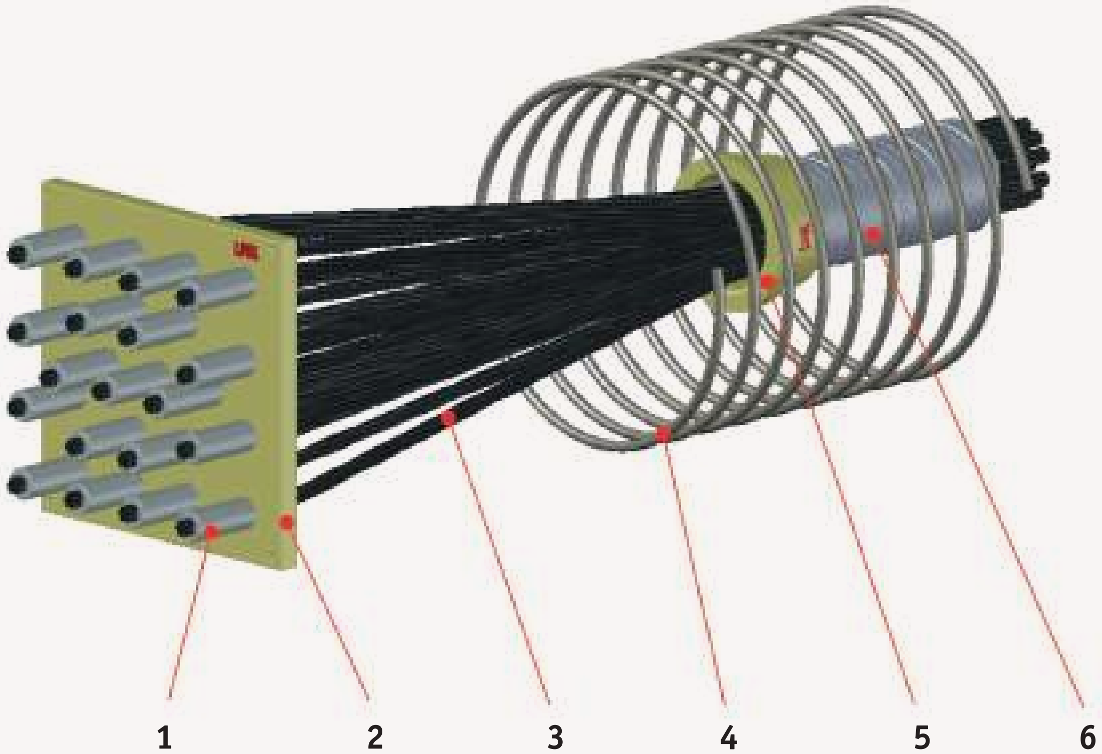


Fig.9 Fixed Swaged Anchorage Axonometric View

S/N	DESCRIPTION
1	SWAGES
2	ANCHOR HEAD
3	STRANDS
4	SPIRAL
5	COLLAR
6	DUCT Sheath diameter can be modified according to design requirements

LMK-FB M15 (0.6") & M13 (0.5") - FIXED BULB ANCHORAGE

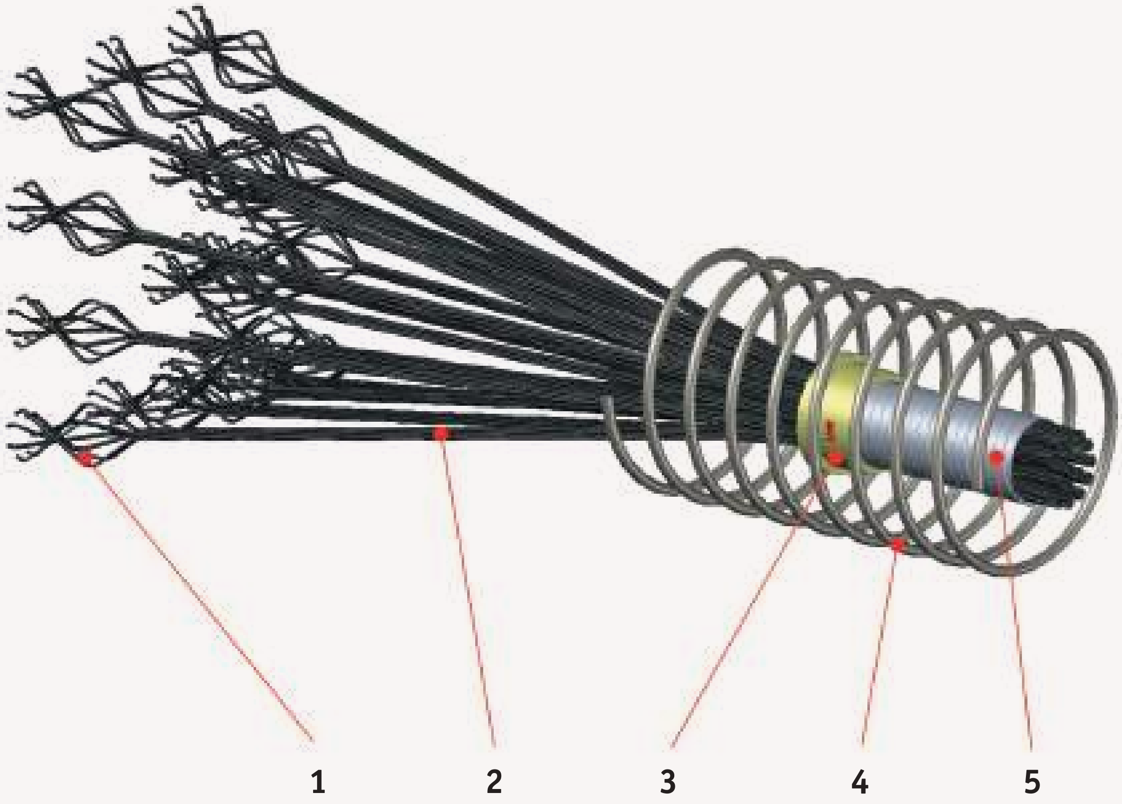


Fig.10 Fixed Bulb Anchorage Axonometric View

S/N	DESCRIPTION
1	BULBS
2	STRANDS
3	COLLAR
4	SPIRAL
5	DUCT Sheath diameter can be modified according to design requirements

LMK-FSB M15 (0.6") & M13 (0.5") - FIXED SWAGED ANCHORAGE with BEARING PLATE

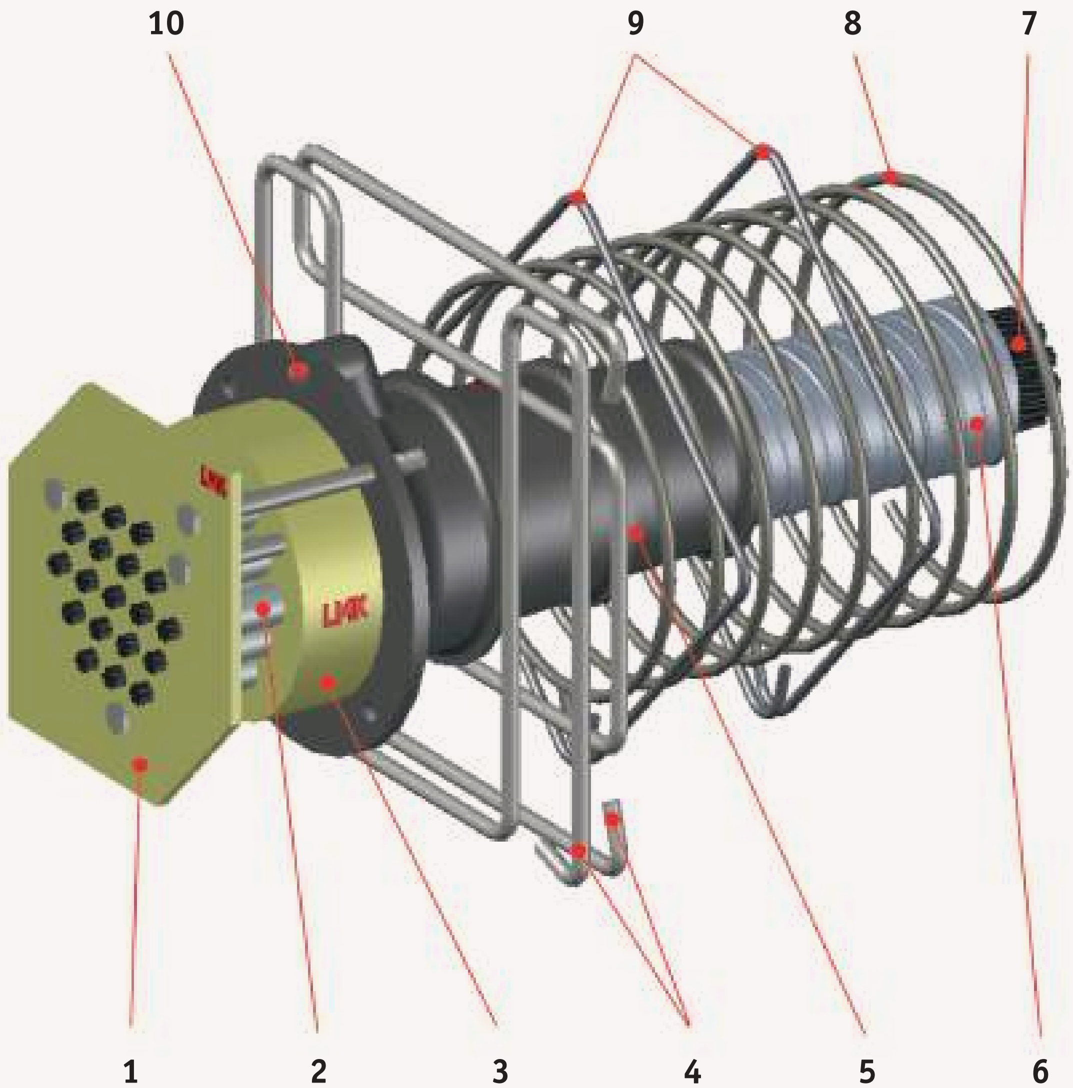


Fig.11 Fixed Swaged with Bearing Plate Anchorage Axonometric View

S/N	DESCRIPTION
1	PRESSING BOARD
2	SWAGES
3	ANCHOR HEAD
4	"W" STIRRUPS can be modified according to design requirements
5	BEARING PLATE ensure proper anchorage distance X_2 when simultaneously stressing
6	DUCT Sheath diameter can be mod ified according to design requirements
7	STRANDS
8	SPIRAL
9	"◊" ADDITIONAL BURSTING REINFORCEMENT distributed along the spiral length
10	GROUT PORT

LMK-MC M15 (0.6") & M13 (0.5") - MOVABLE COUPLER

Table 6.6

LMK - MC	PROTECTIVE COVER			
	ΦA	B	C	D
TYPE	mm	mm	mm	mm
2-3M15/13	101	965	62	169
4M15/13	112	1205	62	180
5M15/13	125	1260	62	193
6-7M15/13	136	1300	76	204
8-9M15/13	156	1380	86	224
10-12M15/13	177	1430	96	245
13-14M15/13	187	1540	106	255
15M15/13	197	1570	106	265
16-19M15/13	217	1635	106	285
20-22M15/13	237	1705	106	305
23-27M15/13	256	1840	126	324
28-31M15/13	272	1855	136	340
32-37M15/13	308	2070	140	376

Movable Coupler Side View

Movable Coupler Rear View

LMK-MC M15 (0.6") & M13 (0.5") - MOVABLE COUPLER

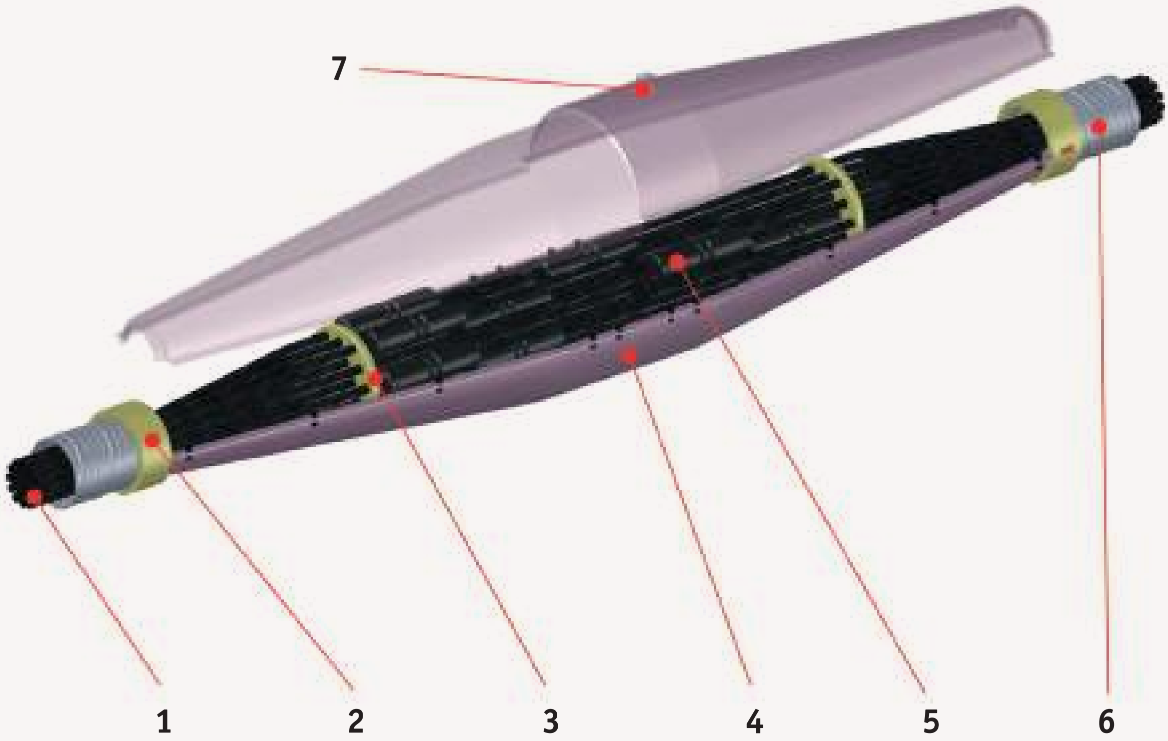


Fig.12.1 Movable Coupler Axonometric View

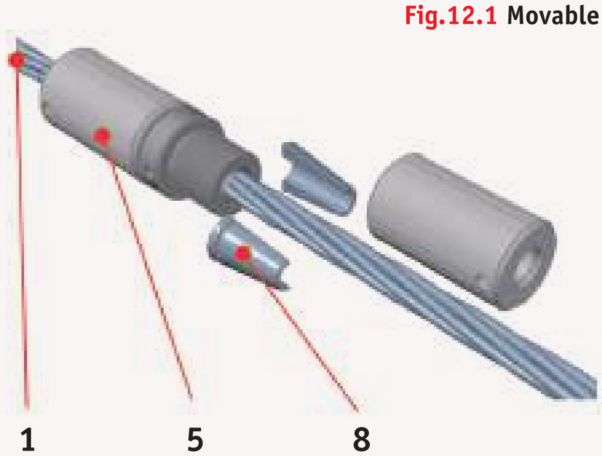


Fig.12.2 Mono-Coupler Axonometric View

S/N	DESCRIPTION
1	STRANDS
2	COLLAR
3	SPREADING BOARD
4	PROTECTIVE COVER
5	MONO-COUPLER
6	DUCT Sheath diameter can be modified according to design requirements
7	GROUT PORT
8	MONO-COUPLER INNER WEDGES

LMK-FC M15 (0.6") & M13 (0.5") - FIXED COUPLER

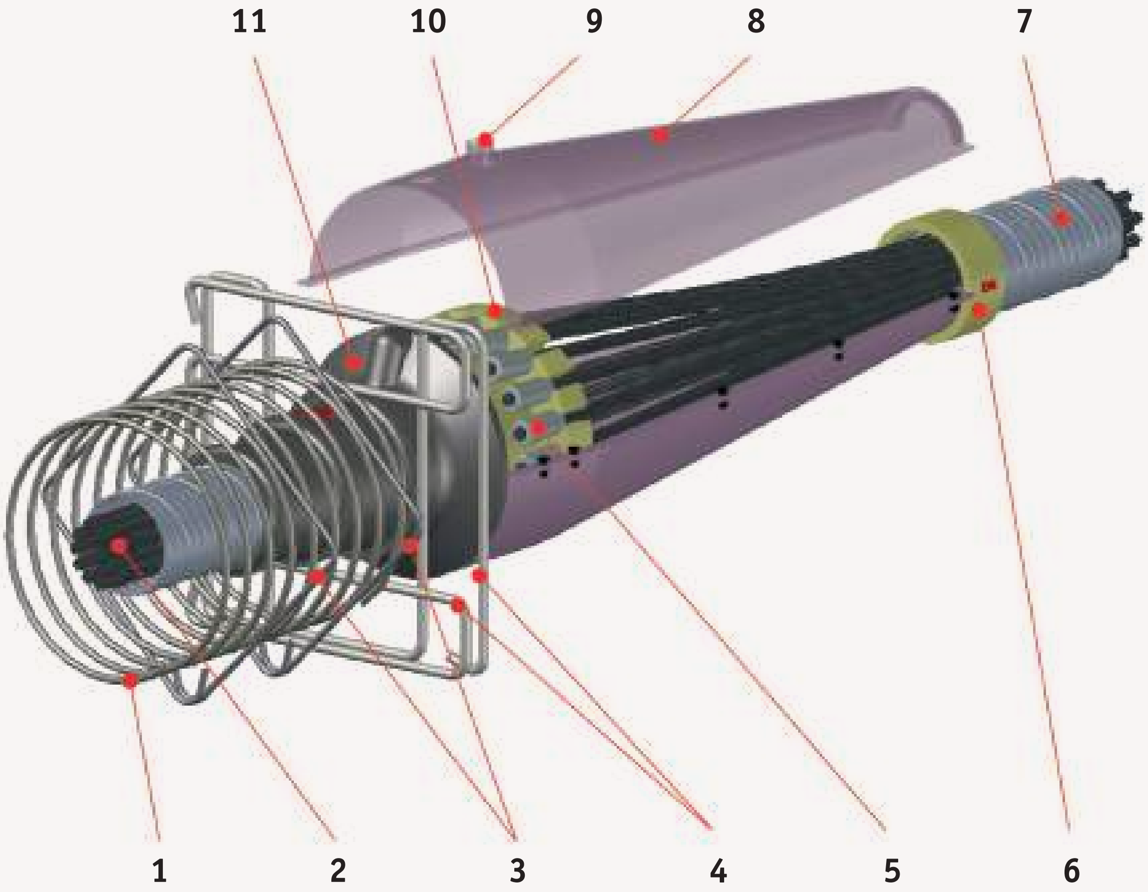


Fig.13 Fixed Coupler Axonometric View

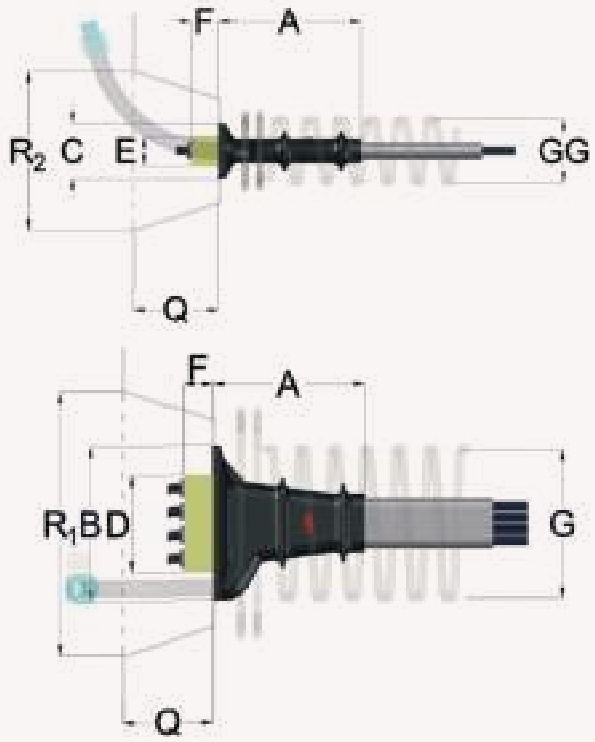
S/N	DESCRIPTION
1	SPIRAL
2	STRANDS
3	"◊" ADDITIONAL BURSTING REINFORCEMENT distributed along the spiral length
4	"W" STIRRUPS can be modified according to design requirements
5	SWAGES
6	COLLAR
7	DUCT Sheath diameter can be modified according to design requirements
8	PROTECTIVE COVER
9	GROUT PORT
10	COUPLING HEAD
11	BEARING PLATE

LMK-SFL M15 (0.6") & M13 (0.5") - STRESSING FLAT ANCHORAGE

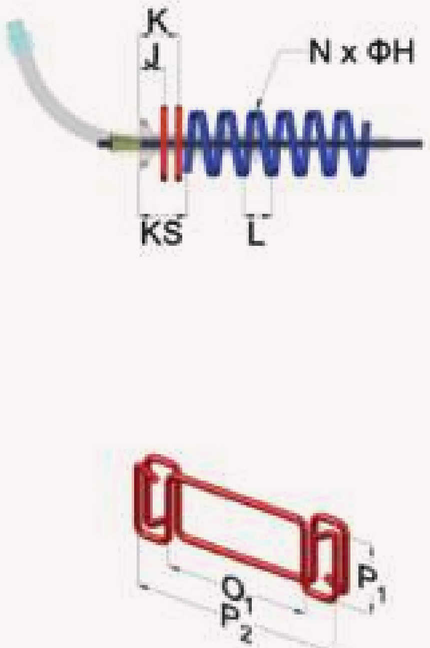
Table 6.8

LMK - SFL	BEARING PLATE			ANCHOR HEAD			SPIRAL						W STIRRUPS							RECESS	
	A	B	C	D	E	F	G	GG	N	ΦH	L	KS	P_1	P_2	O_1	$ΦS_1d$	J	N	K	R_1	R_2
TYPE	mm	mm	mm	mm	mm	mm	mm	mm	Nos	mm	mm	mm	mm	mm	mm	mm	mm	Nos	mm	mm	mm
2M15	120	150	70	80	48	50	150	120	5	12	50	75	95	300	170	8	35	2	55	170	90
2M13	120	150	70	80	48	50	150	120	5	10	50	75	95	300	170	8	35	2	55	150	90
3M15	150	180	70	115	48	50	190	120	5	12	50	100	95	300	190	8	60	2	80	210	90
3M13	150	180	70	115	48	50	190	120	5	10	50	100	95	300	190	8	60	2	80	170	90
4M15	210	220	70	150	48	50	230	120	6	12	50	125	120	350	200	12	80	2	100	250	90
4M13	210	220	70	150	48	50	230	120	6	10	50	125	120	350	200	12	80	2	100	230	90
5M15	250	260	70	185	48	50	260	120	6	14	50	135	120	350	240	12	90	2	110	280	90
5M13	250	260	70	185	48	50	260	120	6	12	50	135	120	350	240	12	90	2	110	260	90

Recommended values for Spiral, Bursting Reinforcement & Recess



Stressing Anchorage Side & Plan View



Configuration of Spiral & W Stirrups

LMK-SFL M15 (0.6") & M13 (0.5") - STRESSING FLAT ANCHORAGE

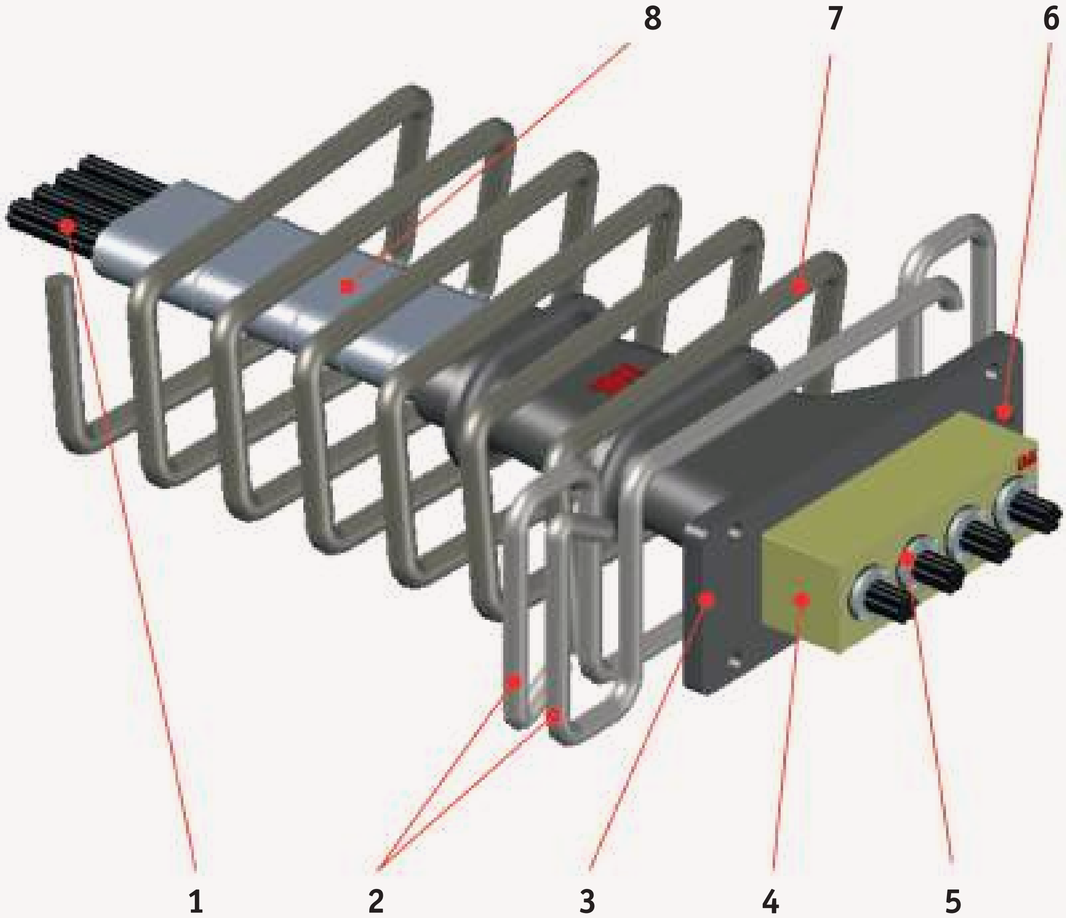


Fig.14 Stressing Flat Anchorage Axonometric View

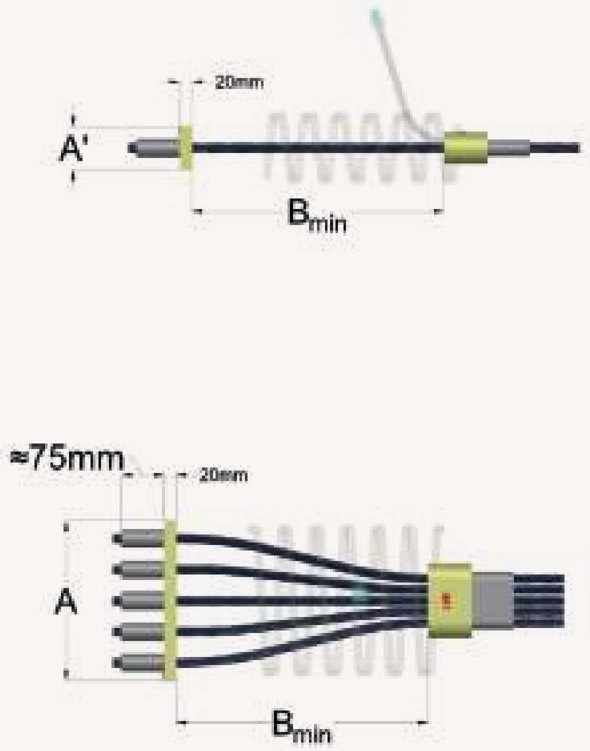
S/N	DESCRIPTION
1	STRANDS
2	"W" STIRRUPS can be modified according to design requirements
3	BEARING PLATE
4	ANCHOR HEAD
5	WEDGES
6	GROUT PORT
7	SPIRAL
8	FLAT DUCT Sheath dimensions can be modified according to design requirements

FFL M15 (0.6") & M13 (0.5") - FIXED FLAT ANCHORAGE

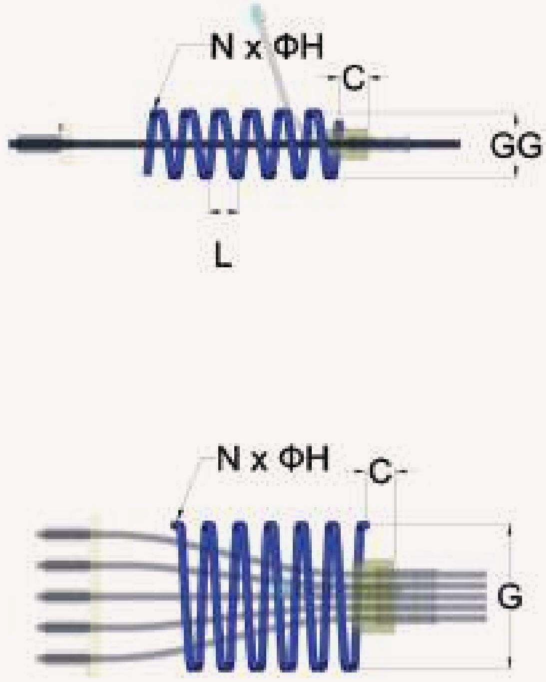
Table 6.9

LMK - FFL	ANCHOR HEAD		SPIRAL					DIMENSIONS	
	A	A'	G	GG	N	ΦH	L	Bmin	C
TYPE	mm	mm	mm	mm	Nos	mm	mm	mm	mm
2M13/15	130	70	130	100	5	12	50	190	50
3M13/15	180	70	170	100	5	12	50	250	50
4M13/15	220	70	210	100	6	12	50	320	50
5M13/15	260	70	250	100	6	14	50	400	50

Recommended values for Spiral



Fixed Anchorage Side & Plan Views



Configuration of Spiral

FFL M15 (0.6") & M13 (0.5") - FIXED FLAT ANCHORAGE

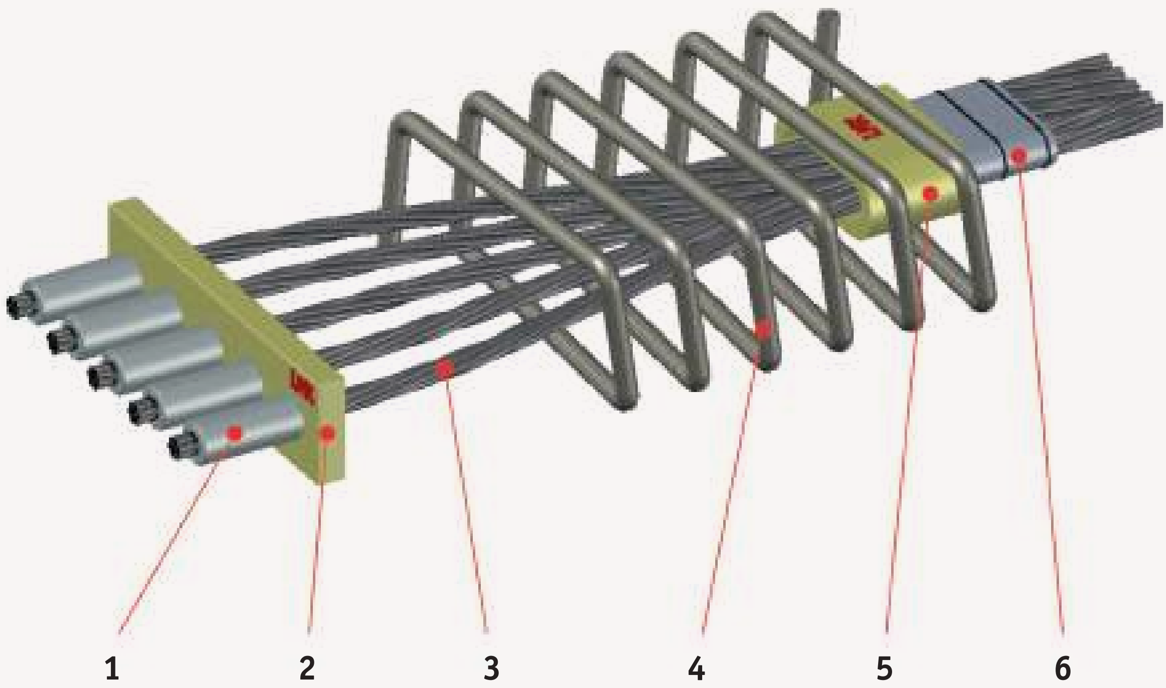
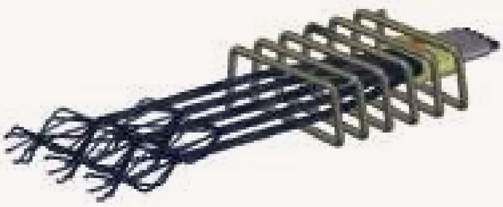


Fig.15 **Fixed Flat Anchorage Axonometric View**

S/N	DESCRIPTION
1	SWAGES
2	ANCHOR HEAD
3	STRANDS
4	SPIRAL
5	COLLAR
6	FLAT DUCT Sheath dimensions can be modified according to design requirements

Note: Fixed Flat Bulb (LMK-FFB) please refer to table 6.4 for 2 up to 5 strands



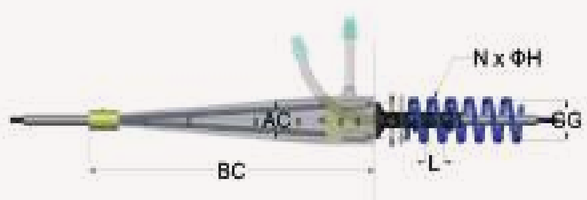
LMK-FFB

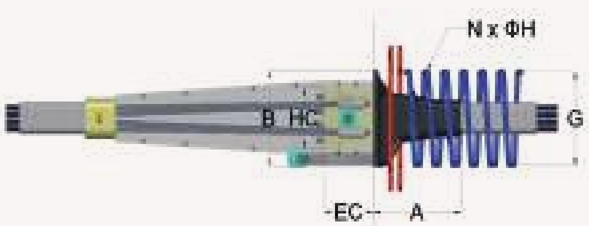
LMK-FFC M15 (0.6") & M13 (0.5") - FIXED FLAT COUPLER

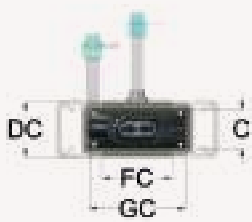
Table 6.10

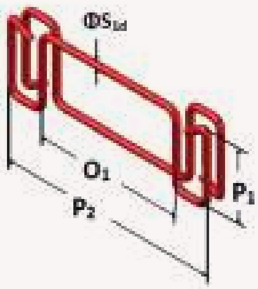
LMK - FFC	BEARING PLATE			COUPLING HEAD & PROTECTIVE COVER							SPIRAL						W STIRRUPS						
	A	B	C	AC	BC	DC	EC	FC	GC	HC	G	GG	N	ΦH	L	KS	P_1	P_2	O_1	$ΦS_1d$	J	N	K
TYPE	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	Nos	mm	mm	mm	mm	mm	mm	mm	mm	Nos	mm
2M15	120	150	70	100	650	118	135	90	130	80	150	120	5	12	50	75	95	300	170	8	35	2	55
2M13	120	150	70	100	650	118	135	90	130	80	150	120	5	10	50	75	95	300	170	8	35	2	55
3M15	150	180	70	100	650	118	135	125	165	115	190	120	5	12	50	100	95	300	190	8	60	2	80
3M13	150	180	70	100	650	118	135	125	165	115	190	120	5	10	50	100	95	300	190	8	60	2	80
4M15	210	220	70	100	700	118	135	160	200	150	230	120	6	12	50	125	120	350	200	12	80	2	100
4M13	210	220	70	100	700	118	135	160	200	150	230	120	6	10	50	125	120	350	200	12	80	2	100
5M15	250	260	70	100	700	118	135	195	235	185	260	120	6	14	50	135	120	350	240	12	90	2	110
5M13	250	260	70	100	700	118	135	195	235	185	260	120	6	12	50	135	120	350	240	12	90	2	110

Recommended values for Spiral & Bursting Reinforcement









Flat Coupler Side & Plan Views, Spiral Configuration

Rear View

Configuration of W Stirrups

LMK-FFC M15 (0.6") & M13 (0.5") - FIXED FLAT COUPLER

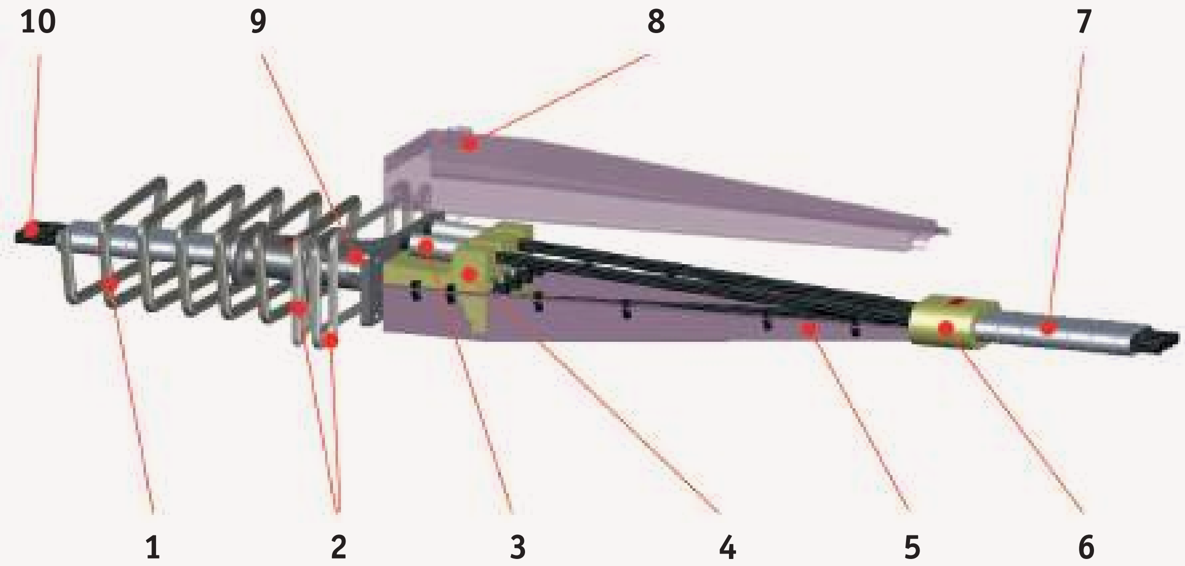


Fig.16 Fixed Flat Coupler Axonometric View

S/N	DESCRIPTION
1	SPIRAL
2	"W" STIRRUPS can be modified according to design requirements
3	SWAGES
4	COUPLING HEAD
5	PROTECTIVE COVER
6	COLLAR
7	FLAT DUCT Sheath dimensions can be modified according to design requirements
8	GROUT PORT
9	BEARING PLATE
10	STRANDS

Stressing

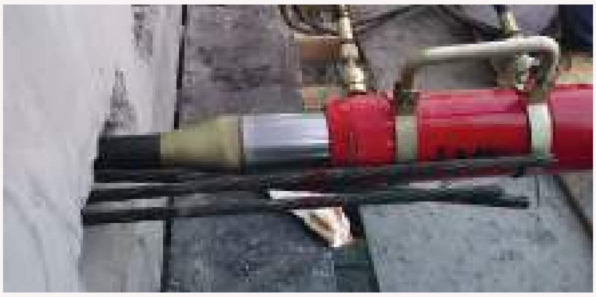
◗ Jacks & Clearance Requirements

The jacking apparatus is specially designed and manufactured in order to reduce the weight and volume for an easier handling and a practical use/operation. Pumps have a high-pressure capacity and flow rate so as to promptly respond when using jacks of high capacity and long piston stroke.

The bundle of strands passes through the jack, thus the applied force on each strand remains equal at the entire group of strands. Depending on the type of jack (front or rear locking/hollow), a variety of stressing heads/ chairs and spacers (commonly known as stressing tools) is provided.

When the required load/elongation is reached, the pressure is released and the stressing force is transferred to the anchor head through wedges achieving the same wedge draw-in to all strands. The tensioning can be accomplished in more than one jack's setting, depending on the required elongation and jack's piston stroke capacity.

Upon need, tensioned strands can be de-tensioned and released one by one using a proper releasing apparatus and a mono-strand jack.



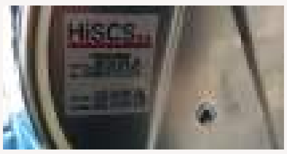
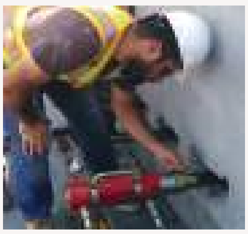
The swages in fixed & coupling type anchorages utilize the cold extrusion process, by griping the strand's end using special swage jack.

Each jack is connected through a system of high pressure hoses to a pump. The developed pressure is monitored during stressing by calibrated gauges.
Maintenance and repair of hydraulic equipment follows LMK strict and frequent inspection schedule routine.

◗ Jacks Data Table

LMK stressing jacks combine a compact design, high fidelity and easy handling. The jacks are factory calibrated with force/pressure calibration certificates and graphs. Stressing pumps and jacks are delivered fully equipped with calibrated gauges, high pressure hoses, connectors and spare fittings.

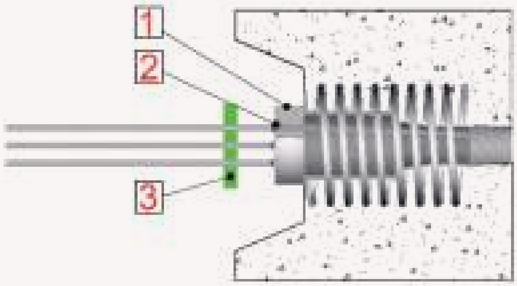


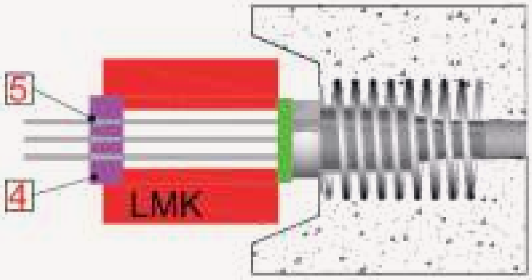



Typical Tensioning Procedure

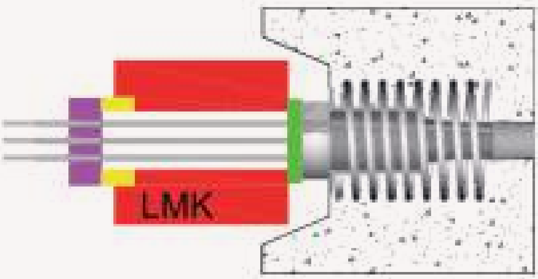
Rear Locking Jack



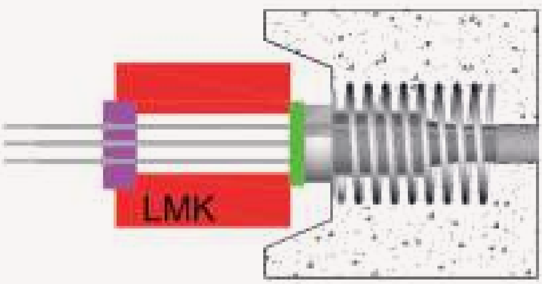
Step 1 - Positioning of anchor head (1), wedges (2) and spacer (3)



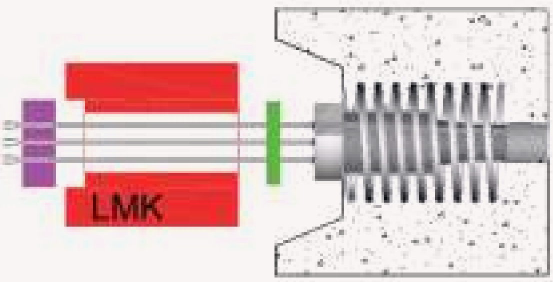
Step 2 - Positioning of jack and rear stressing head (4) with jack wedges (5)



Step 3 - Stressing in one or multiple phases

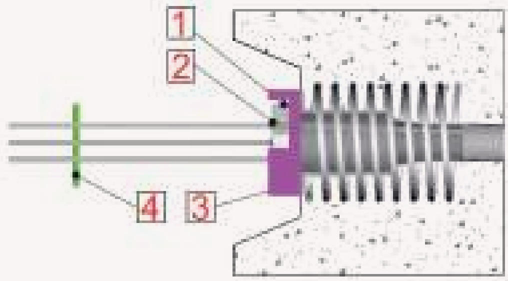


Step 4 - Release of tension and locking of wedges

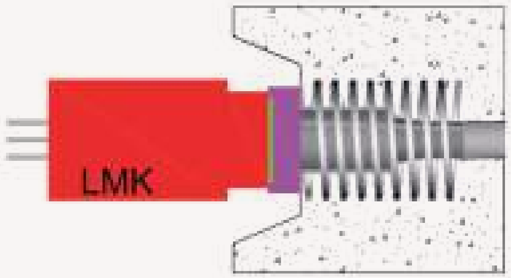


Step 5 - Removal of jack and stressing tools

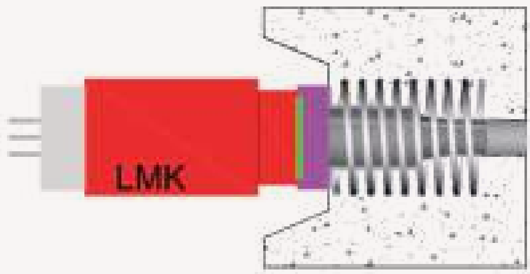
Front Locking Jack



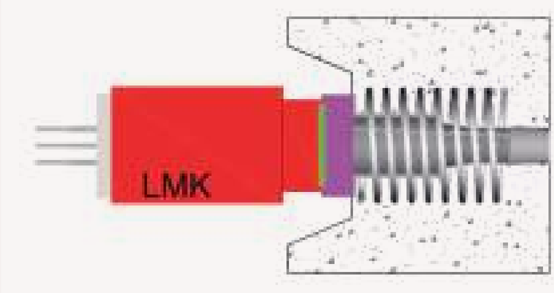
Step 1 - Positioning of anchor head (1), wedges (2), chair (3) & spacer (4)



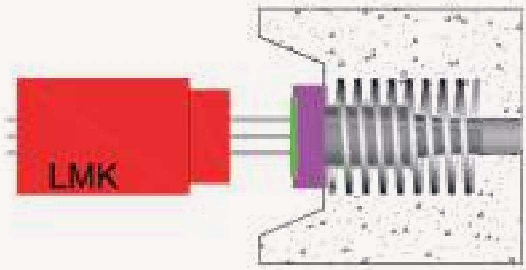
Step 2 - Positioning of jack



Step 3 - Stressing in one or multiple phases



Step 4 - Release of tension and locking of wedges



Step 5 - Removal of jack and stressing tools

Grouting

Procedure

Grout ensures the corrosion protection of the strands, providing the necessary bond between the strands and the structure as well. The quality of the produced grout should comply with Int'l standards and specifications (EN & ASTM). The grout is a mixture of cement and water and may contain admixtures such as expanding additives and water reducer/ plasticizers. The grout shall be free from chlorides, nitrates or other chemicals which cause steel corrosion and its strength should not be less than the required by the Design strength.

Tendons are grouted immediately but not earlier than 12 hours after stressing.

The permissible recommended intervals between strand installation and grouting, without use of corrosion inhibitor (water soluble oil) in ducts or directly applied to the strand, depending on exposure conditions, are:

- Very damp environment:
  (humidity > 70%) - 7 days
- Moderate environment:
  (humidity from 40% up to 70%) - 15 days
- Very dry environment:
  (Humidity < 40%) - 20 days

In order to avoid humidity concentration (water penetration and condensation) in tendons, the intervals between threading of strands and grouting should not exceed 12 weeks, considering 4 weeks out of 12 without concreting (placement on formwork) and up to 2 weeks in case of tendons under tension.

Tendons are grouted immediately after sealing of the recess in the anchorage area with concrete or grouting caps. The grout should flow from the lowest to the highest elevation of tendons geometry. Grout must be allowed to flow out from the outlets till there are no signs of trapped air.

Prior of grouting, it is recommended to check the tendons for possible blockage using compressed air. When fixed couplers are used, the grouting of the previous tendon section precedes the tensioning of the next adjacent section.

The grouted tendon must remain under pressure of no more than 3-5 bars for at least one minute, having all venting ports closed in order to verify the tightness of the system. The grouting / venting valves assure the proper accomplishment of the procedure.

Formula

The water to cement ratio (w/c) should be as low as possible, providing a grout with low bleeding and volume change having at the same time adequate fluidity, allowing tendon's proper filling. Grout temperature must be kept between 10 to 25 °C, and fluidity has to be within 14~19 sec.

Testing for fluidity is carried out at site using a fluidity cone. If the value is out of range, the batch should not be used and a new w/c ratio must be defined so as to obtain a satisfactory fluidity.
The grout quantity is defined as lit/m and can be given by the formula:

Water is batched through high-accuracy weighting devices in order to assure the stability of the produced grout. Usually, with 36-38 lit of water and 100 kg of cement, 72-74 lit of grout can be produced.

In case of vacum grouting, the use of a vacum grouting pump is required.

Grease, gel and wax can also be used as tendons filling material for un-bonded applications.

Round ducts $$\frac{\pi*\left(\frac{\Phi_i^2}{2}\right)-A*n}{1000}$$

Flat ducts $$\frac{\pi*r_1*r_2-A*n}{1000}$$

Φ_i (mm) = inner diameter of sheath

A (mm2) = one strand nominal area

n = number of strands per tendon

r_1 & r_2 (mm) = internal radius of flat sheath

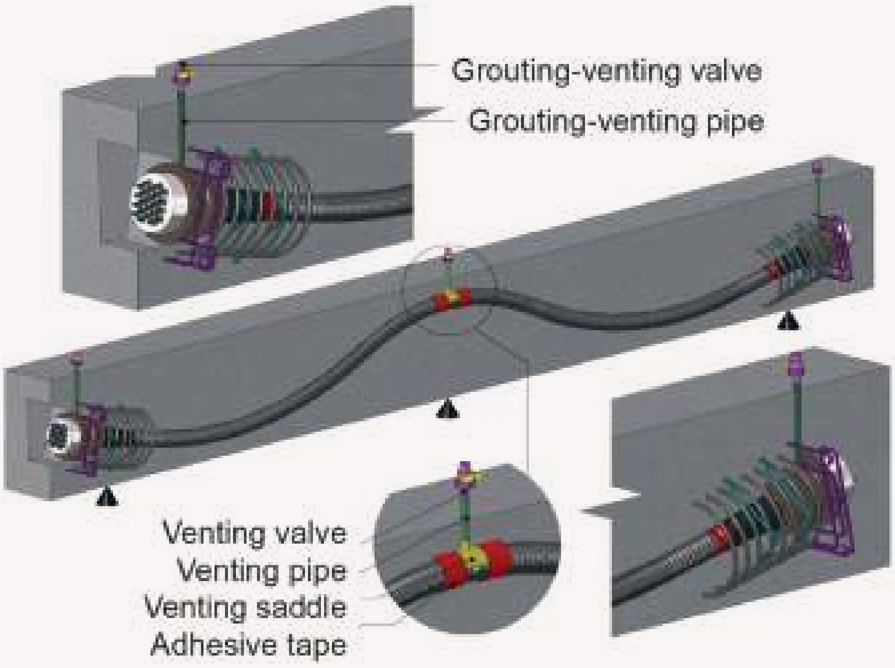
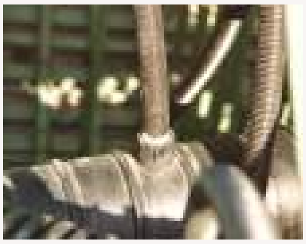


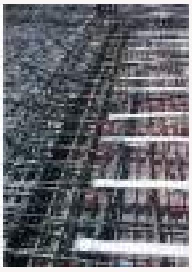
Fig.18 **Typical Grouting Ancillaries Configuration**

Grouting Equipment

The grouting equipment is consisted of a highspeed mixer, an agitator, a grout-pump and a power unit, capable of continuous mechanical mixing which produces a grout free of lumps and undispersed cement. The pump shall have seals adequate to prevent penetration of oil, air and other foreign substances into the grout and to prevent loss of grout or water.

The mixer shall be kept partially filled with grout at all times during the pumping operation, so as to prevent air from infiltrating the system. Under normal conditions, the grouting equipment shall be capable of continuously grouting the longest tendon on the structure in no more than 20 minutes.





Design Requirements

◗ Tendon Force Losses

The effective stressing force differs from the initial stressing force (prior of seating as commonly known) for various reasons. The main reasons are:

◗ Short Term - Initial losses

- Friction losses (wobble and curvature effects)
- Concrete elastic deformation
- Anchor set / wedges drawn-in

◗ Long Term - Time dependent losses

- Creep & shrinkage of concrete
- Strand relaxation

After the wedges are finally locked, they slightly recede into the anchor head causing a loss of tension. This tension loss should be taken into account to the calculations, especially in short length tendons (< 15 m) and can be completely or partially compensated with over-stressing. The wedge draw-in is 4 mm with maximum value 6 mm.

Reference in Int'l standards and technical literature foresees the calculation of losses due to creep & shrinkage and elastic shortening of concrete, especially in cases where tendons are not stressed simultaneously in a section.

The relaxation of the strands depends primarily on the type of steel (class of relaxation), the magnitude of the pre-stress and the temperature. For low relaxation class, the maximum losses are about 2,5% after 1000 h @ 20 ^{0}C and an initial stress of about 70% of the nominal tensile strength. Further information can be obtained from strand steel Int'l literature.

◗ Stressing Losses at Seating

Stressing losses occur when the load is transferred from the jack to the anchorage, as a result of a shortening of the tendon due to wedges drawn-in, anchor head setting and strand slippage. This loss due to wedge drawn-in affects only a certain length (d) of the tendon (see below graphs).

In case of short tendons (< 15 m), the wedge drawn-in effect dominates over the stressing losses.

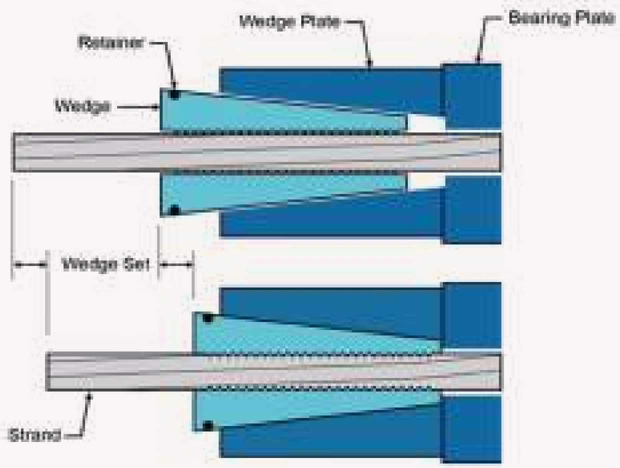
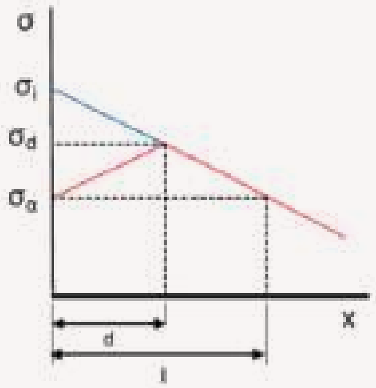


Fig.19 **Wedge drawn-in mechanism**

Basic Formulas



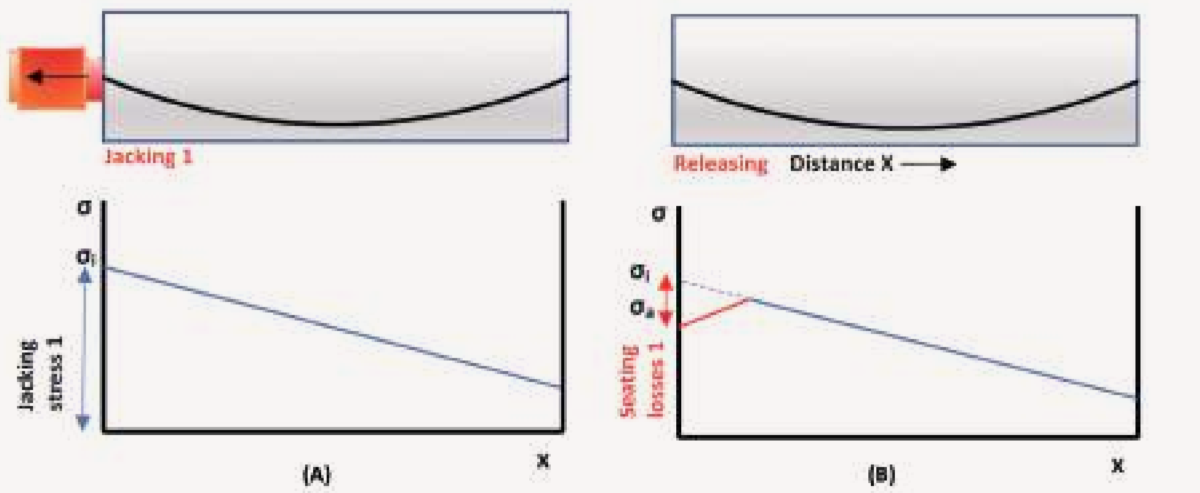
Where:

$$d = \sqrt{\frac{r * E * l}{\sigma_i - \sigma_l}}, \sigma_a = \sigma_i - \frac{2 * r * E}{d}, \sigma_d = \frac{\sigma_i + \sigma_a}{2}$$

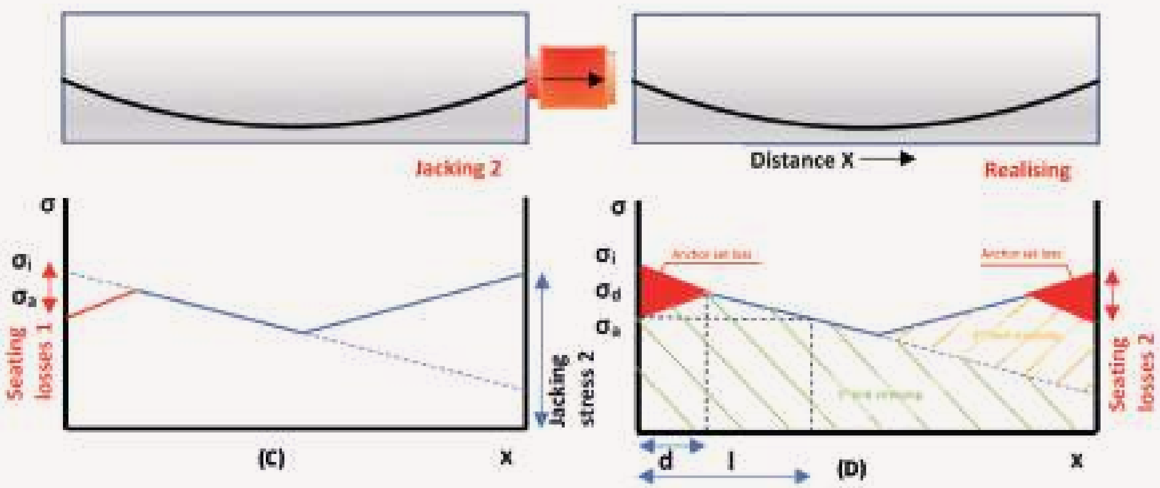
r = wedge drawn-in
l = tendon's length where the tension is known
σ_l = tension at distance l from the anchorage
σ_i = tension at jack
E = strand's modulus of elasticity (theoretical value 195-197 GPa)
d = the affected tendon length due to wedge drawn-in
σ_a = tension after wedge drawn-in
σ_d = tension at a distance d from the anchorage

Schematic View of Stressing Losses

Left side jacking



Right side jacking



Basic Equations

The tension σ in a distance X is given by the formula:

$$\sigma_x = \sigma_i * e^{-(\mu*\alpha+k*x)}$$

(LRFD equation)

or

$$\sigma_x = \sigma_i * e^{-\mu(\alpha+\kappa*x)}$$

(EN-1992-1-1 equation)

σ_i = tension at the anchorage

x = cable length from the anchorage to X (ft or m)

α = the total angle of the deviation (rad) between the anchorage and X

μ = friction coefficient between strand and sheath (rad^{-1})

k = μ*κ=coefficient of unintentional angular deviation - wobble

The friction coefficient μ depends on various factors such as inaccurate placement of PT tendon, improper placement of strands or damaged sheathing, bending radius, strands and sheaths nature and contact surfaces, etc.

The wobble coefficient is related to sloppy placement or excessive tendon deviations, stiffness of ducts, distances between tendons supports, vibrations during concreting, etc.

Table 8 **Recommended values of μ, κ & k**

TYPE of TENDON & DUCT	μ	κ (EN)	k (AASHTO)
	rad^{-1}	rad/m	m^{-1} (x 10^{-3})
Internal tendons-Steel corrugated ducts	0.17-0.20	0.005-0.01	0.85-2.0
Internal tendons-Plastic ducts	0.10-0.14		0.5-1.4
External tendons-Steel deviators	0.16-0.24		0.8-2.4
External tendons-Plastic deviators	0.10-0.14		0.5-1.4
Unbonded greased and coated	0.04-0.06	0.009-0.01	0.36-0.6

The following values may be assumed for design:

Table 9 **AASHTO LRFD**

TYPE of TENDON & DUCT	μ	k (AASHTO)
	rad^{-1}	ft^{-1}
Internal tendons-Steel corrugated ducts	0.15-0.25	0.0002
Internal tendons-Plastic ducts	0.23	0.0002
External tendons-Steel deviators	0.25	0.0002

Table 10 **EN-1992-1-1**

TYPE of TENDON & DUCT	μ non-lubricated	μ lubricated	κ (EN)
	rad^{-1}	rad^{-1}	rad/m
Internal tendons-Steel corrugated ducts	0.19	--	0.005-0.01
External tendons-Steel deviators	0.24	0.16	
External tendons-Plastic deviators	0.12	0.10	

The tendons' elongation is given by the formula:

$$\Delta_X = \int_0^x \frac{\sigma_x}{E} * d_x$$

where:
E = strands modulus of elasticity

LMK Solutions


◗ Breakthrough in PT Technology

LMK anchorages have successfully passed many efficiency tests proving the quality and adequacy in line with Int'l specifications & standards (EN-ETAG-EAD, AASHTO LRFD).


The **LMK** Post Tensioning system can provide full engineering services and support, including preliminary and final designs, supply of materials, equipment/machinery, installation, training, supervision, stressing, grouting, planning and management services and customized solutions for all types of structures.


This brochure contains selectively the most characteristic topics related to PT technology and general information for design and construction.


Depending on project's requirements data can be modified accordingly.

Contact **LMK** technical department for further details or stay tuned via our social media and blog website.



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