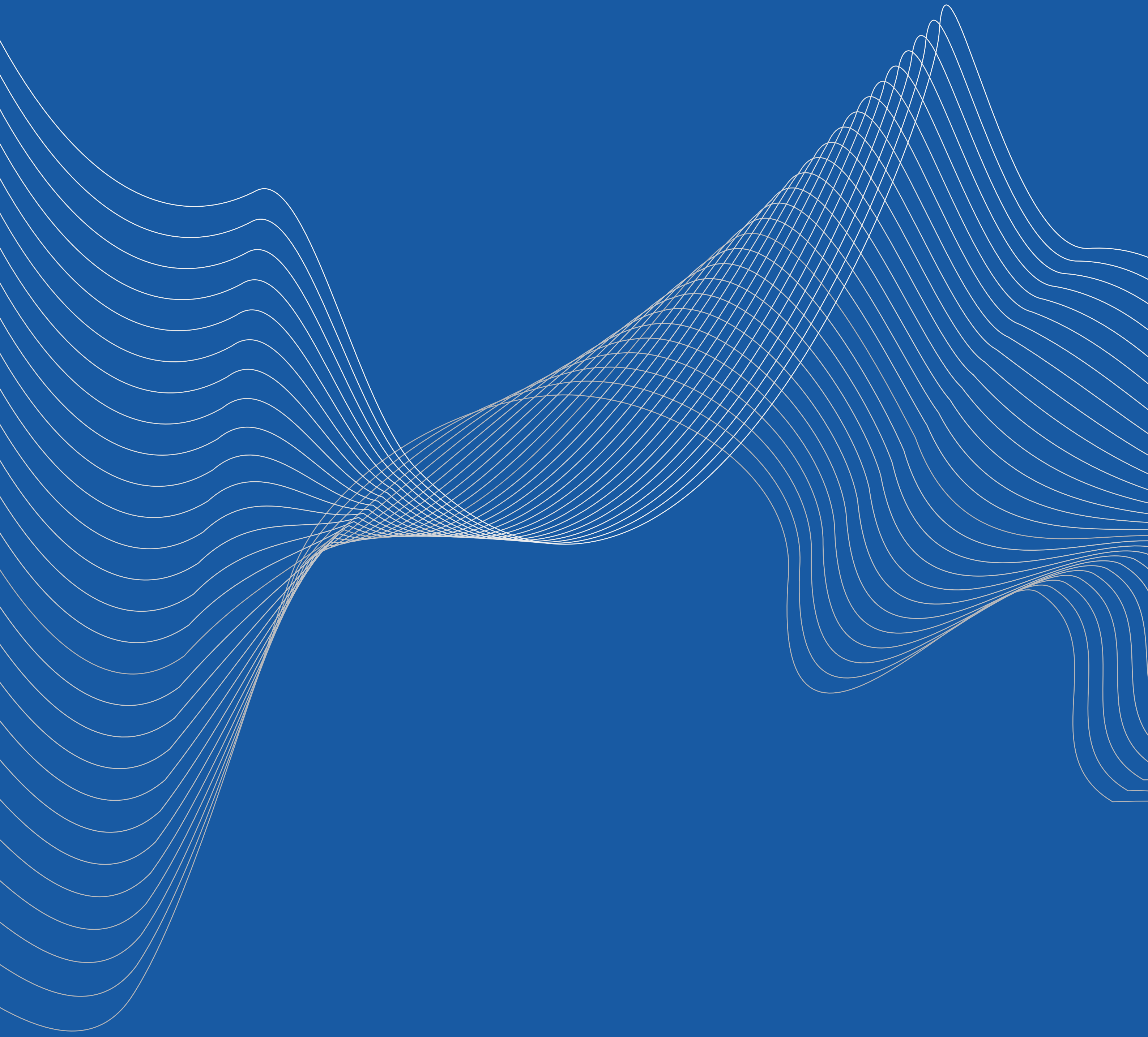
FORTEC

POST TENSIONING

CONSTRUCTION, ENGINEERING
& GEOTECHNICAL
SPECIALISTS



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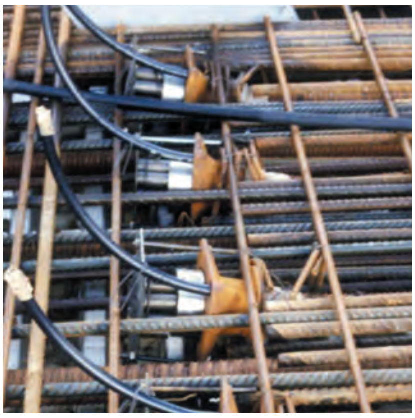
Introduction

Fortec Australia Pty Ltd is a privately owned Australian company specialising in construction, engineering and geotechnical services, and is part of the Ertech Group of Companies. Our team comprises specialist engineers and contracting professionals who have worked in the industry for many years. Fortec Australia has considerable knowledge and experience in all aspects of post-tensioning works. The services we offer include the following post-tensioning systems:

- Multi-strand post-tensioning: Our MK4 post-tensioning system is used in buildings, tanks, bridges and many other structures within Australia and the world.
- Flat slab post-tensioning: Our post-tensioned slab system (Flat Slab system) is predominately used for building structures and industrial pavements.
- External post-tensioning: External PT is mostly used in strengthening existing structures or for replacement applications where previous designs do not meet updated standards.
- Bar post-tensioning: Our high tensile threaded bar system is suitable for a range of applications including shorter post-tensioning tendons, strengthening works, soil nails and micropiles.



Fortec staff has been responsible for the design and installation of post-tensioning systems throughout Australia, Europe, Asia and the Middle East. Our post-tensioning system includes a range of anchorages, accessories and the necessary equipment to respond to the technical requirements for the construction of building, bridges and other structures.

All multi-strand components have been designed and tested in accordance with the European code ETAG-013, thus we deliver world class technologies and systems to every market we service.

Our experience in various post-tensioning applications and our team of engineers and technicians are the reason for our success in delivering exceptional results for our clients. We provide post-tensioning solutions for many structures like bridges, buildings, Liquefied LNG tanks, silos and various other suspended structures.

Fortec Australia can provide the following services:

- Technical assistance in all the phases of the project; from the design to the final execution.
- Installation of post-tensioning only services where design input is not required.
- Design and construct building design packages
- Study of alternative design or construction method as an improvement for the optimum solution for every project.

Quality

Fortec Australia and its parent companies utilise a complete Quality Assurance Programme conforming to ISO 9001:2000, including the design, production, supply and installation of all post-tensioning works.

Strand properties

The strand used for post-tensioning tendons are comprised of 7-wires low relaxation steel. The most common diameters used in Australia are 0.5" (12.7mm) and 0.6" (15.2mm).

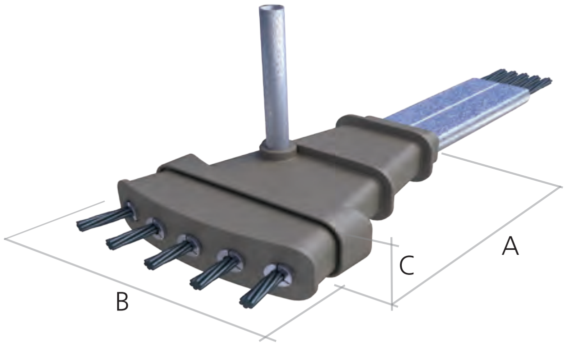
The following table gives the main characteristics of each common size of strand manufactured and corresponding code manufactured to.

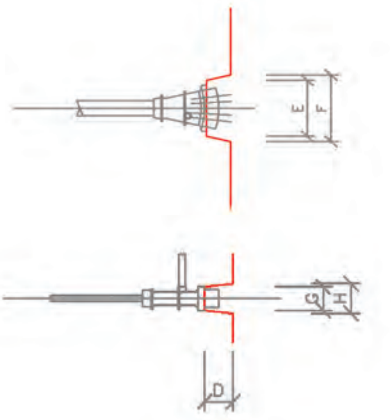
Strand Type	Standard	Strand Size	F_{pk}	Nominal ø	Cross Section	Weight	Min. Breaking Load F_{pk}	Relaxation 1000h at 70% of F_{pk}	% Proof Force
		mm	Mpa	mm	mm^2	kg/m	kN	%	kN
12.7mm (0.5")	AS 4672	12.7	1870 MPa	12.7	98.6	0.774	184	2.50%	156*
	BS 5896:1980	12.9	1860 MPa	12.9	100	0.785	186	2.50%	158*
	prEN 10138-3	12.9	1860 MPa	12.9	100	0.781	186	2.50%	164*
15.2mm and 15.7mm (0.6")	AS 4672	15.2	1830 MPa	15.2	143	1.122	261	2.50%	222*
	BS 5896:1980	15.7	1770 MPa	15.7	150	1.180	265	2.50%	225*
	prEN 10138-3	15.7	1860 MPa	15.7	150	1.172	279	2.50%	246*

Note: * AS4672 Proof Force = 0.2%, BS 5896, prEN10138 Proof Force = 0.1%
Notes: Modulus of Elasticity for 7 Wire Strand ranges between 180 - 205GPa

Flat Slab Live End Anchorage FMA505

Fortec FMA505 anchorages for slab post-tensioning in buildings, bridge decks and other applications consist of up to 5 No. strands of 12.7mm (0.5") or 4No. strands of 15.2mm (0.6") diameter placed inside a 70mm flat duct. The strands are tensioned and locked off individually using a mono-strand jack.





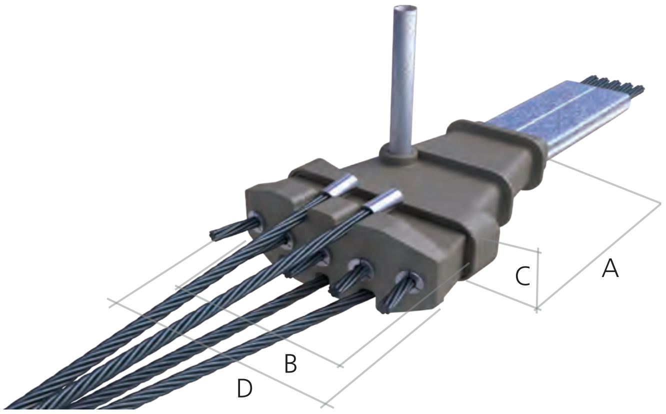
Flat Slab Live End Anchorage FMA506

The FMA506 system is similar to the FMA505 system but has additional capacity to accommodate 5 No.15.2mm diameter strands. The system uses the larger 90mm x 19mm flat duct system.

Strand Size	Tendon Type	No Strands	Anchorage Casting Dimension (mm)			Recess Former Size (mm)					Flat Duct Size	Minimum Concrete Thickness	Minimum Vertical Anchor Spacing	Minimum Edge Distance/ Anchor Spacing
		mm	A	B	C	D	E	F	G	H	mm	mm	mm	mm
12.7mm (0.5")	305	3	215	220	79	100	265	315	80	100	70 x 19	140	100	300
	405	4	215	220	79	100	265	315	80	100	70 x 19	150	100	300
	505	5	215	220	79	100	265	315	80	100	70 x 19	160	100	300
15.2mm (0.6")	306	3	215	220	79	100	265	315	80	100	70 x 19	150	100	300
	406	4	215	220	79	100	265	315	80	100	70 x 19	160	100	300
	506	5	270	265	79	100	265	315	80	100	90 x 19	170	100	300

Flat Slab Coupling Anchorage FSC505/506

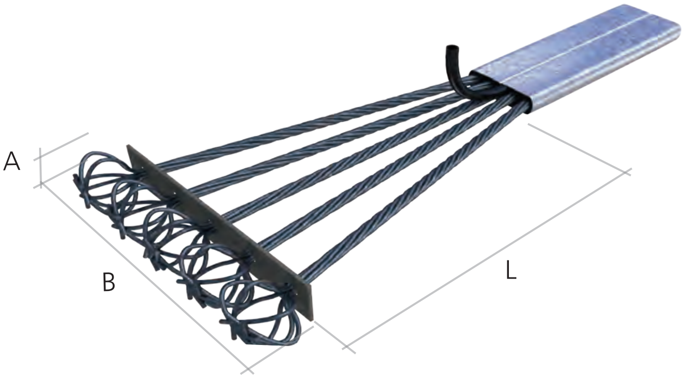
When there is a requirement for continuity of the tendon through a construction joint couplers are a solution that engineers can utilise to ensure the tendon force is continuous throughout the entire length of the tendon. Couplers are mostly used on industrial pavements where a reduction of movement joints is preferred or where load continuity is critical.



Strand Size	Tendon Type	No Strands	FSC Coupling Anchorage (mm)				Minimum Concrete Thickness	Minimum Edge Distance/Anchor Spacing
		mm	A	B	C	D	mm	mm
12.7mm (0.5")	405	2, 3 or 4	100	220	80	220	170	300
	505	5	100	220	110	220	200	300
15.2mm (0.6")	406	2, 3 or 4	100	220	110	220	220	300
	506	5	100	250	120	270	220	300

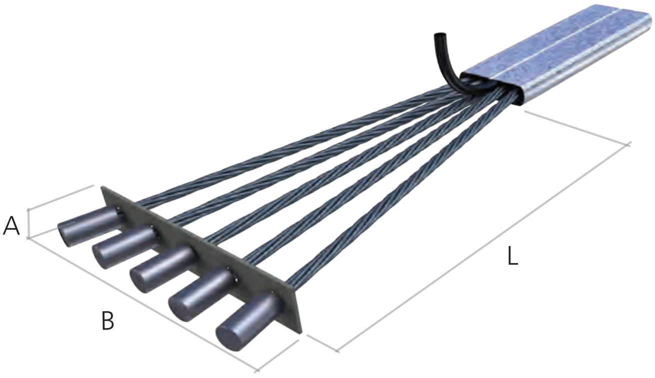
Flat Slab Dead End Anchorage FSO505/506

For the dead ends of a flat anchorage we utilise the anchorage type FSO which is easy to execute and cost effective. The anchorage consists of 'onion end' bulbs manufactured on site with our specialist equipment. The anchorage lengths and dimensions are indicated in the table below.



Flat Slab Swaged End Anchorage FSS505/506

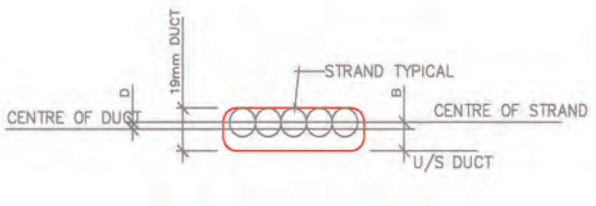
An alternative dead end option for the flat slab system is a Swaged Dead End. The anchorage consists of a swaged strand manufactured on site, bearing against a 12mm thick steel plate. The swage can consist of a compressed barrel/wedge or conventional swage. This exposed strand is greased to ensure load transfer to the swage plate. This anchorage is typically used in beams to ensure force is transferred to the back of the column. The anchorage lengths and dimensions of the dead end plate are indicated in the table below.



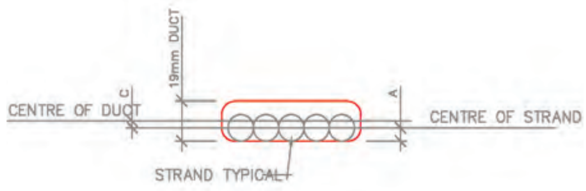
Strand Size	Tendon Type	No Strands	FSO Onion Dead End (mm)			FSS Swaged Dead End (mm)			Minimum Concrete Thickness	Minimum Vertical Anchor Spacing	Minimum Edge Distance/ Anchor Spacing
			A	B	L	A	B	L	mm	mm	mm
12.7mm (0.5")	305	2 or 3	50	230	1050	75	200	500	140	100	300
	405	4	50	270	1050	75	250	500	150	100	300
	505	5	50	350	1050	75	300	600	160	100	300
15.2mm (0.6")	306	2 or 3	50	230	1350	75	225	500	150	100	300
	406	4	50	270	1350	75	300	600	160	100	300
	506	5	50	350	1350	75	350	600	170	100	300

Mono Strand Duct Systems

Post-tensioned tendons are encapsulated within concrete in a duct which is usually manufactured in galvanised steel with a wall thickness between 0.3 mm and 0.5 mm. The ducts are normally supplied in 5-6m lengths and are joined on site via a manufactured bell-end. Once stressing has been completed and approved by the design engineer the ducts are filled with cementitious grout to ensure the tendon achieves adequate bond and corrosion protection throughout the life of the structure. The flat slab system has two common sizes being 70mm and 90mm ducting. (Note - 43mm ducting is available for use with 3 strand systems but not commonly used).



Section at tendon low point



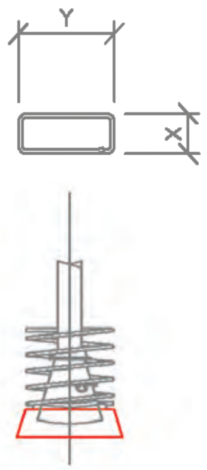
Section at tendon high point

Strand Size	Tendon Type	No Strands	Flat Duct Size	FSO Onion Dead End (mm)			FSS Swaged Dead End (mm)			Strand Offsets and Eccentricity (mm)		
			mm	A	B	L	A	B	L	A	B	E
12.7mm (0.5”)	505	2 or 3	70x19	50	230	1050	75	200	500	7	12	2.5mm
	505	4	70x19	50	270	1050	75	250	500	7	12	2.5mm
	505	5	70x19	50	350	1050	75	300	600	7	12	2.5mm
15.2mm (0.6”)	406	2 or 3	70x19	50	230	1350	75	225	500	8	12	1.5mm
	406	4	70x19	50	270	1350	75	300	600	8	12	1.5mm
	506	5	90x19	50	350	1350	75	350	600	8	12	1.5mm

Anchorage Reinforcement Requirements

The flat slab system requires anti-burst reinforcement to ensure the forces generated during stressing are confined. There are numerous types of anti-burst solutions but the common anti-burst reinforcement is the spiral. This allows the anti-burst to be installed over the anchorage with minimum disruption and improves the installation process, thus is the most commonly used option.

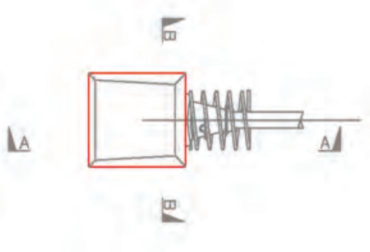
Strand Size	Tendon Type	No Strands	Helical Cage (Spiral) Anti-Burst (mm)				Bar Type	Transfer Strength
			X	Y	N	PITCH	(mm)	MPa
12.7mm (0.5”)	405	2, 3 or 4	100	260	5	60	R10	22
	505	5	100	260	5	60	R10	22
15.2mm (0.6”)	406	2 or 3	100	260	5	60	R10	22
	406	4	110	300	7	60	N10	25
	506	5	110	300	7	60	N10	25

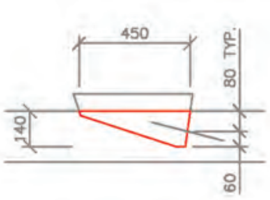


Note: Anti-burst reinforcement is for the primary bursting stresses and must be supplemented with other edge reinforcement and/or additional shear ties within a beam. Along the edge of the slab it is always recommended to detail U-bars/L-bars plus longitudinal reinforcement to control tensile spalling stresses between the anchorages and to adequately reinforce the untensioned zone which occurs between anchorages.

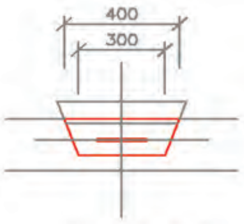
Surfacing Stressing Blockout Requirements (Pans)

Surface stressing blockouts (Pans) are used in locations where edge access is not available or not preferred due to finishing requirements. It is common for stressing pans to be used in residential developments where exposed balcony edges require strict finishing requirements, and as such edge stressing is not possible. Pans are also required in areas where stressing access is not possible.





SECTION A–A

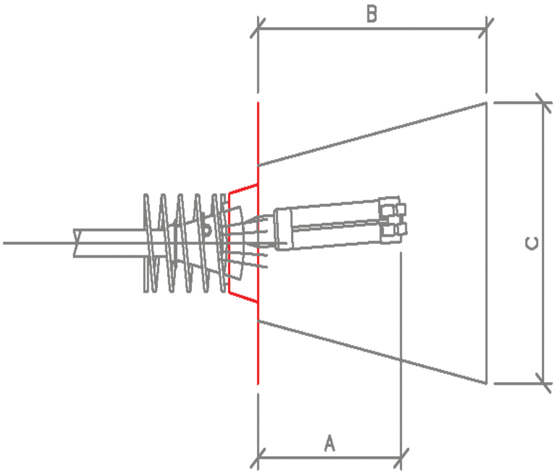


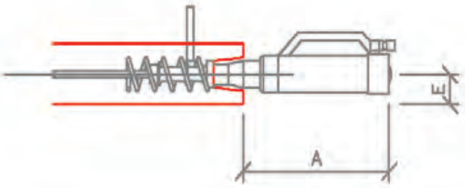
SECTION B–B

Jacking

The commonly used single strand centre hole jack is compact, lightweight and can be handled without the requirement for crane or support frames. Current mono-strand jacks are designed to be able to stress both common strand sizes. The nose and internal wedges can be modified with ease to allow stressing of both strand sizes. The jacks used require certain minimum clearance requirements to allow the effective stressing. The table below details these minimum jacking clearance requirements.

Strand Size	Tendon Type	No Strands	Minimum Clearance Requirement Dimensions (mm)				
		mm	A	B	C	D	E
12.7mm (0.5")	405	2, 3 or 4	500	800	750	450	70
	505	5	500	800	750	450	70
15.2mm (0.6")	406	2, 3 or 4	500	800	750	450	70
	506	5	600	800	850	450	70





The Multi-Strand System

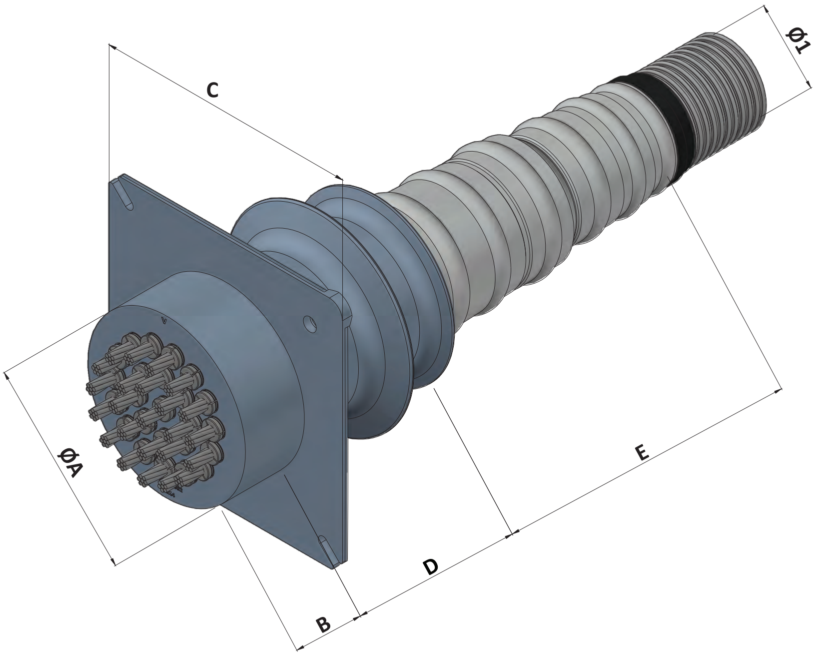
Fortec Australia is the licensee of MK4 systems. Design and testing on the systems are in accordance with the new European standard ETAG-013 for post-tensioning systems. Our range of anchorages include live end, dead end, coupled and free floating anchorage systems for use on numerous civil and structural applications.

Multi-Strand Live End Anchorages MSA

Multi-Strand anchorages facilitate the introduction of a typically significant and concentrated post-tensioning force in the tendon, with the tensioning operations carried out by hydraulic jacks. Predominately used on civil structures like bridges, tanks and dam walls, and are used in Building applications where transfer beams, slabs are required.

The MSA Live End anchorages have been designed to comply with the most demanding of international standards such as ETAG, Eurocode etc.

Each basic anchorage consists of an anchor casting trumplate, anchor block and individual wedges. All the elements of the anchorages and corresponding dimensions have been carefully selected and tested to achieve the greatest economy in design. (See table below).

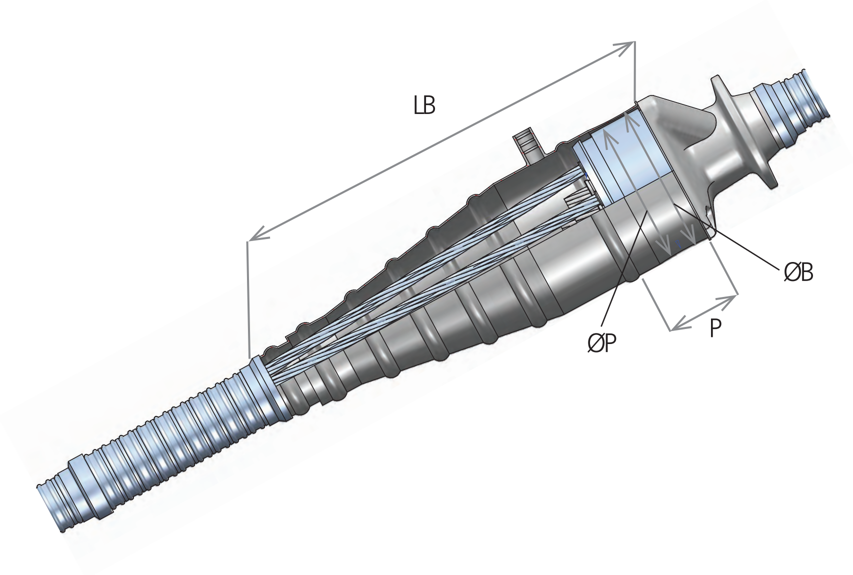


Strand Type	Tendon Type	Trumpet Type	øA	B	C	D	Trumpet	ø1	Minimum Radius of Curvature
			mm	mm	mm	mm	mm	mm	mm
(0.6”) 15.2mm and 15.7mm	4	T-4	110	50	170	155		51/56	3000
	5	T-4	110	50	170	155		51/56	3000
	7	T-5	130	61	194	150		62/67	3000
	9	T-6	144	60	220	175		72/77	4000
	12	T-7	165	72	254	200		85/90	4000
	15	T-8	186	78	282	235		90/95	4500
	19	T-19	200	94	314	275		100/105	5000
	24	TR-24	240	90	356	240	399	110/115	5000
	27	TR-31	252	105	395	275	444	120/125	6000
	31	TR-31	268	110	395	275	444	120/125	6000
	37	TR-37	296	120	444	300	464	130/137	6500
	43	TR-43	330	140	490	340	848	140/147	6500

Multiple Coupler MCB

An economic range of couplers has been designed for ease of assembly on site. Couplers are used to give continuity to the tendons which cannot be installed or tensioned as one unit.

The first-stage of the tendon is stressed and anchored in the normal way and the dead end of the second-stage tendon is then assembled around it.
The complete coupler assembly is enclosed within a conical/cylindrical plastic housing which has a grout inlet.

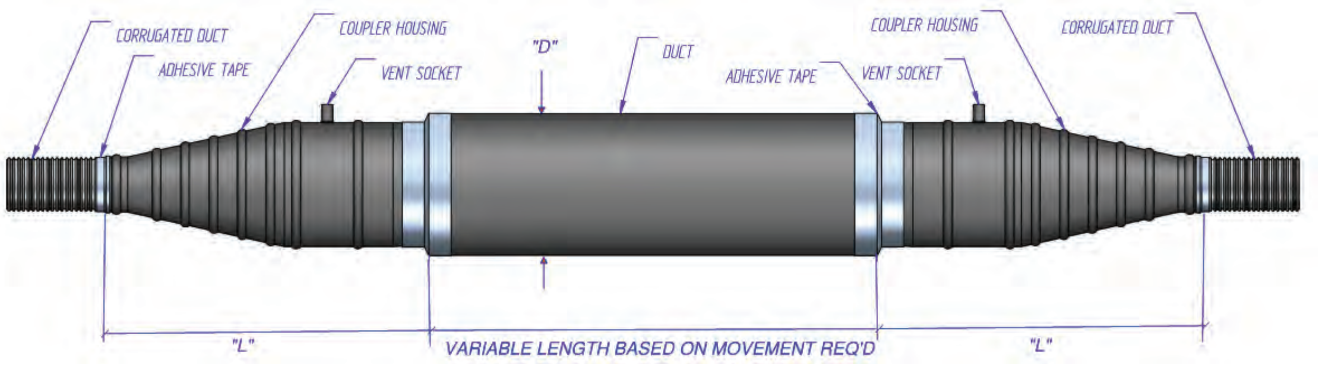


Strand Type		Tendon Type	øB	LB	øP	P
			mm	mm	mm	mm
(0.6") 15.2mm and 15.7mm		4	188	580	180	98
	Cylindrical Conical	5	188	580	180	98
		7	188	580	180	98
		9	208	636	200	97
		12	252	719	244	97
		15	274	723	265	102
		19	274	723	265	127
		24	325	1.015	315	122
		27	350	1.150	354	137
		31	350	1.162	354	127
		37	390	1.248	354	137
		43	455	1.680	440	182

Movable Coupler MCR

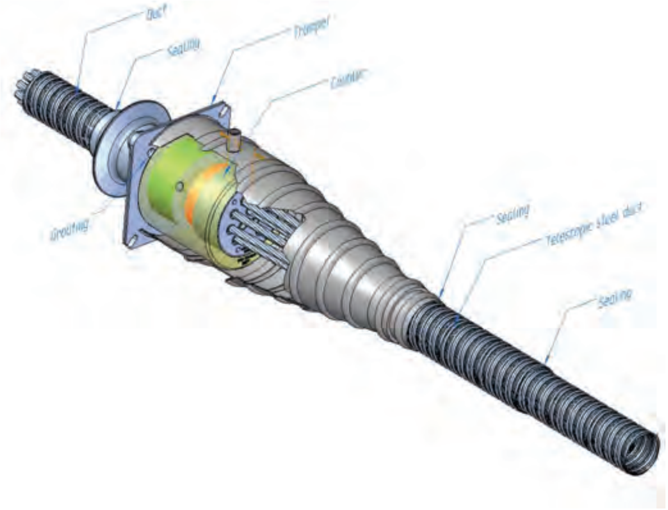
The movable coupler is designed to lengthen unstressed or partially stressed tendons.

The 1st stage of the tendon is assembled and a coupler anchor head & preset wedges installed and secured with a flat retaining plate. The nest tendon that has been fabricated with a coupler anchor head & spring loaded wedges with a retaining plate can then be coupled to the first tendon by means of an internally threaded coupler.
The complete coupler assembly is enclosed within a conical/cylindrical plastic housing which has a grout inlet.



Fixed Coupler MCR

The Fixed Coupler MCR can also be used as an alternative to the MCB coupler.

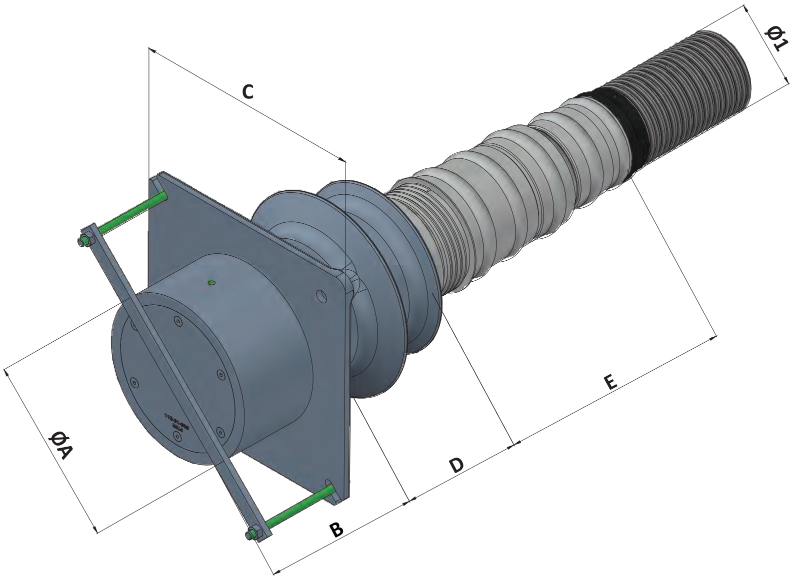


Strand Type		Tendon Type	D	L
			(mm)	(mm)
(0.6")		4	188	580
	Cylindrical	5	188	580
15.2mm		7	188	580
and		9	208	636
15.7mm		12	252	719

Automatic Dead End Anchorage MPA

The unique MK4 Automatic Dead End Anchorage MPA is intended to be used at one end of a tendon, the other end being fitted with a live end anchorage MSA.

Its principal characteristic is the automatic retention of the strands by the anchor plate and its primary use is in situations where extrusion grips cannot be fitted satisfactorily due to space limitations.

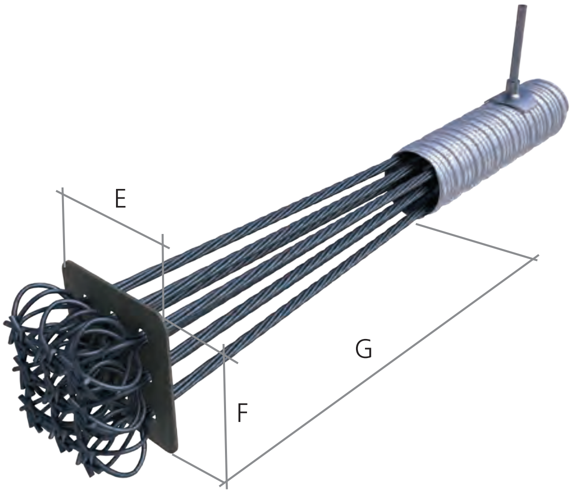


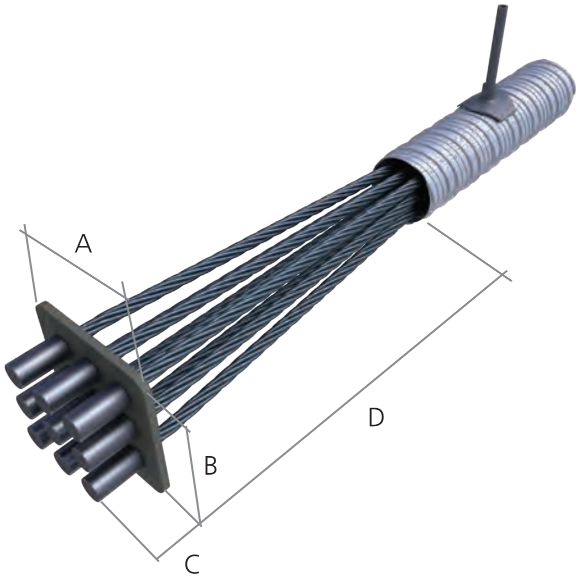
Strand Type	Tendon Type	Trumpet Type	øA	B	C	D	LR	ø1	Minimum Radius of Curvature
			mm	mm	mm	mm	mm	mm	mm
0.6” (15 mm)	4	T-4	110	88	170	155	600	51/56	3.000
	5	T-4	110	88	170	155	600	51/56	3.000
	7	T-5	130	93	194	150	600	62/67	3.000
	9	T-6	144	93	220	175	900	72/77	4.000
	12	T-7	165	105	254	200	900	85/90	4.000
	15	T-8	186	111	282	235	900	90/95	4.500
	19	T-19	200	128	314	230	1,200	100/105	5.000
	24	TR-24	240	128	356	640	1,200	110/115	5.000
	27	TR-31	252	138	395	720	1,500	120/125	6.000
	31	TR-31	268	148	395	720	1,500	120/125	6.000
	37	TR-37	296	161	444	770	1,500	130/137	6.500
	43	TR-43	330	177	490	1,100	1,500	140/147	6.500

Bonded Dead End Anchorage MSO

The anchorage MSO comprises a thin spacer plate with each consisting of a forged onion. These anchorages are embedded in the structure and so take advantage of the bond between the strand and concrete.

Please note for approved TRANSPORT FOR NSW applications use automatic dead end anchorage type MPA as detailed on previous page.





Swaged End Anchorage MSS

The anchorage MSS comprises of swaged strands that bear on a 15mm thick steel plate. These anchorages are embedded in the structure and so take advantage of the bond between the strand and concrete, and have the added strength of a swaged strand supported by the bearing plate.

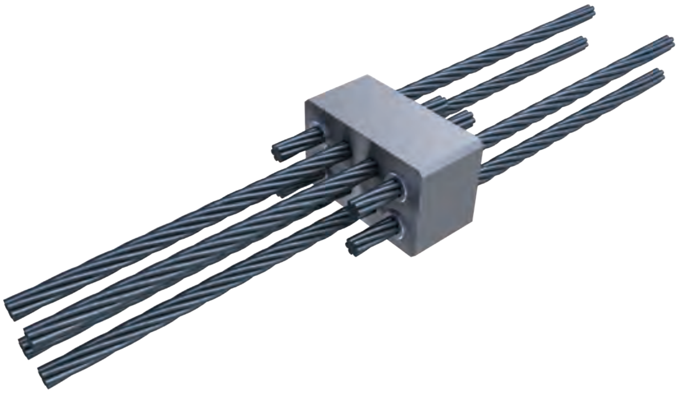
Pease note for approved TRANSPORT FOR NSW applications use automatic dead end anchorage type MPA as detailed on previous page.

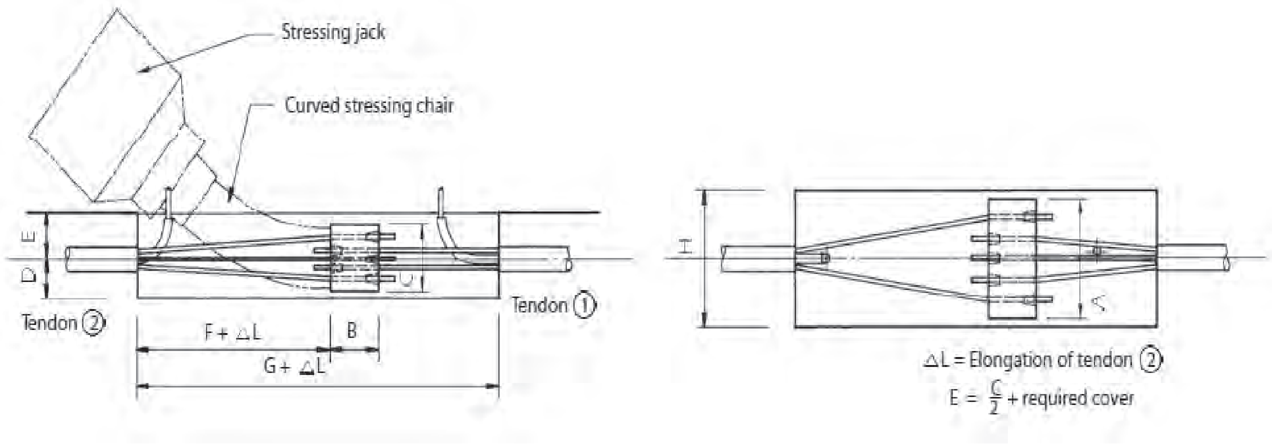
Strand Type	Tendon Type	A	B	C	D	E	F	G
		mm	mm	mm	mm	mm	mm	mm
(0.6”) 15.2mm	4	160	160	115	600	220	220	1250
	7	240	240	115	600	340	220	1250
	12	260	260	115	750	340	280	1500
	19	360	300	115	900	460	340	1500
	22	360	300	115	900	580	340	1500
	31	450	400	115	1.050	700	400	1500
	35	450	400	115	1.050	700	400	1500
	43	500	400	115	1.200	700	540	1500

Intermediate Anchor MZE

This MZE Block Anchor consists of an anchorage plate with opposing wedges and serves as both a coupler and a stressing point to which the jack can be applied.

Due to the unique geometry this connector/coupler can be used in applications where another type of coupler will not fit, or in situations where clients wish to minimise the requirement for buttress style terminations. The MZE anchorages are primarily used for the tensioning of circular structures such as tanks and silos and stressing is carried out using a specially designed mono-strand or multi-strand jack.





Strand Type	Tendon Type	A	B	C	D	F*	G*	H
		mm	mm	mm	mm		mm	mm
(0.6”) 15.2mm	6-2	140	70	90	65	450	620	180
	6-4	170	80	100	70	900	1180	210
	6-6	210	100	140	90	1000	1400	250
	6-12	300	160	160	100	1350	1960	340
	6-18	380	180	200	120	1450	2280	420
	6-22	400	180	250	145	1500	2380	440

Note 1. * The values stated apply to surfaces which are not curved

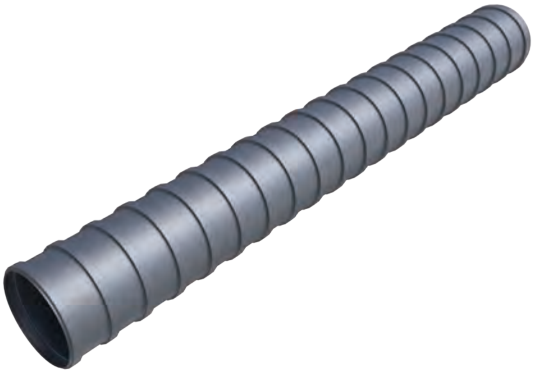
Corrugated Steel Ducts

Post-tensioned tendons are encapsulated within concrete in a duct which is usually manufactured in galvanized corrugated steel, with a wall thickness between 0.3 mm and 0.5 mm. The ducts are normally supplied in 5-6 m lengths and are coupled on site. Ducts are injected with cementitious grout after stressing to ensure the tendon achieves adequate bond and corrosion protection throughout the life of the structure.

HDPE and PP Ducts

For enhanced corrosion protection and fatigue resistance of the tendons, the use of corrugated high strength polyethylene (HDPE) and polypropylene (PP) products is highly recommended.

The diameters available are detailed in the table below. Due to the nature of the product all HDPE and PP Ducts for post-tensioning are imported thus ensure adequate lead times are considered. Please contact our technical department for further information.



Strand Size	Tendon Type	Duct Size Steel (mm)		Corrugated Steel Min Wall Thickness	Duct Size HDPE/PP (mm)		HDPE/PP Min Wall Thickness	Minimum Radius of Curvature	Minimum Straight Length	Minimum Loop Tendon Radius	Strand Eccentricity
		Inside ø mm	Outside ø mm	(mm)	Inside ø mm	Outside ø mm	(mm)	(m)	(m)	(mm)	(mm)
(0.6”) 15.2mm	4	51	56	0.3	48	59	2.0	3000	400	600	5
	5	51	56	0.3	48	59	2.0	3000	400	600	4
	7	62	67	0.3	59	73	2.0	3000	500	700	10
	9	72	77	0.3	76	91	2.0	4000	500	700	9
	12	85	90	0.3	85	100	2.5	4000	600	800	12
	15	90	95	0.3	95	111	3.0	4500	700	800	11
	19	100	105	0.5	100	116	3.0	5000	750	900	11
	24	110	115	0.5	109	126	3.0	5000	800	1100	15
	27	120	125	0.5	115	135	3.5	6000	900	1200	16
	31	120	125	0.5	127	150	4.0	6000	1000	1300	19
	37	130	137	0.5	127	150	4.0	6500	1050	1400	19
	43	140	147	0.5	145	168	4.0	6500	1150	1500	20

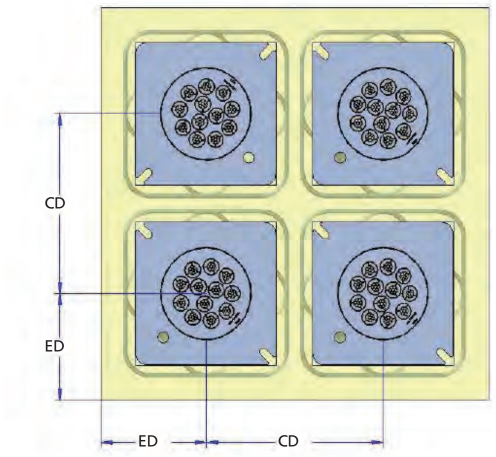
Multi-Strand Stressing Minimum Edge Distance/Bursting Reinforcement

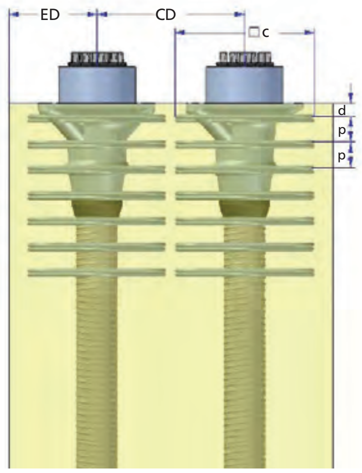
The centre spacing distance CD and edge distance ED between individual anchorages are shown in the table below. These dimensions are dependent on the cover required for the structure. Note 1) details the alternative method for calculating the minimum distances required for different concrete cover specifications.

The typical bursting reinforcement is in the form of a paired stirrup cage. This reinforcement is required in the local zone to resist the bursting stresses. Additional stirrups will need to be assessed to aid the bursting spiral in reducing crack widths under various loading conditions. The local bursting reinforcement is given in the working tables below.

Ribbed reinforcing steel grade Re > 500 MPa is specified for our multi-strand post-tensioning systems.

Note that the concrete section will still require a section check for the adequacy of the reinforcement required.





Tendon Type		406		506		706		906		1206		1506		1906		2406		2706		3106		3706	
Number of Strands		4		5		7		9		12		15		19		24		27		31		37	
Minimum concrete strength at time of stressing, cylinder																							
Minimum concrete strength in Mpa	$f_{cm, 0}$	25	45	25	45	25	45	25	45	25	45	25	45	25	45	25	** 45	25	** 45	25	** 45	25	** 45
Anchorage centre spacing and minimum edge distance																							
Centre spacing	CD	245	185	270	205	320	245	365	275	420	320	470	355	530	400	600	485	640	510	680	545	745	600
Edge Distance 1)	ED	145	115	155	125	180	145	205	160	230	180	255	200	285	220	320	265	340	275	360	295	395	320
Additional reinforcement - Pair of stirrups - ribbed reinforcing steel, Re > 500MPa																							
Number of pairs	n	4	3	4	3	5	4	7	5	8	7	10	9	9	5	11	9	8	8	10	8	10	8
Diameter	Ø	16	8	16	8	16	8	16	8	16	8	16	8	16	12	16	12	20	14	20	16	20	16
Outer dimensions	c	225	165	250	185	300	225	345	255	400	300	450	335	510	380	580	465	620	490	660	525	725	580
Distance from concrete edge	d	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Spacing	p	74	81	74	81	61	66	54	57	50	50	47	49	64	86	55	75	75	85	70	100	80	100

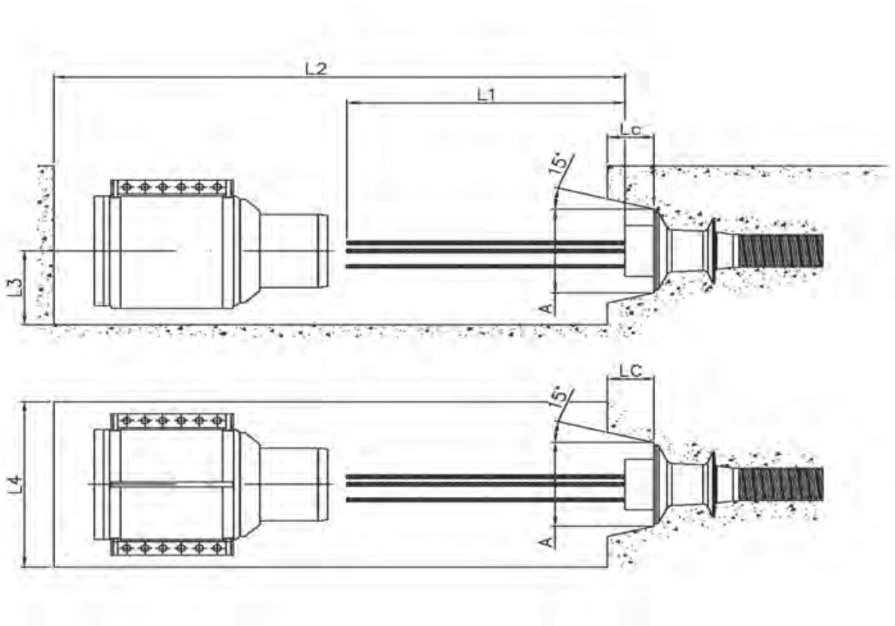
Dimensions in mm rounded up to the nearest 5mm

1) Values of edge distance are based on a concrete cover of 30mm. For different concrete covers the edge distance is calculated to ED = CD/2 + concrete cover - 10mm

** The 2406, 2706, 3106 & 3706 anchorage bursting reinforcement as detailed for the 25 Mpa concrete strength must be used for all concrete strengths >25 Mpa at time of stressing for TRANSPORT FOR NSW approved projects

Multi-Strand Blockout Dimensions

Attached below is our table showing the block-out dimensions and stressing-length of strands with the space requirements for location of jacks used during multi-strand stressing operations.



Strand	Tendon Type	L1	L2	L3	L4	A	LC
		mm	mm	mm	mm	mm	mm
(0.6”) 15.2mm	4	800	1.750	170	410	220	120
	5	800	1.650	200	450	220	120
	7	800	1.650	200	450	250	131
	9	850	1.700	240	580	270	130
	12	850	1.700	240	580	310	150
	15	900	1.750	280	660	340	150
	19	900	1.750	280	660	370	170
	24	1.000	2.000	315	750	410	170
	27	1.000	2000	340	800	450	180
	31	1.000	2.000	340	800	450	190
	37	1.000	2.050	370	850	500	200

STRAND 0.6”

Tendon		Strand ø15.2mm Grade to AS4672				Strand ø15.7mm Y 1860 S7 to EN10138-3				Duct	Cement
Type	Nº of Strands	Breaking Load F_{pk} (kN)	Tens. Force (1) P_0 (kN)	Weight Kg/m	Section mm^2	Breaking Load F_{pk} (kN)	Tens. Force (2) P_0 (kN)	Weight Kg/m	Section mm^2	Inside ø mm	Kg/ml
1-0.6”	1	261	222	1.122	143	279	246	1.172	150		
4-0.6”	2	522	444	2.244	286	558	492	2.344	300	51	2.6
	3	783	666	3.366	429	837	738	3.516	450		2.4
	4	1.044	888	4.488	572	1.116	984	4.688	600		2.2
5-0.6”	5	1.305	1.110	5.61	715	1.395	1.230	5.86	750	51	2.0
7-0.6”	6	1.566	1.332	6.732	858	1.674	1.476	7.032	900	62	3.2
	7	1.827	1.554	7.854	1.001	1.953	1.722	8.204	1.050		3.0
9-0.6”	8	2.088	1.776	8.976	1.144	2.232	1.968	9.376	1.200	72	4.3
	9	2.349	1.998	10.098	1.287	2.511	2.214	10.548	1.350		4.1
12-0.6”	10	2.610	2.220	11.22	1.430	2.790	2.460	11.72	1.500	85	6.2
	11	2.871	2.442	12.342	1.573	3.069	2.706	12.892	1.650		6.0
	12	3.132	2.664	13.464	1.716	3.348	2.952	14.064	1.800		5.8
15-0.6”	13	3.393	2.886	14.586	1.859	3.627	3.198	15.236	1.950	90	6.6
	14	3.654	3.108	15.708	2.002	3.906	3.444	16.408	2.100		6.4
	15	3.915	3.330	16.83	2.145	4.185	3.690	17.58	2.250		6.2
19-0.6”	16	4.176	3.552	17.952	2.288	4.464	3.936	18.752	2.400	100	8.2
	17	4.437	3.774	19.074	2.431	4.743	4.182	19.924	2.550		8.0
	18	4.698	3.996	20.196	2.574	5.022	4.428	21.096	2.700		7.8
	19	4.959	4.218	21.318	2.717	5.301	4.674	22.268	2.850		7.6
24-0.6”	20	5.220	4.440	22.44	2.860	5.580	4.920	23.44	3.000	110	9.8
	21	5.481	4.662	23.562	3.003	5.859	5.166	24.612	3.150		9.6
	22	5.742	4.884	24.684	3.146	6.138	5.412	25.784	3.300		9.4
	23	6.003	5.106	25.806	3.289	6.417	5.658	26.956	3.450		9.2
	24	6.264	5.328	26.928	3.432	6.696	5.904	28.128	3.600		9.0
27-0.6”	25	6.525	5.550	28.05	3.575	6.975	6.150	29.3	3.750	120	11.4
	26	6.786	5.772	29.172	3.718	7.254	6.396	30.472	3.900		11.2
	27	7.047	5.994	30.294	3.861	7.533	6.642	31.644	4.050		11.0
31-0.6”	28	7.308	6.216	31.416	4.004	7.812	6.888	32.816	4.200	120	10.8
	29	7.569	6.438	32.538	4.147	8.091	7.134	33.988	4.350		10.6
	30	7.830	6.660	33.66	4.290	8.370	7.380	35.16	4.500		10.4
	31	8.091	6.882	34.782	4.433	8.649	7.626	36.332	4.650		10.2
37-0.6”	32	8.352	7.104	35.904	4.576	8.928	7.872	37.504	4.800	130	12.8
	33	8.613	7.326	37.026	4.719	9.207	8.118	38.676	4.950		12.6
	34	8.874	7.548	38.148	4.862	9.486	8.364	39.848	5.100		12.4
	35	9.135	7.770	39.27	5.005	9.765	8.610	41.02	5.250		12.2
	36	9.396	7.992	40.392	5.148	10.044	8.856	42.192	5.400		12.0
	37	9.657	8.214	41.514	5.291	10.323	9.102	43.364	5.550		11.8
43-0.6”	38	9.918	8.436	42.636	5.434	10.602	9.348	44.536	5.700	140	14.7
	39	10.179	8.658	43.758	5.577	10.881	9.594	45.708	5.850		14.5
	40	10.440	8.880	44.88	5.720	11.160	9.840	46.88	6.000		14.2
	41	10.701	9.102	46.002	5.863	11.439	10.086	48.052	6.150		14.0
	42	10.962	9.324	47.124	6.006	11.718	10.332	49.224	6.300		13.8
	43	11.223	9.546	48.246	6.149	11.997	10.578	50.396	6.450		13.5

(1) Po according toAS4672.1 [85%Fpk]

(2) Po according to Eurocode 2 [85%Fpk]

Notes: For compact strands options please contact with our technical department.

High Tensile Threaded Bars

Fortec stock a comprehensive range of high tensile (UTS of 1080Mpa) threaded bars from 25mm to 50mm suitable for a range of construction applications including:

- Post-tensioning
- Ground anchors
- Micro-piles
- Soil nails
- Tunnelling, and
- Formwork applications

Physical Parameters

	Nominal Diameter	(mm)	25	32	36	40	50
Bar	Sectional Area	mm^2	491	804	1018	1257	1964
	Minimum Yield Strength	(Mpa)	930	930	930	930	930
	Minimum Tensile Strength	(Mpa)	1080	1080	1080	1080	1080
	Yield Load	(KN)	457	748	947	1169	1827
	Ultimate Load	(KN)	530	868	1099	1358	2121
	Elongation A	>(%)	6	6	6	6	6
	Weight	(kg/m)	4.1	6.65	8.41	10.34	16.28
Flat Nuts	Across the Flats	(mm)	50	60	65	70	80
	Height	(mm)	60	72	72	100	110
Flat Washers	Outside Diameter	(mm)	60	70	75	90	105
	Thickness	(mm)	5	5	5	5	5
Coupler	Diameter	(mm)	50	60	70	75	90
	Height	(mm)	132	168	180	220	270
End Plates	Size	(mm)	100 x 100	125 x 125	140 x 140	160 x 160	200 x 200
	Thickness - Standard	(mm)	40	50	50	60	60
	Hole Diameter	(mm)	34	41	45	51	61
Ducts	Recommended Duct ID	(mm)	40	50	55	60	75
	Larger diameter ducts mat be required locally to accommodate couplers						

POST-TENSIONING

CALCULATION NOTES

Introduction

For the design and application of post-tensioned tendons, consideration should be given to factors such as the following:

I Limitation of the prestressing force
II Loss of prestress
III Tendon elongation
IV Anchor block Requirement

The calculation methods that follow generally meet the requirements of the AS3600, EUROCODE 2 and the "Post-tensioning Manual" of the PTI (Post-tensioning Institute).

These notes are of an information nature and it is important that the presiding standard in the country of use are checked independently to ensure compliance.

Some paragraphs introduce notes referring to other standards, in this case the name of the standard is indicated.

I. Limitation of the Prestressing Force

Final Lock Off Force (After immediate Hydraulic and System losses)

Immediately after anchoring, the force in the post-tensioned tendon should not exceed the following values:

EUROCODE 2	The minimum of the following values: - 75% of the characteristic strength of the tendon - 85% Yield strength (0,1% proof load)
AS 3600-2009	- 80% of the characteristic strength of the tendon

Jacking force

The Jacking force is greater than the final lock off force and is restricted to the following stressing over the value of the maximum initial prestress up to the following limits:

EUROCODE 2	The minimum of the following values: - 80% of the characteristic strength of the tendon - 90% Yield strength (0,1% proof load)
AS 3600-2009	- 85% of the characteristic strength of the tendon

These jacking force maximum values are only applied temporarily to the tendon prior to lock off of the anchorage. The force in the tendon shall not exceed maximum final lock off after transfer from the jack to the anchorage.

II. Loss of Prestress

The initial post-tensioning force applied to the live anchorage (Po) is transmitted along the tendon, but decreases as a consequence of instantaneous and long term losses.
The effective post-tensioning force (Px) at each tendon point can be deduced as follows:

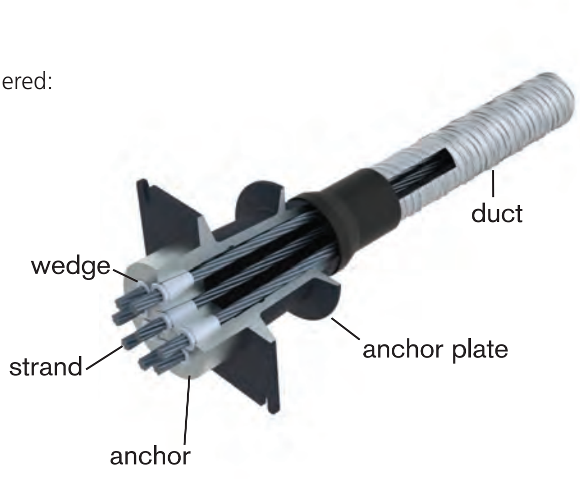
$$P_x = P_o - P_i - P_{dif}$$

where:
$P_{x:}$ is the post-tensioning force at a point located at x meters from the anchorage.
$P_{o:}$ is the stressing force at x = 0m.
P_i = instantaneous post-tensioning losses.
P_{dif} = long term post-tensioning losses.

In order to define with accuracy the value of Po, calibration curves for the equipment (jacks and manometers) shall be provided.

For the instantaneous losses the following parameters have to be considered:
a) Friction of the duct with the tendon.
b) Draw in of the anchorage wedges.
c) Elastic deformation of the concrete.

For long term losses the following need to be considered:
d) Shrinkage of the concrete.
e) Creep of the concrete.
f) Relaxation of the steel.



A. Instantaneous Losses

a) Friction Losses in the Duct

The losses due to friction are calculated in accordance with Coulomb formulae.

$$P_i = P_o \left(1 - e^{-\mu(\alpha + kx)}\right)$$

where:
μ = is the friction coefficient
α = is the sum of angular change over distance x.
x = is the distance along the tendon from the point where the prestressing force is equal to P_o
k = is the wobble coefficient per metre

The friction coefficient depends on various factors such as the condition of the duct inner surface, the condition of the strand external surface and the tendon layout.
The below table shows the recommended values for friction and wobble coefficients applicable.

FRICTION COEFFICIENT	RECOMMENDED		RANGE OF VALUES	
	μ rad	k rad/m	μ rad	k rad/m
Corrugated Metal Duct	0.2	0.005	0.17 - 0.19	0.004 - 0.008
Flat Metal Duct	0.2	0.008	0.16 - 0.24	0.006 - 0.010
Corrugated Plastic Duct	0.14	0.005	0.10 - 0.14	0.004 - 0.008
Smooth Plastic Duct	0.14	0.005	0.10 - 0.14	0.004 - 0.008
Greased and Sheathed Strand	0.06	0.009	0.05 - 0.07	0.009

b) Loss of Prestress at Transfer

A loss of prestress occurs when the load is transferred from the stressing jack to the anchorage of the tendon. This loss of prestress during transfer is the result of a shortening of the tendon at transfer due to the draw in of the anchorage wedges and the adjustment of the anchorage plate on the trumpet.

After stressing, the wedges are then firmly seated into the anchorage. The jack is then retracted thus transmitting the force of the tendon to the anchorage plate.

As a result of this seating the wedge still penetrates into the anchorage several millimetres, until equilibrium of the tension and deformation is achieved. The culmination of all these factors, results in a shortening of the tendon and therefore a loss of prestressing force, and is referred to as "Wedge Draw In". This can very between 4 to 7 mm.

Due to duct friction losses within the tendon the 'Wedge Draw In" affects only certain portion of the tendon from a maximum loss at the stressing anchorage till a nil loss at a length "1a" from the anchorage.

In the case of short tendons, special attention should be given to the effect of the losses due to the draw in of the wedges, since tension losses due "Wedge Draw In" are far higher in this case.

l_a is calculated in an iterative process.

Where: $$\boxed{l_a = \frac{\alpha E_p A_p}{\Pi_o(\mu\alpha + k l_a)}}$$

l_a = Length affected by the draw in of the wedge (m).
α = Draw in of the wedge (4-7 mm) (in metres).
E_p = Modulus of Elasticity of the prestressing steel (N/mm^2).
A_p = Area of prestressing tendons (mm^2).

Losses due to draw in of the wedge (P_2) are calculated as follows:

$$\boxed{\Delta\Pi_2 = 2\Pi_o \left(1 - \varepsilon^{-(\mu\alpha + k l_a)}\right)}$$

c) Loss of Prestress due to Elastic Deformation of Concrete

During the stressing process, concrete suffers an immediate elastic shortening due to the compression force that is being introduced. If all tendons of the concrete section are not stressed simultaneously, there is a progressive loss of prestress due to the shortening of the tendons produced by the deformation of the concrete. Assuming that all tendons experience a uniform shortening and are stressed one after the other in a unique operation, losses can be calculated with the following expression:

$$\boxed{\Delta\Pi_3 = \frac{\nu - 1}{2\nu} \frac{E_p}{E\chi\varphi} A_p \sigma_{cp}}$$

Where:

σ_{cp}: Concrete compressive stress at the level of the c.o.g. of the tendons due to the post-tensioning force and actuating forces at the stressing moment.

$$\boxed{\sigma_{X\pi} = \frac{\Pi_o - \Delta\Pi_1 - \Delta\Pi_2}{A_c} + \frac{(\Pi_o - \Delta\Pi_1 - \Delta\Pi_2)\,\varepsilon^2 - M_{X\pi}\cdot\varepsilon}{I_c}}$$

$E_{X\varphi}$: Modulus of elasticity of the concrete at j days.

ε: Eccentricity of the tendon with reference to centre of gravity of the concrete section.

I_c: Second moment of area of the concrete section.

$M_{x\pi}$: Maximum moment in the concrete section.

A_x: Area of the concrete section.

ν: Number of stressed tendons in the concrete section.

φ: Age at application of prestressing force.

B. Long Term Losses

These prestress losses occur as a result of concrete creep and shrinkage as well as strand steel relaxation.
Long term losses are calculated using the following formula:

$$\Delta\Pi_{\delta l_{\o}} = \boxed{\frac{\varphi(\tau,\tau_o)\,\sigma_{x\pi} + E_{\pi}\varepsilon_{x\sigma}(\tau,\tau_o) + 0.80\,\Delta\sigma_{\pi P}}{1+\nu\,\frac{A_P}{A_X}\left(1+\frac{A_X\psi\pi^2}{I_X}\right)(1+\xi\varphi(t,t_o))}\quad A_P}$$

Where:

n: Ratio between modulus of elasticity of the prestressing steel and the modulus of elasticity of the concrete: E_p/E_c

$\varphi(t,t_o)$: Creep coefficient at the time of tensioning the tendons.

σ_{cp}: Concrete compressive stress at the level of the c.o.g. of the tendons due to the post-tensioning force, dead load and superimposed dead load.

ε_{cs}: Strain due to shrinkage of the concrete.
Assumed as approximate value: ε_{cs} = 0.4 mm/m at time infinite.

σ_{pr}: Stress due to the steel relaxation:

$$\boxed{\Delta\sigma_{\pi p} = \rho_f\,\frac{\Pi_o - \Delta\ _1 - \Delta\Pi_2 - \Delta\Pi_3}{A_p}}$$

ρ_f: Relaxation value of prestressing steel at time infinite.
Assumed as approximate values: ρ_f = 0,029 at 60% of GUTS
ρ_f = 0,058 at 70% of GUTS

(GUTS – guaranteed ultimate tensile strength of prestressing steel)

y_p = e: Distance between the centre of gravity of the concrete section and centre of gravity of the prestressing tendons.

x = 0,8: coefficient of concrete age.

M_{cp}: Moment due to dead load and superimposed dead load in the concrete section.

III. Tendon Elongation

Stressing operation of tendons is carried out in a controlled process where elongation and gauge pressures are measured at all steps.

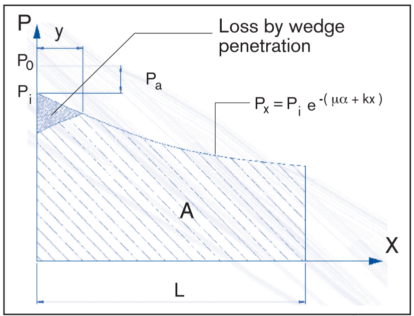


Figure 2

The final elongation of a tendon, obtained by in situ calculation, is compared to the theoretical elongation value in order to check if the result is acceptable.
The elongation of a post-tensioned tendon is assumed to be linear and is calculated with the use of the Hooke's Law.

$$\boxed{\Delta l = \varepsilon \cdot l = \frac{\sigma_\sigma l}{E_p}}$$

Where:
Δl: Tendon elongation.
l: Length of the tendon.
$\varepsilon \cdot$l: Tendon strain per unit of length.
σ_s: Prestressing steel tensile stress ($\sigma_s = P/A_p$).

Due to the post-tensioning losses, the elongation is given as a function of the force exerted on every section of the tendon.

$$\boxed{\Delta l = \int_o^l \frac{\sigma_\Sigma}{E_p}\, d\xi}$$

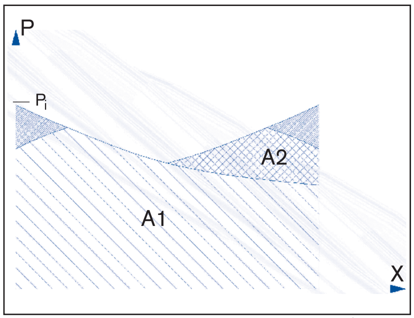


Figure 3

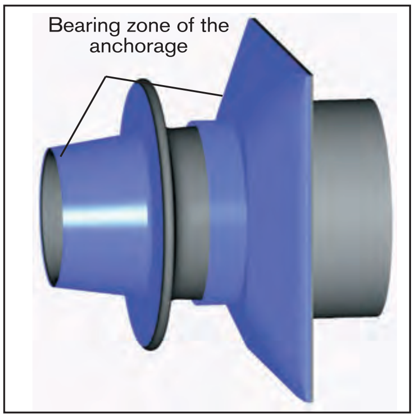
The elongation is proportional to the area under the curve of the post-tensioning force applied on the tendon (refer to figure 2).

$$\boxed{\Delta l = \frac{1}{A_p E_p} \int_o^l \Pi_\xi\, d\xi}$$

Where:
l: Length of the tendon.
P_x: Prestressing force at section "x" (Jacking force minus friction losses).

If the tendon has two live end anchors, it can be post-tensioned from both ends and thus the elongation of the tendon is now proportional to the area under the graph of both post-tensioning forces applied at both ends of the tendon, i.e. proportional to area A1+A2 (refer to figure 3).

IV. Anchor Block



The anchor block is defined as the highly stressed zone of concrete around the two end points of a post-tensioned tendon. It extends from the tendon anchorage to that section of the concrete at which linear distribution of stress is assumed to occur over the whole cross section.

For the design of the anchor blocks it is convenient to consider and check two different kinds of stresses and forces that are produced around the prestressing anchorage:

a) Bearing stresses.
b) Bursting tensile forces.

Checking the bearing stresses will help to determine if the type of anchorage that has been chosen is valid and if the concrete compressive stress is acceptable.

Checking the bursting tensile forces will be necessary to evaluate the required anchorage bursting reinforcement.

A. Bearing Stresses

The force that is transmitted through the bearing zone of the anchorage to the end block produces a high concrete compressive strength that can be evaluated as follows:

$$\boxed{\sigma_c = \frac{P}{A_b}}$$

Where:

P: Force applied on the anchorage.

A_b: Bearing area of the anchorage.

The bearing area for the different trumpets of the MK4 system anchors is as listed in the following table.

Anchorage Type	Anchorage Bearing Area
0,6" (15 mm)	cm^2
4/0,6"	328
5/0,6"	328
7/0,6"	454
9/0,6"	582
12/0,6"	778
15/0,6"	981
19/0,6"	1.218
24/0,6"	1.561
27/0,6"	2.050
31/0,6"	2.050
37/0,6"	2.487
43/0,6"	2.822

The compression tension in the bearing zone of the anchorage should be checked at two different stages:

- At transfer load (Jacking force)

$$\boxed{\sigma^{xo} = \frac{\Pi_o}{A_b}}$$

P_o: Maximum Jacking force applied to the anchorage at stressing.

A_b: Bearing area of the anchorage.

σ_{co}: Concrete compressive stress at transfer load.

σ_{co} should not exceed the lowest of the following two values of cpo (permissible compressive concrete stress at transfer load).

$$\boxed{\sigma_{xo} \leq \sigma_{xo\pi o} = 0.8\o_{xl}\sqrt{\left(\frac{A}{A} - 0.2\right)}}$$

$$\boxed{\sigma_{xo} \leq \sigma_{xo\pi o} = 1.25\o_{xl}}$$

Where:

f_{ci}: Concrete compressive strength at the time of stressing.

A'_b: Area of the anchor block - Maximum area of concrete concentric with the anchorage and limited by the concrete borders of the section or another anchor block.

- At service load

$$\boxed{\sigma_{x\sigma} = \frac{\Pi_s}{A_b}}$$

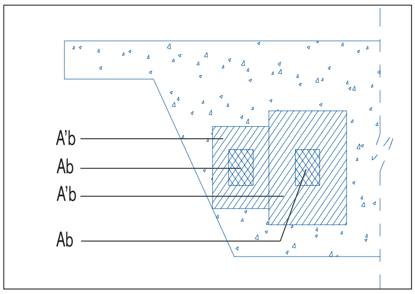
σ_{cs}: Concrete compressive stress at service load.

P_s: Prestressing force of the post-tensioned tendon at service.

Service load can be calculated deducting all type of prestress losses from the initial force at the anchorage zone.

Assumed Service load: 80% of the jacking force.

σ_{cs} should not exceed the lowest of the two following values of σ_{cps} (permissible compressive concrete stress at transfer load).



$$\boxed{\sigma_{x\sigma} \leq \sigma_{x\pi\sigma} = 0.6\text{ø}_{\iota} \sqrt{\left(\frac{A}{A}\right)}}$$

$$\boxed{\sigma_{x\sigma} \leq \sigma_{x\pi\sigma} = 1.25\text{ø}_{x}}$$

Where:
f_c: Characteristic concrete compressive strength.

B. Bursting Tensile Forces

In the anchor block some severe transversal tensile forces appear that should be absorbed by steel reinforcement. These bursting tensile forces are produced from the curvature of the force line and are originated at the bearing zone of the anchorage where the force lines divert until they reach a uniform distribution.

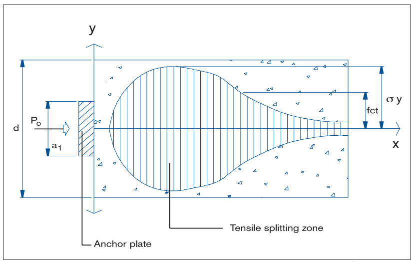
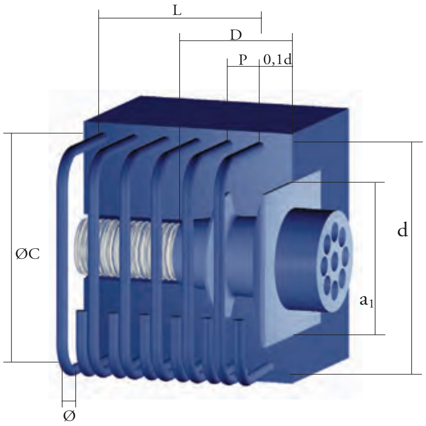


Figure 6

Figure 6 shows the distribution of stresses due to the bursting tensile force, perpendicular to the centre line of the tendon.

To determine the value of the bursting tensile forces the following formula can be used.

$$\boxed{\text{ø}_s A_{\text{ø}} = \xi = 0.25\Pi_o \left(1 - \frac{\Omega a_1}{\delta}\right)}$$



Where:
Z: Total bursting tensile force.
f_s: Design strength for the bursting reinforcement.
Assumed design strength:
400 MPa* (for 500 MPa Yield load Steel).
A_s: Area of steel required for the bursting reinforcement.
P_o: Maximum jacking force at stressing.
Ω: Shape factor.
Assumed shape factors:
Ω = 1 for anchors with a unique bearing plate without ribs.
Ω = 0,93 for MK4 anchors with ribs.

*Note: Besides limiting the design strength for the bursting reinforcement to a maximum of 80% of the yield load, it is also convenient to limit the stress to a value corresponding to a steel strain of 0.002. This last limit has to be reduced to a steel strain of 0.001 on areas where the concrete cover is less than 50 mm.

Anchorage bursting reinforcement for the MK4-MSA anchors is listed in the following table. To prepare the table, the following assumptions have been made:
Prestressing force = 85% of the characteristic strength of the tendon.
Ratio between anchorage upper plate side and anchor block side (a_1/d) = 0.5.
Concrete compressive strength: 28 MPa (Cylindrical test sample).

Please note for TRANSPORT FOR NSW approved projects use the bursting reinforcement as detailed on Page 15 of this brochure.

Anchorages	Trumpet	a_1	D	L	P	øC	CIR.	ø
15 mm		mm	mm	mm	mm	mm	units	mm
4/0.6”	T-4	170	155	240	80	210	4	12
5/0.6”	T-5	170	155	240	60	210	5	12
7/0.6”	T-5	194	150	280	70	260	5	14
9/0.6”	T-6	220	175	325	65	310	6	14
12/0.6”	T-7	254	200	375	75	350	6	16
15/0.6”	T-8	282	235	420	60	400	8	16
19/0.6”	T-19	314	230	450	90	440	6	20
24/0.6”	TR-24	356	520	500	125	500	5	25
27/0.6”	TR-31	395	570	575	115	560	6	25
31/0.6”	TR-31	395	570	570	95	560	7	25
37/0.6”	TR-37	444	670	630	90	620	8	25
43/0.6”	TR-43	490	1.100	720	80	680	10	25

Note: a_1/d = 0,5 Concrete compressive strength = 28MPa

If the value of a1/d is not equal to 0.5 and the concrete compressive strength is different to 28MPa, the bursting reinforcement listed on the table does not apply and a new bursting reinforcement for the anchorage should be calculated.

Note: Changes may be made to the information contained in this brochure at any time as new techniques and/or materials are developed.

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