Fam Rah Bestar
FRB

Your Construction Partner

2014 Catalog

Contents

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The Company

FAM RAH BESTAR Co. is an Iranian company, specialized in manufacturing PT equipment & offering technical solutions for the construction of bridges and structures, by providing to the market a wide range of products and services, leading in quality and customized services.

Within our scope of activities, there is the design, supply and installation of stay cables, post-tensioning, together with the supply of ground anchors and high tensile bars. The FRB post-tensioning system proposed includes a wide range of anchorages, accessories and the necessary equipment to respond to the technical requirements for the construction of bridges and other structures.

The design and calculation of all the components were performed according to the new European code ETAG-013, for which verification is an obligation in all post-tensioning structures, built in the European Union. As application, we are providing post-tensioning and cable stayed solutions for a variety of structure such as bridges, buildings, tanks of liquefied gas LNG, silos, covertures, communication towers, nuclear power stations, suspended structures, etc.

The services provided by FRB include the following aspects:

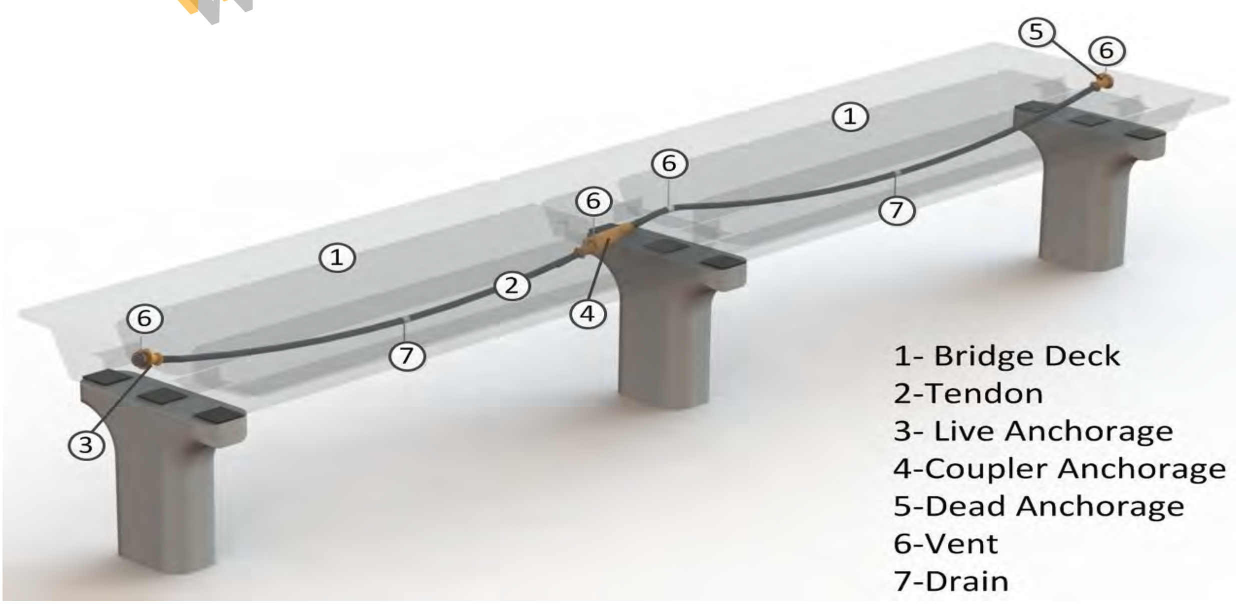
- Technical assistance in all phases of the project; from the design to the final execution.
- A large range of live end and dead end anchorages and couplers, make FRB, always ready for any development or change according to the specifics needs of the project.
- The designed system was successfully tested according to the new European standard ETAG-013 for post-tensioning systems.
- Automatic and lightweight stressing equipment.
- Study of alternative design or construction method as an improvement for the optimum solution for every project.
- Fabrication & erection of bridge & other special steel structures using innovative methods resulting in more efficiency & cost effectiveness.

Quality

FRB has developed a complete Quality Assurance Program conforming to ISO 9001:2008 under the audition of BUREEAU VERITAS (Certificate No. IND10.7330) and according to the requirements of the most recent European code ETAG-013 for Post-tensioning, including the design, production, supply and installation of all the required PT works, as anchorages, auxiliary equipment; pushing strands, stressing and injection. Our comprehensive quality system covers all post-tensioning work performed by **FRB**.

The Post-tensioning Tendon

The tendon is the basic element of a post-tensioning system. A tendon comprises of one or more strands, constrained at both ends by a compact, efficient and easily installed anchorage and encapsulated throughout within a duct. In the photograph below, a general scheme is shown of a tendon consisting of two part tendons joined by a coupler. All tendons can be both pre-assembled and pulled into the duct or the strands can be pushed individually into the duct with the aid of a strand pusher, before or after concreting to suit the construction sequence. All tendons are stressed with the aid of hydraulic jacks. The provisions made in ETAG 013 are based on an assumed intended working life of the PT system of 100 years.



The indications given on the working life cannot be interpreted as a guarantee given by the producer (or the Approved Body), but are to be regarded only as a means for choosing the right product in relation to the expected economically reasonable working life of the works.

Tensile Elements (Steel Strand)

The most important part of a tendon, carrying the loads for the lifetime of the structure, is the strand which is comprised of 7-wires low relaxation steel. The most common diameters are 0.6" (15.2/15.7 mm) and 0.5" (12.7/12.9 mm) corresponding to tensile strengths of 1770/1860 N/mm^2 and 1860 N/mm^2 respectively.

The following table gives the main characteristics of each size of strand.

Strand Type	Standard	Ultimate Tensile Strength	Nominal Ø	Cross Section	Weight	Min. Breaking Load F_{pk}	Relaxation 1000h at 70% of F_{pk}	Yield Strength 0.1% strain
			mm	mm^2	Kg	KN	%	KN
0.6"	EN-10138-3	1860 MPa	15.2	140	1.095	260	2.50%	224
	ASTM A416M99	270 ksi	15.24	140	1.102	260.7	2.50%	234.6
	BS5896:1986	1770 MPa	15.7	150	1.18	265	2.50%	225
	EN-10138-3	1860 MPa	16	150	1.17	279	2.50%	240
0.5"	ASTM A416M99	270 ksi	12.7	98.71	0.775	183.7	2.50%	165.3
	BS5896:1986	1770 MPa	12.9	100	0.785	186	2.50%	158
	EN-10138-3	1860 MPa	13	100	0.781	186	2.50%	160

Nominal Ø	Standard	Initial Post-tensioning Force P_0 (KN)		
		Eurocode 2 85% $F_{P0.1}$ or 75% F_{pk} (KN)	EHE 98 75% F_{pk} (KN)	BS 5400-4 70% F_{PK} (KN)
15.2	EN-10138-3	190.4	195.0	182.0
15.24	ASTM A416M99	195.5	195.0	182.5
15.7	BS5896:1986	191.3	198.8	185.5
16	EN-10138-3	204.0	209.3	195.3
12.7	ASTM A416M99	137.8	137.8	128.6
12.9	BS5896:1986	134.3	139.5	130.2
13	EN-10138-3	136.0	139.5	130.2

Nominal concrete strength: 35 MPa (Cube), 28 MPa (Cylinder) at the time of stressing for a maximum stressing force of 80% of the tendon Breaking Loa

0.6" Strand Tendon Properties

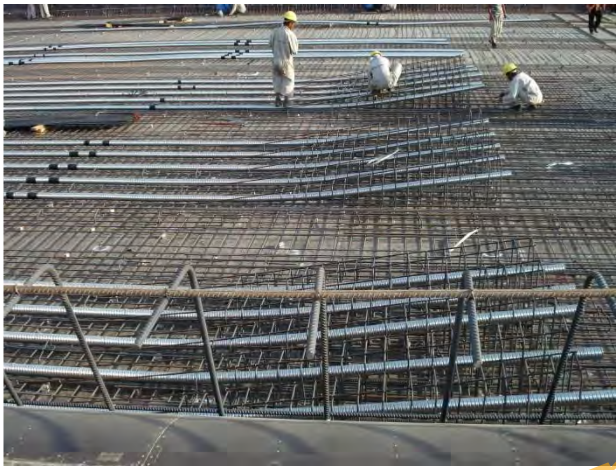
0.6" Strand Prperties			Strand Ø16 mm Y1860 S7 to EN-10138-3				Strand Ø15.24mm Grade 270 to ASTM A416-M-99				Duct	Cement
Type	PT Jack	No. of Strands	Breaking Load F_{pk} kN	PT Force P_0 kN	Weight Kg/m	Section mm²	Breaking Load F_{pk} kN	PT Force P_0 kN	Weight Kg/m	Section mm²	Ø	Kg/m
106	M16	1	279	204	1.17	150	260.7	195.5	1.102	140	22	0.36
306	M76	2	558	408	2.34	300	521.4	391.0	2.20	280	51	2.64
		3	837	612	3.51	450	782.1	586.5	3.31	420		2.52
506		4	1116	816	4.68	600	1042.8	782.0	4.41	560	55	2.72
		5	1395	1020	5.85	750	1303.5	977.5	5.51	700		2.51
706		6	1674	1224	7.02	900	1564.2	1173.0	6.61	840	63	3.42
		7	1953	1428	8.19	1050	1824.9	1368.5	7.71	980		3.21
906	M126	8	2232	1632	9.36	1200	2085.6	1564.0	8.82	1120	75	4.95
		9	2511	1836	10.53	1350	2346.3	1759.5	9.92	1260		4.74
1206		10	2790	2040	11.70	1500	2607.0	1955.0	11.02	1400	85	6.41
		11	3069	2244	12.87	1650	2867.7	2150.5	12.12	1540		6.20
		12	3348	2448	14.04	1800	3128.4	2346.0	13.22	1680		5.99
1506		13	3627	2652	15.21	1950	3389.1	2541.5	14.33	1820	90	6.81
		14	3906	2856	16.38	2100	3649.8	2737.0	15.43	1960		6.60
	M196	15	4185	3060	17.55	2250	3910.5	2932.5	16.53	2100		6.39
1906		16	4464	3264	18.72	2400	4171.2	3128.0	17.63	2240	100	8.42
		17	4743	3468	19.89	2550	4431.9	3323.5	18.73	2380		8.21
		18	5022	3672	21.06	2700	4692.6	3519.0	19.84	2520		8.00
		19	5301	3876	22.23	2850	4953.3	3714.5	20.94	2660		7.79
2206		20	5580	4080	23.40	3000	5214.0	3910.0	22.04	2800		10.05
	M276	21	5859	4284	24.57	3150	5474.7	4105.5	23.14	2940	110	9.84
		22	6138	4488	25.74	3300	5735.4	4301.0	24.24	3080		9.63
2406		23	6417	4692	26.91	3450	5996.1	4496.5	25.35	3220		9.42
		24	6696	4896	28.08	3600	6256.8	4692.0	26.45	3360		9.21
2706		25	6975	5100	29.25	3750	6517.5	4887.5	27.55	3500	120	11.71
		26	7254	5304	30.42	3900	6778.2	5083.0	28.65	3640		11.50
		27	7533	5508	31.59	4050	7038.9	5278.5	29.75	3780		11.29
3106		28	7812	5712	32.76	4200	7299.6	5474.0	30.86	3920	120	11.08
	M376	29	8091	5916	33.93	4350	7560.3	5669.5	31.96	4060		10.87
		30	8370	6120	35.10	4500	7821.0	5865.0	33.06	4200		10.66
		31	8649	6324	36.27	4650	8081.7	6060.5	34.16	4340		10.45
3706		32	8928	6528	37.44	4800	8342.4	6256.0	35.26	4480	130	13.19
		33	9207	6732	38.61	4950	8603.1	6451.5	36.37	4620		12.98
		34	9486	6936	39.78	5100	8863.8	6647.0	37.47	4760		12.77
		35	9765	7140	40.95	5250	9124.5	6842.5	38.57	4900		12.56
		36	10044	7344	42.12	5400	9385.2	7038.0	39.67	5040		12.35
		37	10323	7548	43.29	5550	9645.9	7233.5	40.77	5180		12.14

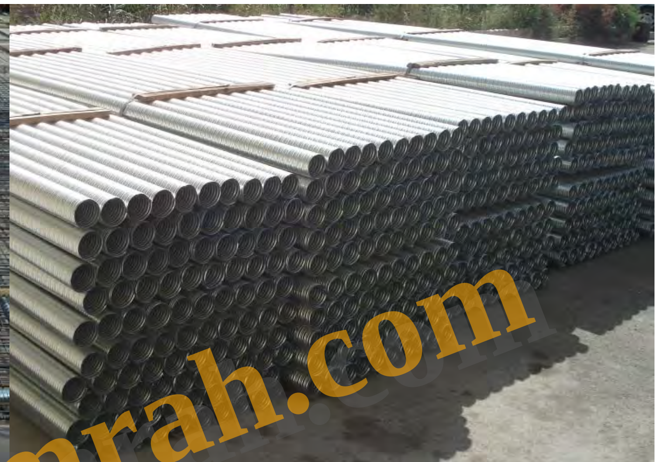
0.5" Strand Tendon Properties for flat anchorages

Tendon Specification			Strand Ø13 mm Y1860 S7 to EN-10138-3				Strand Ø12.7mm Grade 270 to ASTM A416-M-99				Duct	Cement
Type	PT Jack	No. of Strands	Breaking Load F_{pk} kN	PT Force P_0 kN	Weight Kg/m	Section mm²	Breaking Load F_{pk} kN	PT Force P_0 kN	Weight Kg/m	Section mm²	Ø	Kg/m
105	G16	1	186	136	0.78	100	183.7	137.8	0.775	99	22	0.42
305		2	372	272	1.56	200	367.4	275.6	1.55	198	51	2.77
		3	558	408	2.34	300	551.1	413.4	2.33	297		2.62
505		4	744	544	3.12	400	734.8	551.2	3.10	396		2.47
		5	930	680	3.90	500	918.5	689.0	3.88	495		2.32

Ducts

Post-tensioned tendons are encapsulated within the deck in a duct which is usually manufactured in corrugated steel (sometimes galvanized) with a wall thickness between 0.3 mm and 0.5 mm. The sizes of the most frequently used ducts can be found in the table below. The ducts are normally supplied in 4-6 m lengths and are coupled on site. Ducts are injected with cementitious grout, wax or other corrosion resistant compounds after stressing.

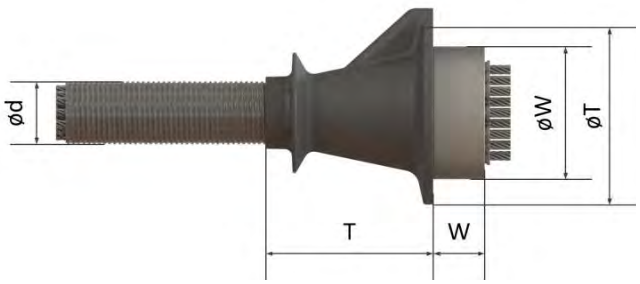




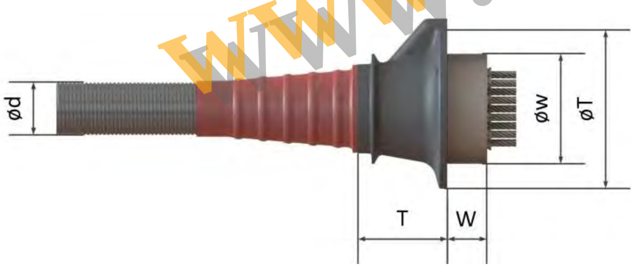
Anchorages

All anchorages are designed to the same principles, varying only in size and number of strands. Live End anchorages facilitate the introduction of a post tensioning force in the tendon with the tensioning operations carried out by hydraulic jacks. The Live End anchorages have been designed to comply with the most demanding of international standards such as PTI, BS, etc. Each basic anchorage consists of a cast trumpet anchor plate and wedges. All the elements of the anchorages and corresponding dimensions have been carefully selected in order to achieve the greatest economy in design.

Live End Anchorage Properties

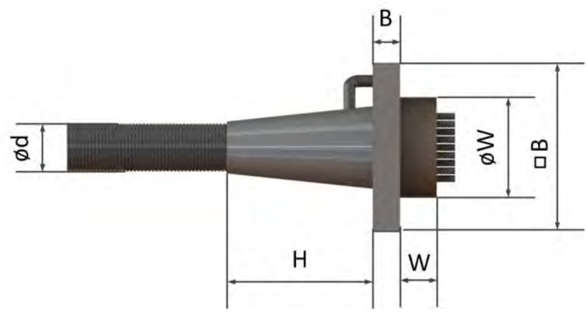


0.6" Wedge Plate	WP 306	WP 506	WP 706	WP 906	WP 1206	WP 1506	WP 1906
Related Cast trumpet	CT3	CT5	CT7	CT9	CT12	CT15	CT19
ØW	80	110	130	140	170	190	210
W	50	55	55	55	60	70	90
ØT	130	160	190	225	245	260	290
T	100	120	150	175	200	230	260
Ød	51	60	68	75	86	90	100



0.6" Wedge Plate	WP 2206	WP 2406	WP 2706	WP 3106	WP 3706
Related Cast trumpet	CT22	CT24	CT27	CT31	CT37
ØW	220	240	250	270	290
W	85	85	95	100	115
ØT	320	330	360	420	450
T	180	200	240	260	300
Ød	105	110	115	125	135

Prefabricated Live end Anchorage Properties



0.6" Wedge Plate	WP 306	WP 506	WP 706	WP 906	WP 1206	WP 1506	WP 1906	WP 2206	WP 2406	WP 2706	WP 3106	WP 3706
Related Steel trumpet	ST3	ST5	ST7	ST9	ST12	ST15	ST19	ST22	ST24	ST27	ST31	ST37

ØW	80	110	130	140	170	190	210	220	240	250	270	290
W	50	55	55	55	65	70	90	85	85	95	100	115
□B	135	180	210	220	270	300	340	370	400	420	440	480
B	20	30	35	40	40	45	50	55	60	65	65	70
Ød	51	60	68	75	86	90	100	105	110	115	125	135
H	170	200	270	350	400	500	570	650	700	700	750	800


FRB Anchorage Set

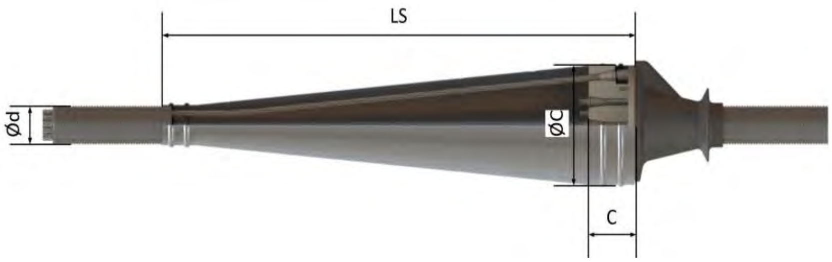
Multistrand Couplers

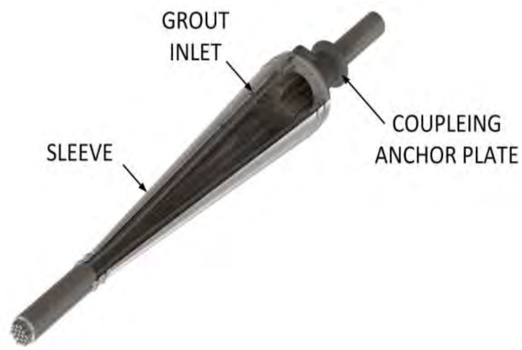
An economic range of couplers has been designed for ease of assembly on site. Couplers are used to give continuity to the tendons which due to their length or the construction method used in the project, cannot be installed or tensioned as one unit. The first-stage of the tendon is stressed and anchored 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 cover (trumpet), which has a grout inlet.

Automatic Dead End Anchorages

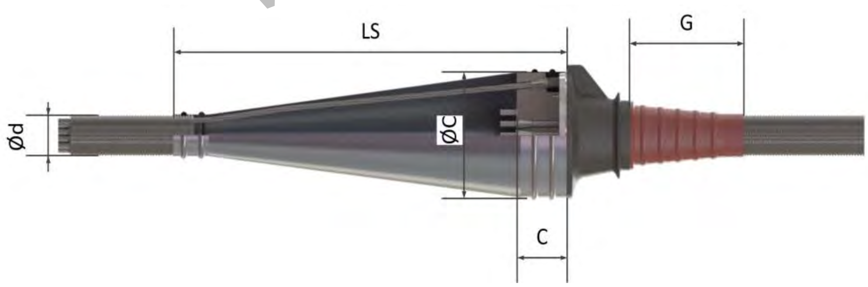
The unique **FRB** Automatic Dead End anchorage is intended to be used at one end of a tendon, the other end being fitted with a live end anchorage. Its principal characteristic is the automatic retention of the strands by the anchor plate and its primary use is in situations where other customary anchorages cannot be fitted satisfactorily due to space limitations.

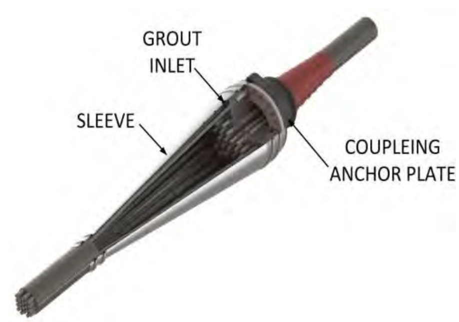
Coupler Anchorage Properties\





0.6" Coupler	CP 306	CP 506	CP 706	CP 906	CP 1206	CP 1506	CP 1906
Related Housing	CH3	CH5	CH7	CH9	CH12	CH15	CH19
ØC	135	150	180	200	245	265	265
C	85	90	95	100	100	105	125
ØS	140	156	188	208	253	270	275
LS	385	460	615	660	750	765	770
Ød	51	60	68	75	86	90	100

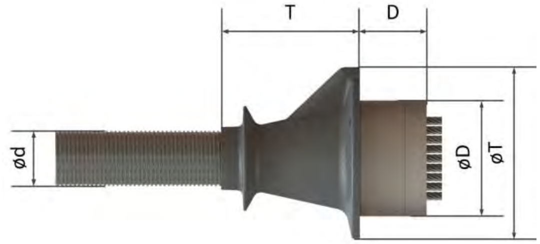




0.6" Coupler	CP 2206	CP 2406	CP 2706	CP 3106	CP 3706
Related Housing	CH19	CH19	CH24	CH24	CH31
ØC	315	315	340	340	375
C	125	125	130	130	160
ØS	325	325	350	350	390
LS	1000	1000	1250	1250	1300
Ød	105	110	115	125	135

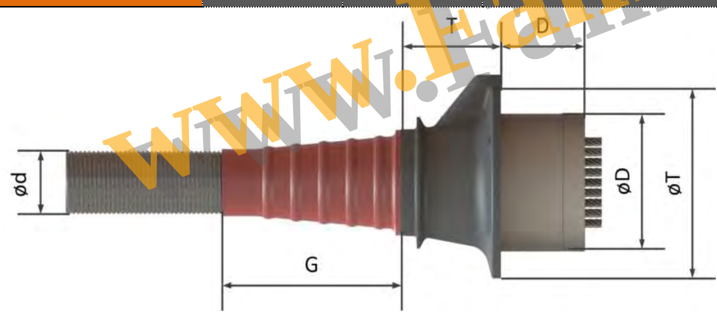
All data in this catalog is subject to modification

Dead End Anchorages



0.6" Dead Plate	DP 306	DP 506	DP 706	DP 906	DP 1206	DP 1506	DP 1906
Cast trumpet	CT3	CT5	CT7	CT9	CT12	CT15	CT19

ØD	80	110	130	140	170	190	210
D	50	55	55	55	60	70	90
ØT	100	120	150	175	200	230	260
T	100	120	150	180	200	230	240
Ød	51	60	68	75	86	90	100



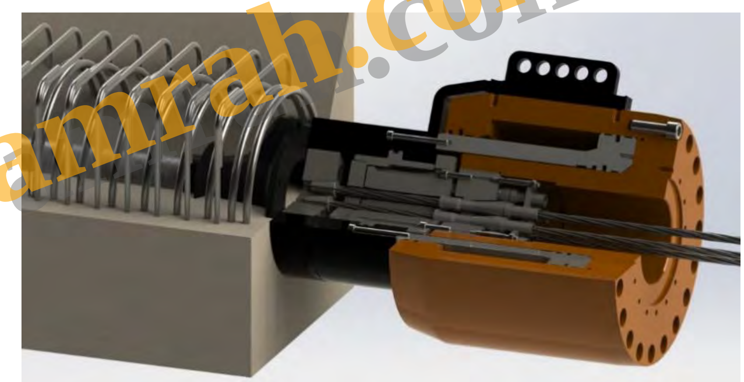
0.6" Dead Plate	DP 2405	DP 3105	DP 3705	DP 4205	DP 4805
Related Cast trumpet	CT22	CT24	CT27	CT31	CT37

ØD	220	240	250	270	290
D	85	85	95	100	115
ØT	315	330	360	420	450
T	320	200	240	260	300
Ød	105	110	115	125	135

Other dead end anchorages

Bulb (onion) & pressed dead end anchorages: This type of anchorage is the best solution when strands need to be pushed through on site. The prestressing force is transferred to the concrete by bond. The spiral (for 705 or 706 and larger units) and tension ring prevent inadmissible stresses due to deviated forces acting on the concrete. The rebar net at the anchorage end zone acts as a spacer for individual strands.

FRB Prestressing Jacks

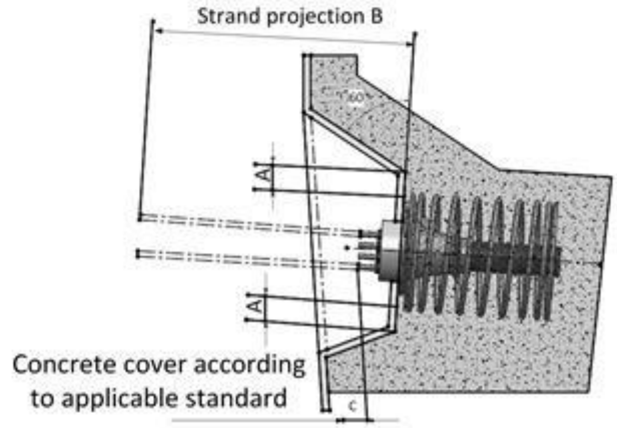


FRB Multi-strand stressing Jacks are the fifth generation of post-tensioning jacks bringing together the capabilities of all pt systems jacks. They are short & handy which can work in confined space conditions. FRB jacks use a front pulling system which provides the possibility of saving strands by leaving only a short length projected from the tendon anchorages. Theses jacks are equiped with a double acting wedge seating system, which maximizes the safety & precision of the post-tensioning work at the time of stressing.

Usage of **FRB** jacks extends beyond ordinary bonded tendon post-tensioning. Jacks can be used in stressing of cable stayed systems, heavy lifting, etc. We design custom made jacks to meet the requirements of special projects. They range from 20 ton to 1500 ton capacity with strokes up to 1000 mm & a maximum working pressure of 700 bars.

FRB Post-tensioning Jacks Data Table

Jack Type	A (mm)	B (mm)	C (mm)
M16	120	370	
M76	290	660	157
M126	320	670	167
M196	390	1433	191
M276	420	1510	201
M376	550	1956	210



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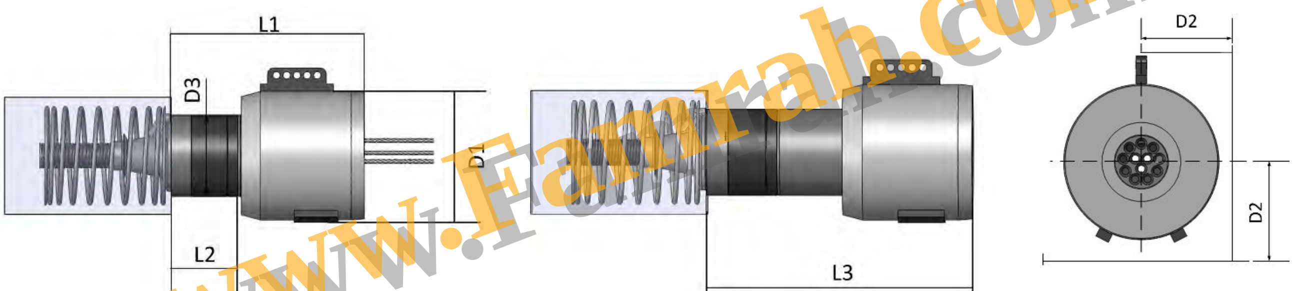


Jack Model & Specifications	M16	M76	M126	M196	M276	M376
Working Capacity (Metric Ton)	22	160	270	420	600	820
Stressing Pressure Area (cm2)	50.26	423.32	581.98	812.88	1028.08	1632.84
Retract Area	28.27	235.42	346.36	450.62	600.82	863.93
Wedge Seating Area	N/A	80.11	87.17	133.32	189.08	258.32
Max. Stroke(mm)	200	200	200	220	250	300
Working Pressure(bar)	450	400	480	520	600	550
D1(mm)	190	445	528	626	726	877.3
D2 (mm)	250	505	588	686	786	937.3
D3 (mm)	77	245	280	345	380	500
L1 (mm)	370	660	670	738	831.1	1033.5
L2 (mm)	83	227	237	257	284.1	330.8
L3 (mm)	570	860	870	958	1081.1	1333.5

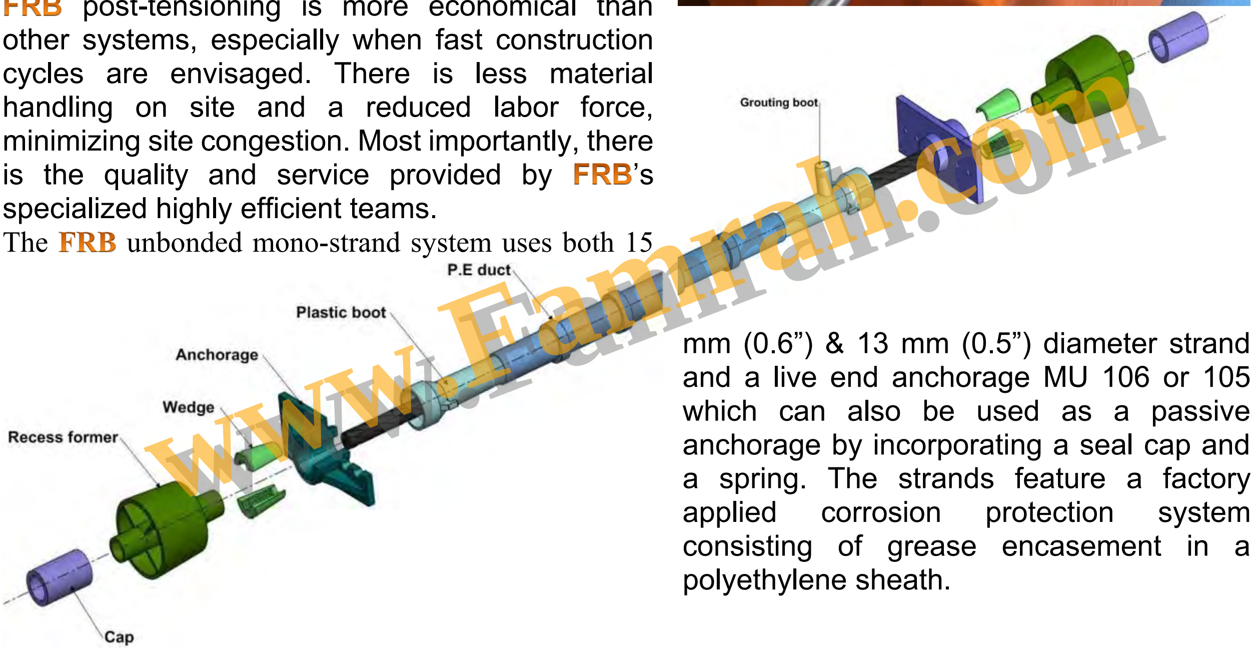
Mono & Flat Anchorages

Today's building owners and designers need to provide a high level of structural flexibility to meet changing user requirements.

Post-tensioning provides greater spans with reduced structural floor depths, resulting in larger column-free areas. As a result, internal layouts are not dictated by tight column grids. Positive deflection and crack control and, if necessary, joint-free water-tight slabs, free designers from the limitations of traditional reinforced concrete structures.

FRB post-tensioning is more economical than other systems, especially when fast construction cycles are envisaged. There is less material handling on site and a reduced labor force, minimizing site congestion. Most importantly, there is the quality and service provided by **FRB**'s specialized highly efficient teams.

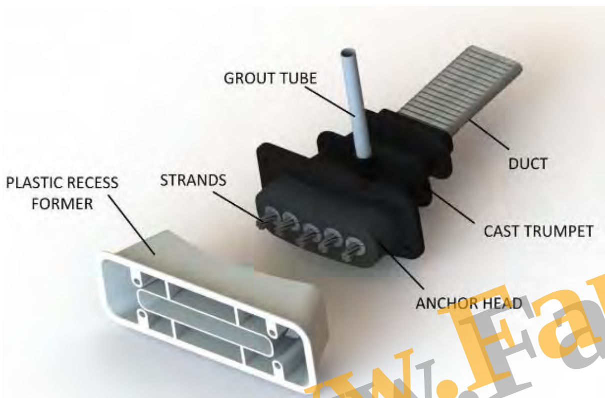
The **FRB** unbonded mono-strand system uses both 15 mm (0.6") & 13 mm (0.5") diameter strand and a live end anchorage MU 106 or 105 which can also be used as a passive anchorage by incorporating a seal cap and a spring. The strands feature a factory applied corrosion protection system consisting of grease encasement in a polyethylene sheath.



In its first application in the USA, the post-tensioning steel was grassed and wrapped in wrapping paper to facilitate its longitudinal movement during stressing. During the last few years, however the method described below for producing the sheathing has generally become common. The strand is first given a continuous film of permanent corrosion-preventing grease in a continuous operation, either at the manufacturer's works or at the post-tensioning firm. A plastic tube of polyethylene or polypropylene of at least 1mm wall thickness is then extruded over this. The plastic tube forms the primary, and the grease, the secondary, form of corrosion protection.

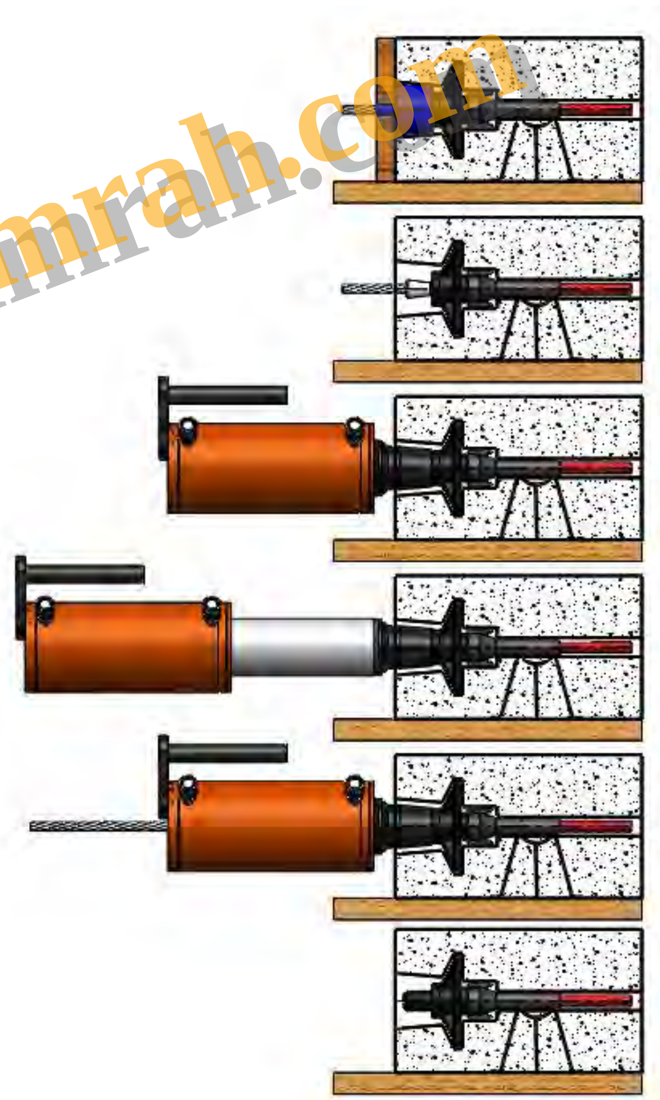
Bonded Flat Anchorages

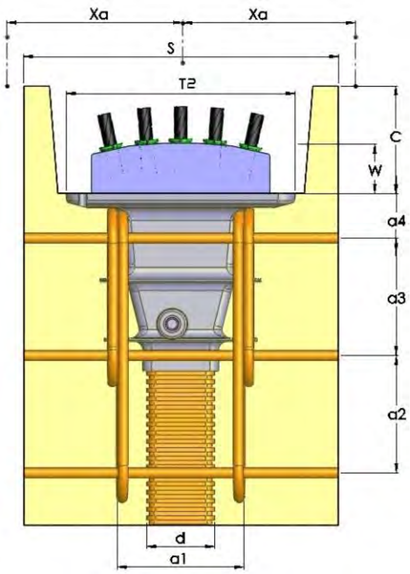
The **FRB** bonded post-tensioning slab system can be used in many types of buildings, bridges and other structures. The system uses up to five strands 13mm (0,5") or 15mm (0,6") contained in flat-shaped ducting, and anchored in a single anchorage. Strands are individually stressed and gripped by wedge action. After stressing, the duct is filled with a cement grout that fully bonds the strands to the surrounding concrete.

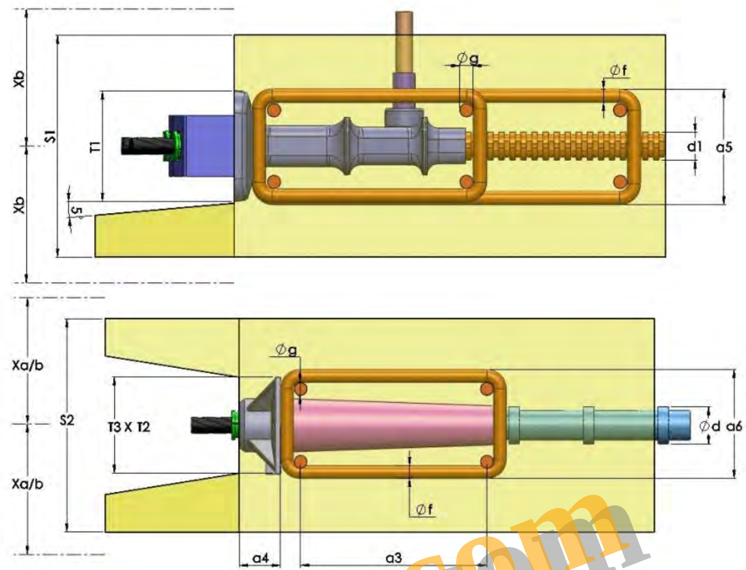


FRB anchorages for slab post-tensioning in buildings, bridge decks and other applications consist of up to 5-strands of 15 mm (0.6") & 13 mm (0.5") diameter placed in a flat duct with corresponding anchorages FA306, FA406, FA506, FA305, FA405 & FA505. The strands are tensioned and locked off individually using a mono-strand jack.

The diagram on right shows the process of stressing in prestressed unbonded flat slabs using FRB System.







Flat & Mono anchorage data table

Anchorage Designation	Mono Anchorage M106	Mono Anchorage M105	Flat Anchorage FA306	Flat Anchorage FA305	Flat Anchorage FA406	Flat Anchorage FA405	Flat Anchorage FA506	Flat Anchorage FA505
T1	70	60	90	85	100	90	90	100
T2	140	130	180	170	220	180	270	220
T3×T2	70 × 140	60 × 130	-	-	-	-	-	-
a1	110	100	240	230	240	240	260	240
a2	-	-	125	120	125	125	125	125
a3	140	130	125	120	125	125	125	125
a4	70	60	50	50	50	50	50	50
a5	-	-	80	75	90	80	90	90
a6	62	52	-	-	-	-	-	-
S	180	160	235	220	285	235	350	285
S1	-	-	155	170	180	155	155	180
S2	180 × 125	160 × 120	-	-	-	-	-	-
d	-	-	75	60	75	75	95	75
d1	-	-	20	20	20	20	20	20
Ød	Ø22/Ø20	Ø22/Ø20	-	-	-	-	-	-
C	55	50	120	120	120	120	120	120
W	-	-	45	45	55	45	65	60
Øg	8	8	10	10	12	10	12	12
Øf	8	6	10	10	12	10	12	12
Xa	120	110	155	150	190	155	220	190
Xb	75	70	90	85	120	90	120	120
Force (kN)	209	138	627	415	837	558	1047	698

Mono strand Coupler Anchorages

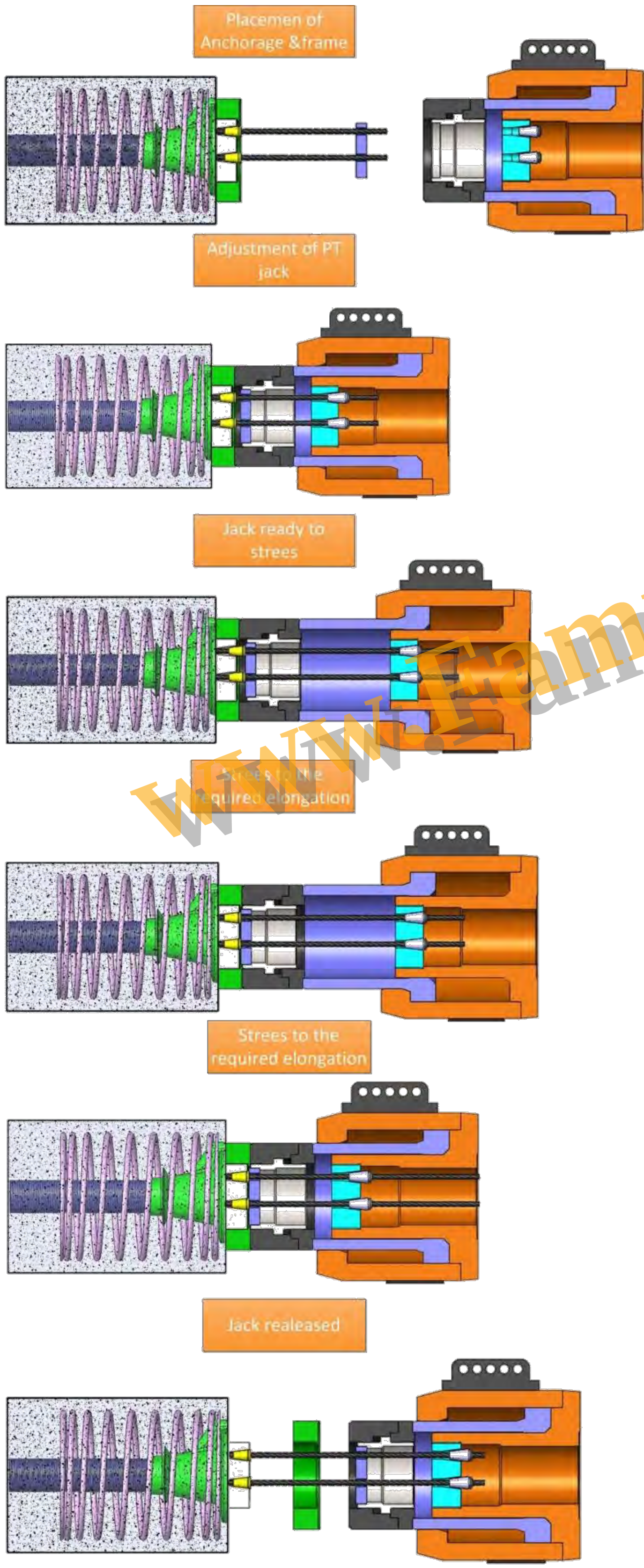
The unitary coupler Type MCU is a single strand coupler –its main advantage being that it can be used in a limited work space. It is an ideal system for bridge decks with limited thickness, where a multiple junction coupler might not fit into the allowable space.

This coupler consists of a twin barrel casting with opposing wedges which serves both as a coupler and a stressing point to which the jack can be applied. Due to its unique geometry this connector (coupler) can be used in applications where another type of coupler will not fit. The MCT unit is primarily used for the tensioning of circular structures such as tanks and silos and stressing is carried out using a mono-strand jack. MCT Couplers provide effective solutions for the circular shaped structures.

Reservoirs, Circular Structures New Construction and Repair

Post-tensioning Applications in Reservoir Structures Construction

Post-tensioning Operation



Compressive forces are induced in a concrete structure by tensioning steel tendons of strands or bars placed in ducts embedded in the concrete. The tendons are installed after the concrete has been placed and sufficiently cured to a prescribed initial compressive strength. A hydraulic jack is attached to one or both ends of the tendon and pressurized to a predetermined value while bearing against the end of the concrete beam. This induces a predetermined force in the tendon and the tendon elongates elastically under this force. After jacking to the full, required force, the force in the tendon is transferred from the jack to the end anchorage. Tendons made up of strands are secured by steel wedges that grip each strand and seat firmly in a wedge plate. The wedge plate itself carries all the strands and bears on a steel anchorage. The anchorage may be a simple steel bearing plate or may be a special casting with two or three concentric bearing surfaces that transfer the tendon force to the concrete. Bar tendons are usually threaded and anchor by means of spherical nuts that bear against a square or rectangular bearing plate cast into the concrete. After stressing, protruding strands or bars of permanent tendons are cut off using an abrasive disc saw. Flame cutting should not be used as it negatively affects the characteristics of the prestressing steel. Approximately 20mm (¾ in) of strand is left to protrude from wedges or a certain minimum bar length is left beyond the nut of a bar anchor. Tendons are then grouted using a cementitious based grout. This grout is pumped through a grout inlet into the duct by means of a grout pump. Grouting is done carefully under controlled conditions using grout outlets to ensure that the duct anchorage and grout caps are completely filled. For final protection, after grouting, an anchorage may be covered by a cap of high quality grout contained in a permanent non-metallic and/or concrete pour-back with a durable seal-coat.

Permanent Post-Tensioned Applications

Cast-in-Place Bridges on False work

Bridges of this type have a superstructure cross-section of solid or cellular construction. They are built on-site using formwork supported by temporary false-work. Formwork creates the shape of the concrete section and any internal voids or diaphragms. Reinforcement and post-tensioning ducts are installed in the forms and then the concrete is placed, consolidated and cured. When the concrete attains sufficient strength, post-tensioning is installed and stressed to predetermined forces.

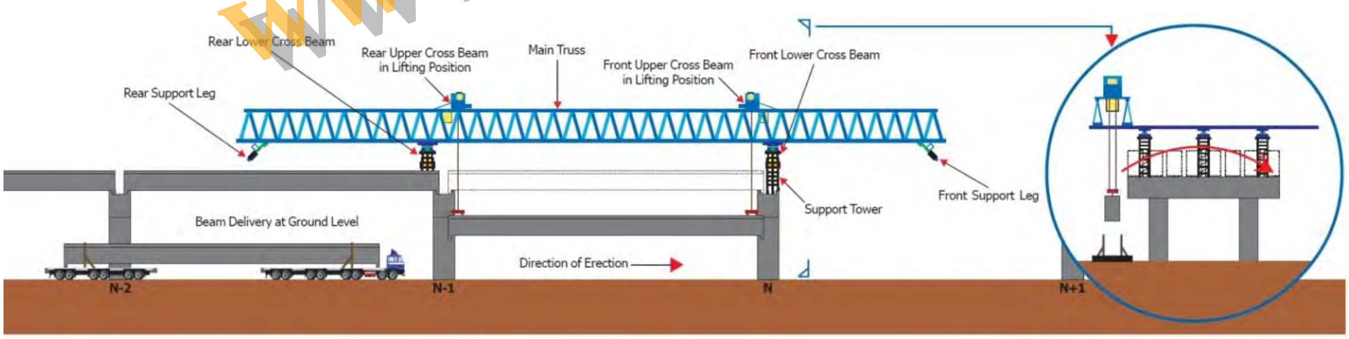
Longitudinal post-tensioning typically comprises multi-strand tendons smoothly draped to a designed profile. In continuous spans, the tendon profile lies in the bottom of the section in the mid-span region and rises to the top of the section over interior supports. In simple spans and at the expansion ends of continuous spans, post-tensioning anchors are arranged vertically so that the resultant of the tendon anchor force passes close to the centroid of the section. A draped profile of this type provides the most effective distribution of internal prestress for this type of construction.

Post-Tensioned AASHTO, Bulb-T, and Spliced Girders

Precast, post-tensioned AASHTO and bulb-T girders are usually pre-tensioned sufficiently at the precast plant to carry their own weight for transportation to the site and erection. On site, girders are first erected as simple spans. However, over the interior piers of a three or four span unit, they are made continuous by cast-in-place joints that connect the girder ends and form transverse, reinforced diaphragms.

Post-tensioning ducts cast into the webs are spliced through the cast-in-place joints. The ducts follow a smoothly curved, draped profile along each girder line, rising to the top of the girders over the interior piers and draping to the bottom flange in mid-span regions. Before the deck slab is cast, some or all of the tendons running the full length of the multi-span unit are installed and stressed, making each simple span I-girder into a series of continuous spans. When the deck slab has been cast and cured, additional tendons may be installed and stressed on the fully composite section. Tendons may be anchored in a variety of configurations at the ends of each continuous unit. Longer spans can be built using similar techniques. A variable depth girder section cantilevering over a pier can be spliced to a typical precast girder in the main and side-spans.

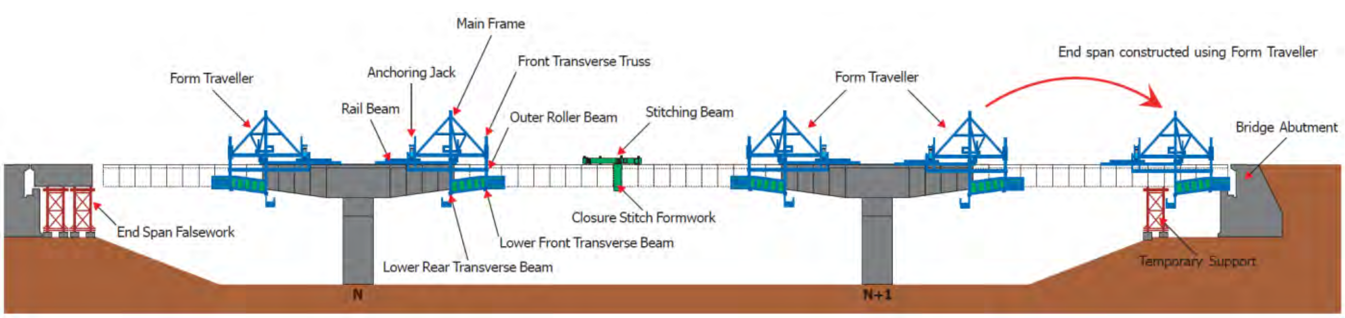
Erection Sequence and Temporary Supports for Spliced I-Girder



Cast-in-Place Segmental Balanced Cantilever Bridges

An example of cast-in-place balanced cantilever construction using form travelers is shown in Figure below. Form travelers support the concrete until it has reached a satisfactory strength for post-tensioning. Longitudinal post-tensioning comprises cantilever tendons in the top slab at supports and continuity tendons in both top and bottom slabs through the mid-span regions.

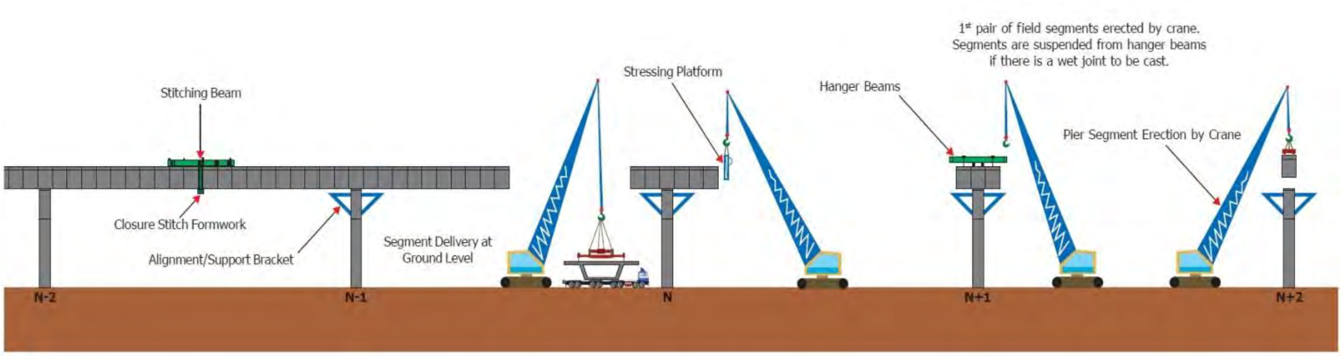
KHORDAD Bridge, KHOOZESTAN, Iran



Precast Segmental Balanced Cantilever Bridges

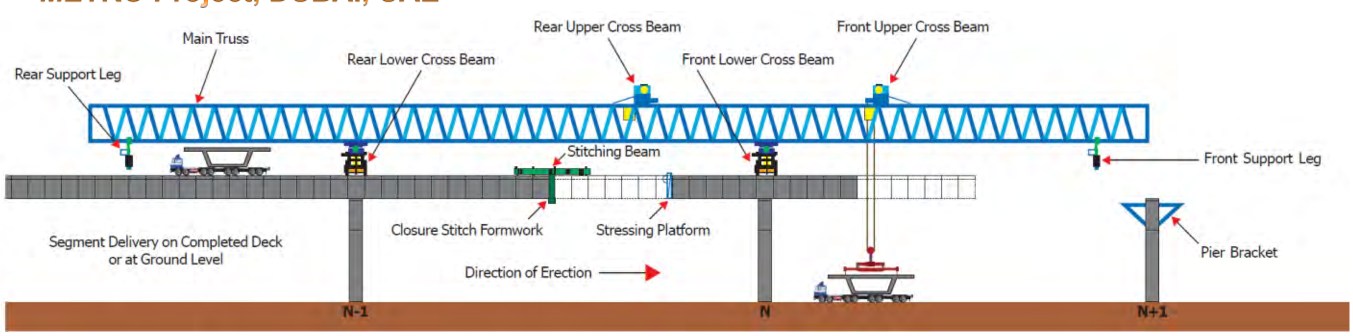
Precast segmental balanced cantilever construction involves the symmetrical erection of segments about a supporting pier. When a segment is lifted into position, adjoining match-cast faces are coated with epoxy and temporary post-tensioning bars are installed and stressed to attach the segment to the cantilever. Typically, after a new balancing segment is in place on each end of the cantilever, post-tensioning tendons are installed and stressed from one segment on one end of the cantilever to its counter-part on the other. Consequently, as segments are added, more top cantilever tendons are also added. The figure below shows two typical methods of placing precast segments in balanced cantilever, using cranes with stability towers at each pier and using an overhead launching gantry. When all segments of a new cantilever have been erected and tendons stressed, a closure joint is made at mid-span. Continuity post-tensioning tendons are installed and stressed through the closure to make the cantilevers continuous.

METRO Project, DUBAI, UAE



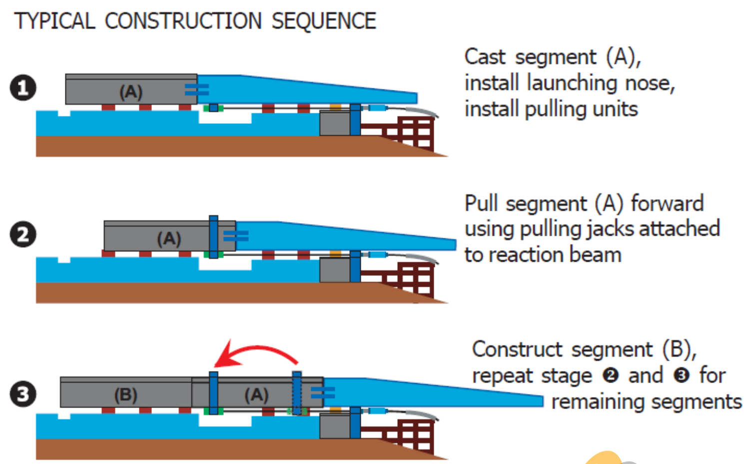
Figures above show two typical methods of placing precast segments in balanced cantilever; sing cranes with stability towers at each pier and using an overhead launching gantry. When all segments of a new cantilever have been erected and tendons stressed, a closure joint is made at mid-span. Continuity post-tensioning tendons are installed and stressed through the closure to make the cantilevers continuous.

METRO Project, DUBAI, UAE



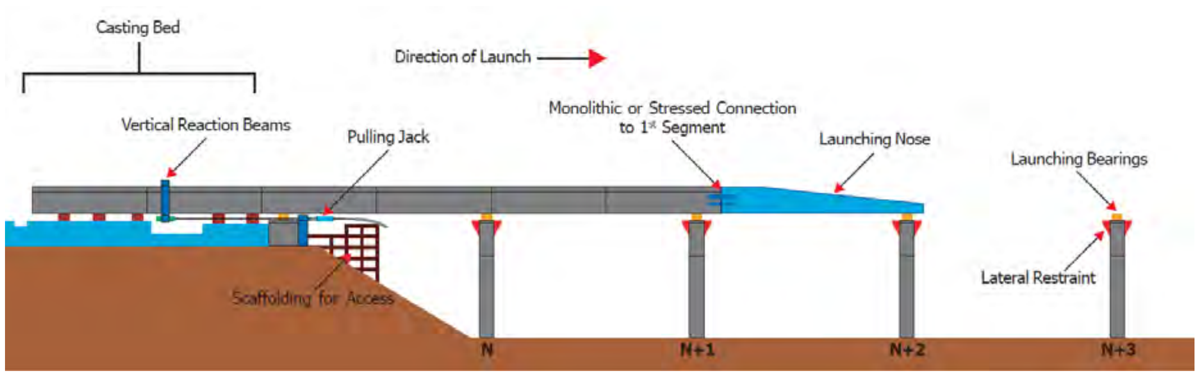
Incrementally Launching Method

The incremental launching construction method was developed in Europe in the 1960s and is now typically used for construction of prestressed concrete, steel, and steel-composite bridges. The method involves the process of building a bridge at a single construction location in sections and launching the bridge incrementally as each section is completed.



Prestressed concrete bridges are constructed by first assembling a small casting yard behind an abutment. The first bridge segment is cast into the formwork and equipped with a light steel extension aimed at controlling the launch stresses. The segment and the steel extension are launched forward onto the piers until clearing the formwork. A second bridge segment is match cast against the first one, and the entire bridge section is launched again. This process (match casting of a new segment and launch of the entire bridge section) is repeated until completion of the bridge.

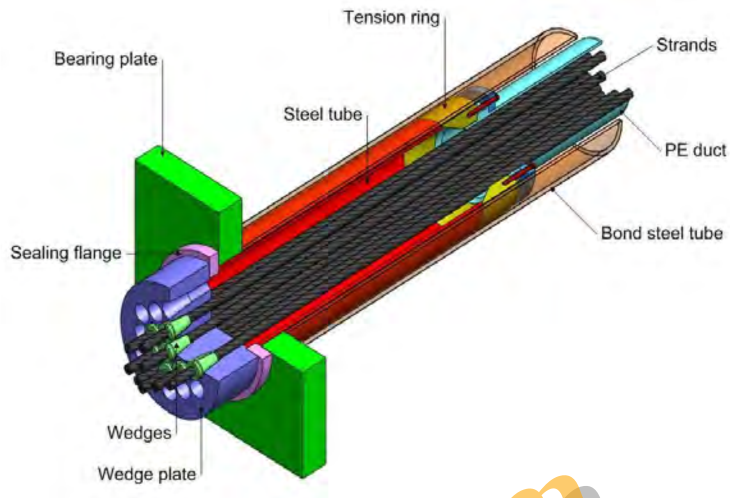
Incremental launching construction for steel girder bridges involves similar operations. In this case, the formwork is replaced with adjustable supports that sustain the girder segments during their assembly. All diaphragms and lateral bracing are also assembled on the ground. The deck slab of steel-composite bridges is typically cast in-place upon completion of the launch of the steel girders.



For prestressed-concrete bridges, the typical application for incremental launching is from 30 to 54 m spans and bridge lengths varying between 300' to 4000'. For steel girders, the optimum span lengths vary from 30 to 120 m. In both cases, much longer spans can be launched with the use of temporary piers.

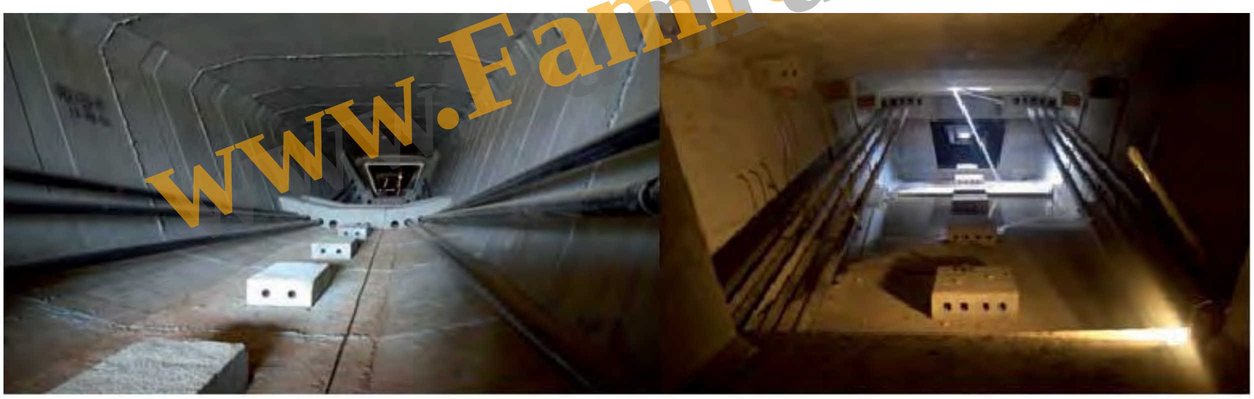
External Post-tensioning

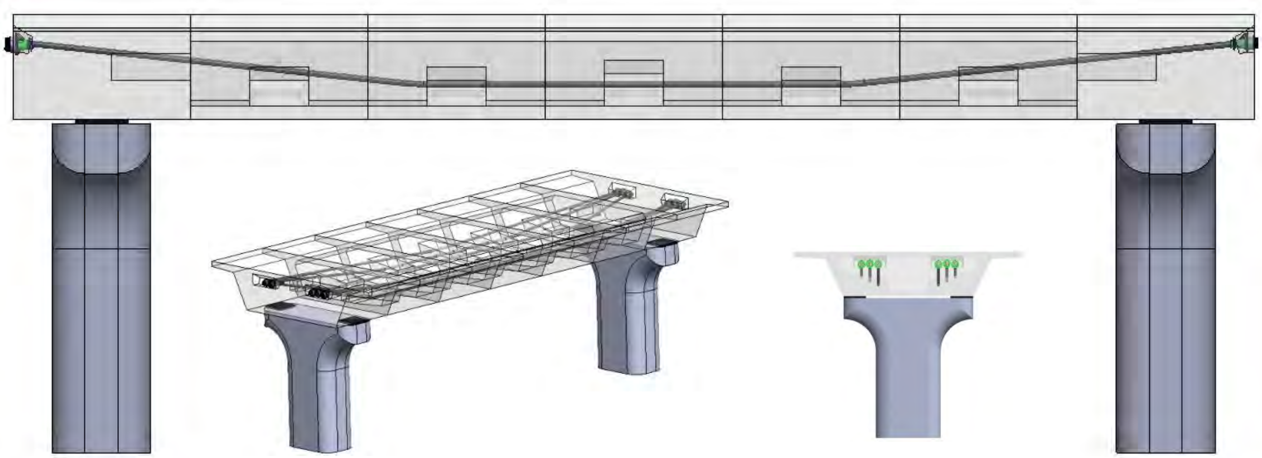
External post-tensioning is well adapted to bridges due to the resulting savings in construction costs and the high degree of corrosion resistance provided by the system. External tendons are easy to inspect and, if necessary, replace. They are ideal for strengthening existing structures and, apart from their uses in bridges, can be used for a wide range of other applications, including buildings, silos, reservoirs and steel structures.



FRB External tendons comprise:

- Strand bundle
- Polyethylene ducts
- Standard multistrand anchorages, and special anchorages permitting easy tendon replacement
- Grouting compound





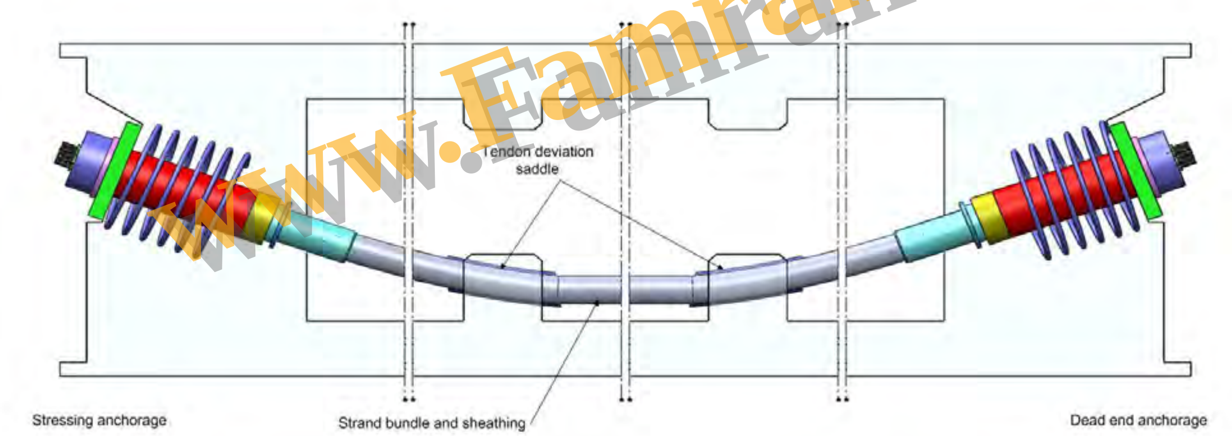
Saddles at points of deviation:

A saddle at a point of deviation consists of:

- A structural element capable of carrying the loads exerted by the tendon in the deviation zone
- A part ensuring the geometry of the deviation.

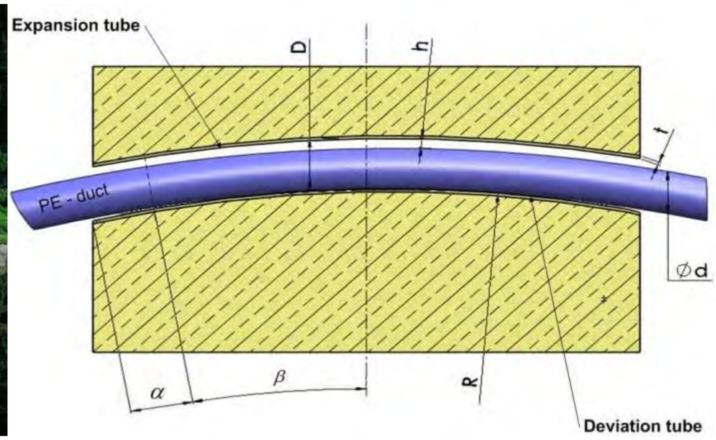
Globally, a saddle at a point of deviation must satisfy the following requirements:

- Withstand both the longitudinal and transversal forces that the tendon applies to it and transmit these forces to the structure
- Ensure, without unacceptable angular breaking, the connection between two straight tendon sections
- Unless otherwise stipulated in the contract, enable removal of the tendon without traumatic effect on the structural elements
- Withstand movements of external tendon during stressing without compromising the tendon's corrosion protection system.



When designing saddles it is important to consider the following:

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



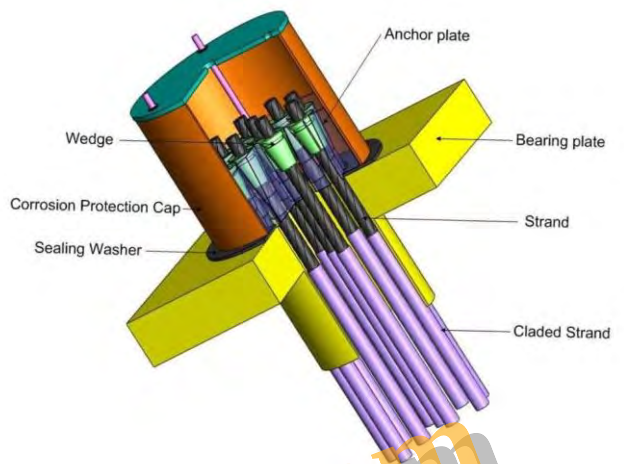
Minimum tendon radii as recommended in Table below must be respected in order to avoid damage to the prestressing steel and the plastic sheathings, as well as to the outer tubing, unless a national regulation is stricter. It is well-established that friction problems may occur if tendon radii are too small.

α = Designed deviation angle
β = Deviation angle in reserve
β ≥ 3° at each end in all directions required, R ≥ R_{min}

Tendon	306	506	706	906	1206	1506	1906	2406	2706	3106	3706
all dimensions are mm except for R_{min}											
R min (m)	2.00	2.00	2.00	2.25	2.50	2.75	3.00	3.35	3.50	3.75	4.00
Ø duct min	50	63	75	75	90	110	110	125	125	140	140
d_o min	70	82.5	95	95	108	133	133	152.4	152.4	168.3	168.3
t	3.6	3.6	3.6	3.6	3.6	4.0	4.0	4.5	4.5	5.0	5.0
e	12.8	12.8	12.8	12.8	10.8	15.0	15.0	18.4	18.4	18.3	18.3

An innovation in using external PT tendons to improve the structural behavior of cranes

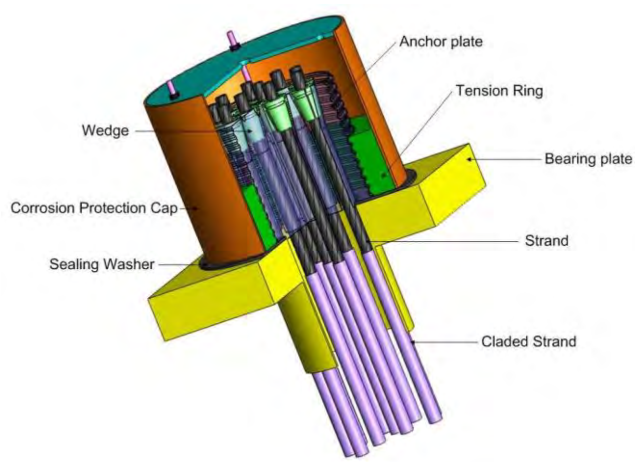
GROUND ANCHORS



FRB Anchors can be divided into two main categories – strand and bar anchors. The type of anchors used depends on whether it is for rock or soil, for temporary or permanent use, whether or not it is to be tensioned, and whether or not permanent corrosion protection is required. FRB offers all of these alternatives and can support a full anchor material supply service (anchors and accessories) with back-up including design services, advice, consultancy, testing, installation, stressing, and site supervision.

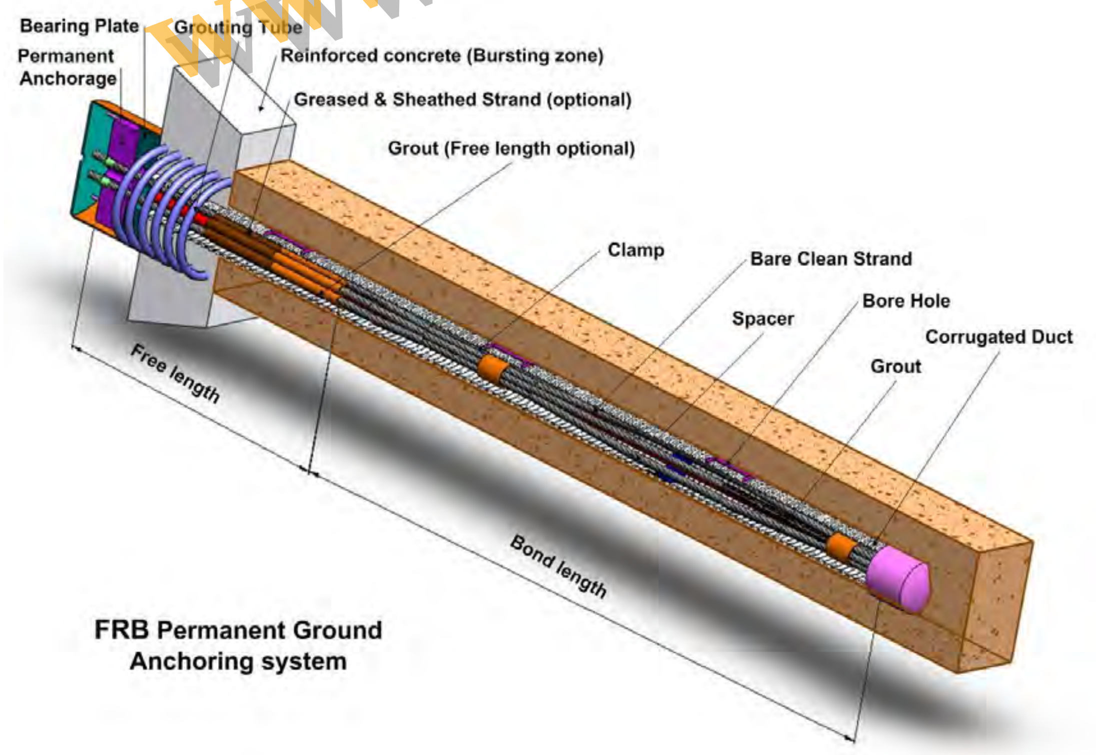
The construction of the FRB Strand Anchor depends on the type of application (rock or soil), the design, the corrosiveness of the environment, the presence of stray electrical currents, and the intended service life. While temporary ground anchors require limited or no corrosion protection, permanent ground anchors (with a service life exceeding two or three years) need to have a comprehensive permanent corrosion protection system. The anchor construction can be adapted to a wide range of specific requirements.

Anchorages can be designed to allow the anchor force to be adjustable, releasable or be used as a monitoring anchor. FRB' s range of anchors extends from permanent anchors that allow special measurements to be taken to check the integrity of the encapsulation during the entire service life, to temporary anchors that can be easily extracted after use.



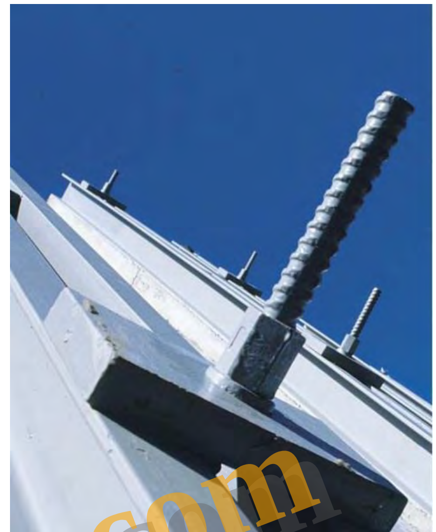
The anchor shown on this page represents a typical permanent strand anchor with a thick walled polyethylene encapsulation acting as a protective barrier against corrosion. Temporary anchors are similarly constructed except that, being designed for a shorter service life, corrosion protection requirements are usually less demanding. The anchor is not normally encapsulated and can take the form of a bundle of bare strands in contact with grout over the bond length of the anchor. Both types of anchor systems comprise the anchor with a bearing plate, anchor head and wedges.

The length and load capacity of rock and soil anchor systems is dependent on many variables. Some of these variables are rock or soil properties, installation methods, underground or overhead obstructions, existing structures, right of way and easement limitations, anchor material strength and anchor type. Topics such as these should be evaluated during an anchor feasibility study prior to final anchor design. Final embedment depths should be determined on a project to project basis after reviewing rock or soil samples, previous experience and geological data. On-site anchor tests are generally the best way to accurately determine anchor lengths and capacities for the given geological conditions.

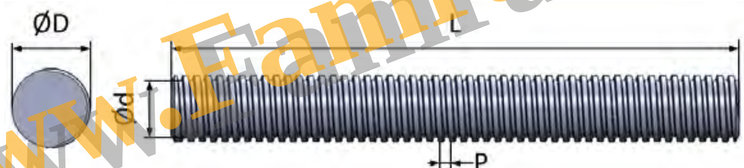


FRB Permanent Ground Anchoring system

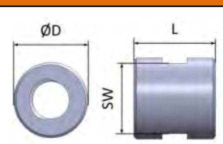
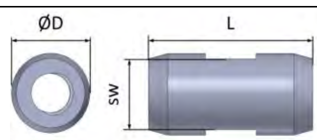
FRB High Tensile Bar System



FRB bar system is one of the most popular tools of engineers wishing to induce and control loads and forces in structures. FRB's product line complies with international standards, including ISO, Euro codes, ASTM and British Standards. A range of diameters is available to give a wide selection of tendon forces. The prestressing force is anchored at the end of the bar by a rolled thread, nut, washer, and bearing plate. Where necessary bars can be joined with threaded couplers, and clevis fittings may be used where pin connections are required. FRB Bars systems are specifically designed to suit all geotechnical applications as well as civil works and building applications. The systems range from High Tensile Cold Worked Stress bar to Low Tensile Architectural bars, all with compact and easy to assemble fittings. FRB bar systems are ideal for the economic application of post-tensioning forces on relatively short tendons. Through the use of threaded connections and anchorages they are simple to use and lend themselves to many applications. All bars and fittings must receive protection when installed under permanent conditions or used in an exposed environment. One of the following coating systems may be used.



Description	TYPE	S1050					
Nominal Size	mm	Ø25	Ø30	Ø35	Ø40	Ø55	Ø65
Diameter	D/d	30/25	35/30	40/35	45/40	60/55	70/65
Length (L)	mm	5800	5800	5800	5800	5800	5800
Pitch (P)	mm	6	6	6	6	6	6
Strength(Yield /Tensile)	N/mm^2	750/1100			650/900		
Characteristic load (Yield)	KN	515.414	742.193	1010.22	1068.14	2019.45	2820.56
working load (DIN 1045)	KN	417	601	818	942	1782	2489
Cross sectional Area	mm^2	491	707	962	1257	2376	3318
Weight	kg/m	4.0	6.3	7.9	10.4	19.6	27.4

Accessories (Nut & Coupler)			Ø25	Ø30	Ø35	Ø40	Ø55	Ø65
	sw	mm	46	55	65	80	90	100
	L	mm	55	65	70	90	120	120
	D	mm	50	60	70	85	100	110
	G	kg	0.6	1.1	1.6	3.1	5.1	5.8
	sw	mm	46	55	65	80	90	100
	L	mm	100	130	150	170	220	240
	D	mm	50	60	70	85	100	110
	G	kg	1.1	2.2	3.4	5.9	9.4	11.6

INTRODUCTION

I. LIMITATION OF THE PRESTRESSING FORCE

II. LOSS OF PRESTRESS

A. Instantaneous losses
- a) Friction losses in the duct
- b) Loss of prestress at transfer
- c) Loss of prestress due to elastic deformation of concrete

B. Long term losses

III. TENDON ELONGATION

IV. ANCHOR BLOCK

A. Bearing stresses

B. Bursting tensile forces

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

The calculation methods that follow meet the requirements of the European Standard EUROCODE 2 "Project of concrete structures" and the "Post-tensioning Manual" of the PTI (Post-tensioning Institute). If these notes are used in countries where other standards are applicable a check should be made to ensure that calculations comply with local requirements. Some paragraphs introduce notes referring to other standards, in this case the name of the standard is indicated.

I. Limitation of the prestressing force

Maximum initial prestress 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)
- BS 5400-4
  - 70% of the characteristic strength of the tendon

Jacking force

The Jacking force may be increased during 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)
- BS 5400-4
  - 80% of the characteristic strength of the tendon

These jacking force maximum values can only be applied temporarily to the tendon. Force in the tendon shall not exceed maximum initial prestress after transfer from the jack to the anchorage.

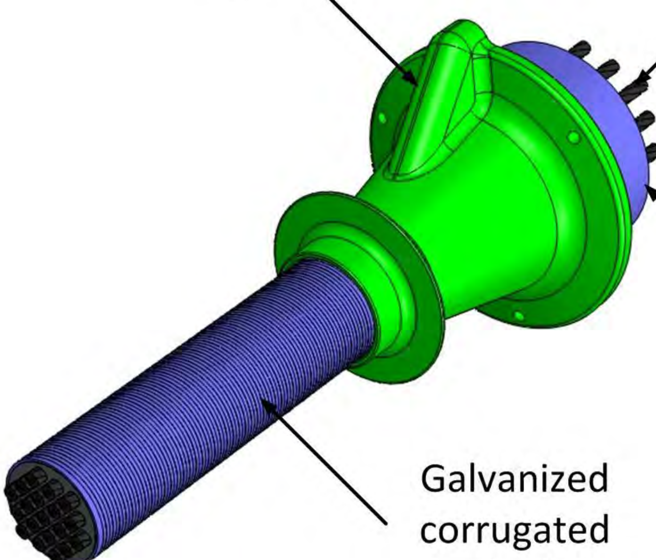
II. Loss of Prestress

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:

$$\Delta P_x = P_0 - \Delta P_i - \Delta P_{dif}$$

Where:

$P_x =$ Post-tensioning force at a point located at x meters from the anchorage
$P_0 =$ Stressing force o initial post-tensioning force at anchorage (x=0)
$\Delta P_i =$ Instantaneous post-tensioning losses.
$\Delta P_{dif} =$ 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.

$$\Delta P_i = P_0 \left(1 - e^{-(\mu\alpha + kx)}\right)$$

where:

μ = coefficient of angular friction (in rad^{-1}).
α = accumulated angular deviation between points 0 and x (radians).
k = Wobble coefficient per unit lenghth of tendon (in m^{-1}).

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.

When $\mu\alpha + kx \leq 0.3$ the following approximate linear equation is used:

$$\Delta P_i = P_0 (\mu\alpha + kx)$$

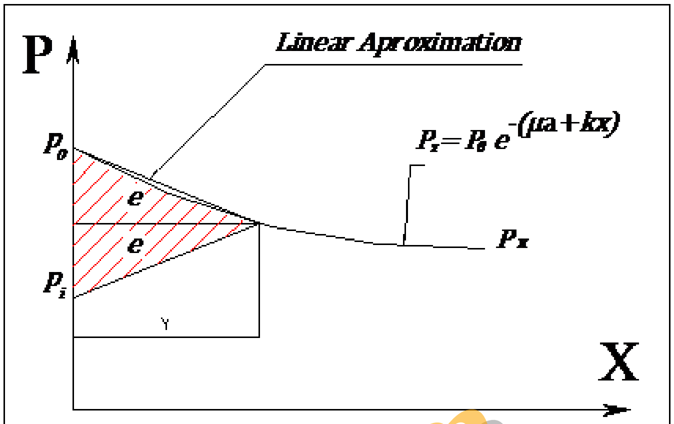


Figure 1

Friction coefficient		μ(Rad^{-1})	k(10^{-3} m^{-1})
Non-lubricated tendons	Range	0.18 – 0.26	0.6 – 3.3
	Calculation Value	0.22	2.5
Lubricated tendons	Range	0.12 – 0.18	0.6 – 1.8
	Calculation Value	0.15	1.8
Unbonded tendons	Range	0.05 – 0.07	0.3 – 0.7
	Calculation Value	0.07	0.7

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, slippage of strand relative to the wedges and the adjustment of the anchorage plate on the trumpet.

After stressing, the wedges are then firmly pushed into its anchorage by the application of a hydraulic wedge seating feature. The jack is then retracted thus transmitting the force of the tendon to the anchorage plate.

As a result of this procedure the wedge still penetrates into the anchorage for several millimeters, until equilibrium of the tension and deformation is achieved. Slippage of the strand and adjustment of anchorage plate are almost negligible. The culmination of all these factors, results in a shortening of the tendon and therefore in a loss of prestressing force, and is referred to as “Draw in of the wedge” amounting between 4 to 6 mm for the FRB prestressing system.

Due to friction losses the loss of prestressing due to draw in of the wedges affects only a certain length of the tendon from a maximum loss at the stressing anchorage till a nil loss at a length "l_a" 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 to the same tendon shortening are far higher in this case.

$$l_a = \frac{\alpha E_p A_p}{P_0(\mu\alpha + k l_a)}$$

l_a is calculated in an iterative process.

Where:

la = Length affected by the draw in of the wedge (m).
α = Draw in of the wedge (4-6 mm) (m).
E_p = Modulus of Elasticity of the prestressing steel (kN/mm^2).
A_p = Area of prestressing tendons (mm^2).

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

$$\Delta P_2 = 2P_0\,(1 - e^{-(\mu\alpha + k l_a)})$$

Tendon Components

c) Loss of Prestress due to Elastic Deformation of Concrete

During the stressing process of the tendons, 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:

$$\Delta P_3 = \frac{n-1}{2n} \frac{E_p}{E_{cj}} A_p \, \sigma_{cp}$$

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.

$$\sigma_{cp} = \frac{P_0 - \Delta P_1 - \Delta P_2}{A_c} + \frac{(P_0 - \Delta P_1 - \Delta P_2)e^2 - M_{cp}.e}{I_c}$$

Ecj = Modulus of elasticity of the concrete at j days.
e = Eccentricity of the tendon with reference to centre of gravity of the concrete section.
Ic = Second moment of area of the concrete section.
Mcp = Maximum moment in the concrete section.
Ac = Area of the concrete section.
n = Number of stressed tendons in the concrete section.
j = 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:

$$\Delta P_{dif} = \frac{n\varphi(t,t_0)\sigma_{cp} + E_p\varepsilon_{cs}(t,t_0) + 0.80\Delta\sigma_{pr}}{1 + n\frac{A_p}{A_c}\left(1 + \frac{A_c y_{p^2}}{I_c}\right)\left(1 + x\varphi(t,t_0)\right)} A_p$$

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 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:

$$\Delta\sigma_{pr} = \rho_f \frac{P_0 - \Delta P_1 - \Delta P_2 - \Delta P_3}{A_p}$$

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

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.

$$\Delta l = \varepsilon . l = \frac{\sigma_s l}{E_p}$$

Where:

Δl = Tendon elongation.
l = Length of the tendon.
$\varepsilon . l$ = Tendon strain per unit of length.

σ_s = Prestressing steel tensile stress ($\sigma_s = P/A_p$).

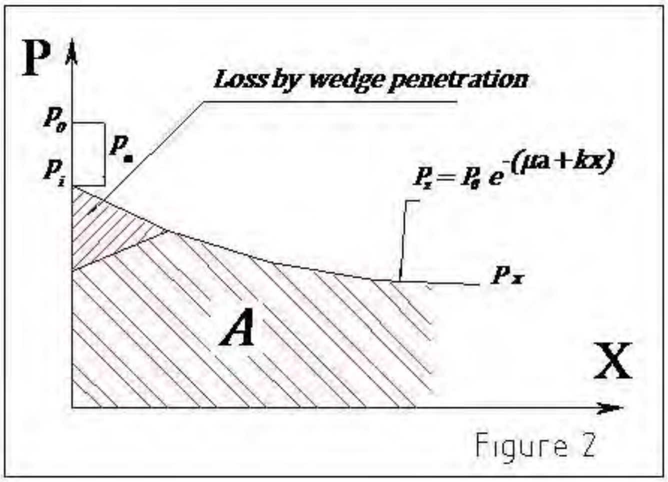


Figure 2

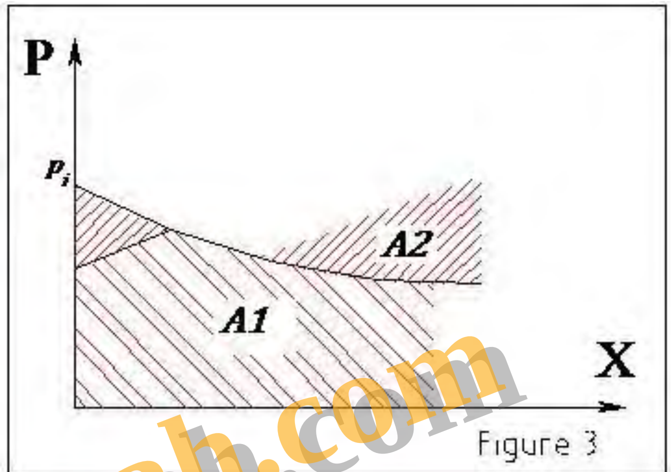


Figure 3

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

$$\Delta l = \int_0^l \frac{\sigma_s}{E_p} dx$$

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

$$\Delta l = \frac{1}{A_p E_p} \int_0^l P_x dx$$

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.

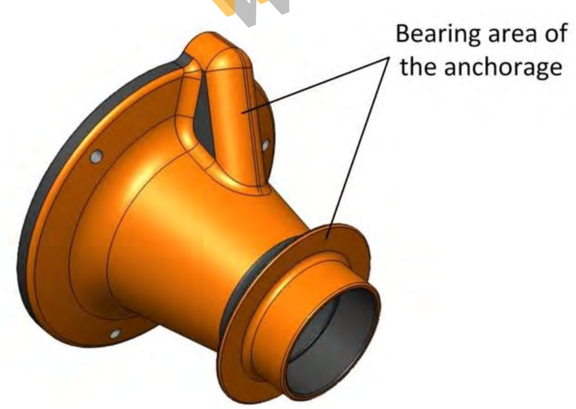
For the design of the anchor blocks it is convenient to consider and check two different kind of stresses and forces that are produced around the prestressing anchorage:

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:



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

Where:

P = Force applied on the anchorage.
A_b = Bearing area of the anchorage.

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

I) At transfer load (Jacking force).

$$\sigma_{co} = \frac{P_0}{A_b}$$

Po = Maximum Jacking force applied to the anchorage at stressing.
Ab = 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 $\sigma_{co\,Po}$ (permissible compressive concrete stress at transfer load).

$$\sigma_{co} \leq \sigma_{co\,P_0} = 0.8 f_{ci}\sqrt{\left(\frac{A`_b}{A_b} - 0.2\right)}$$

$$\sigma_{co} \leq \sigma_{co\,P_0} = 1.25 f_{ci}$$

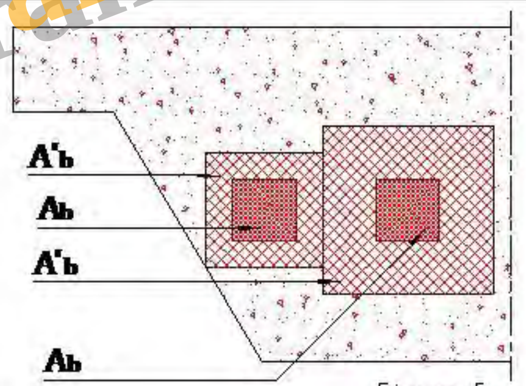


Figure 5

Where:

Fci = 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.

II) At service load

$$\sigma_{cs} = \frac{P_s}{A_b}$$

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).

$$\sigma_{cs} \leq \sigma_{cps} = 0.6 f_{ci} \sqrt{\left(\frac{A'_b}{A_b}\right)}$$

$$\sigma_{cs} \leq \sigma_{cps} = 1.25 f_{ci}$$

Where:

fc : 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 shows the distribution of stresses due to the bursting tensile force, perpendicular to the center line of the tendon.

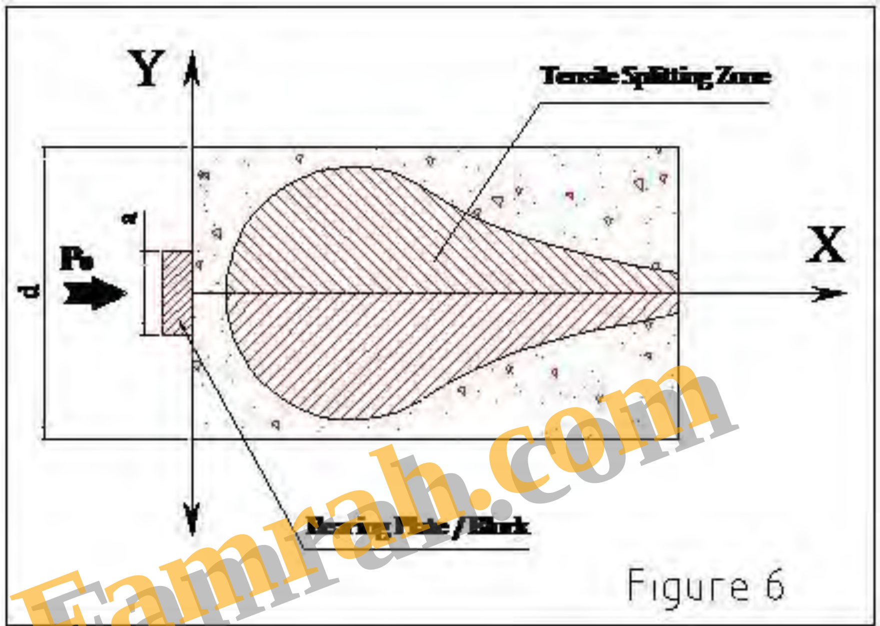


Figure 6

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

$$f_s A_s = Z = 0.25 P_0 \left(1 - \frac{\omega a}{d}\right)$$

Where:

Z = Total bursting tensile force.

f_s = Design strength for the bursting reinforcement.

Assumed design strength: 400 N/mm^2 * (for 500 N/mm^2 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:

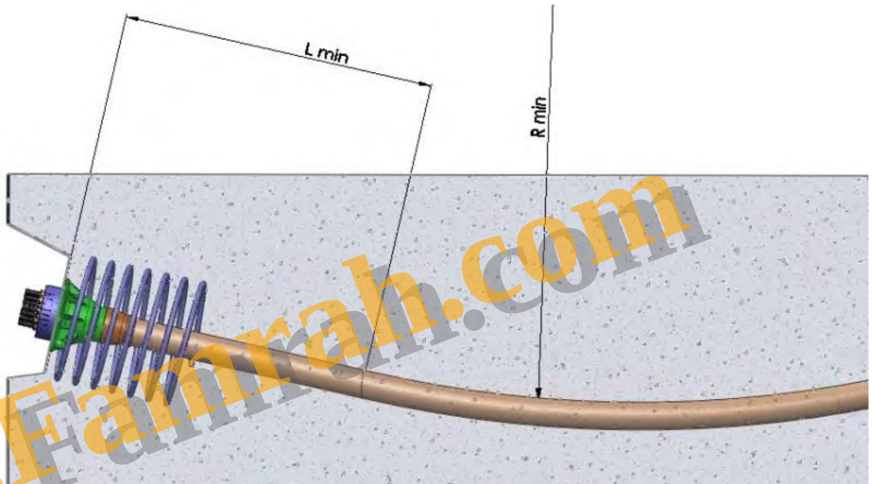
ω = 1 for Bearing Block with a unique bearing plate without ribs.

ω = 0.93 for Bearing Blocks 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.

Minimum radius of tendon curvature & minimum tangent length

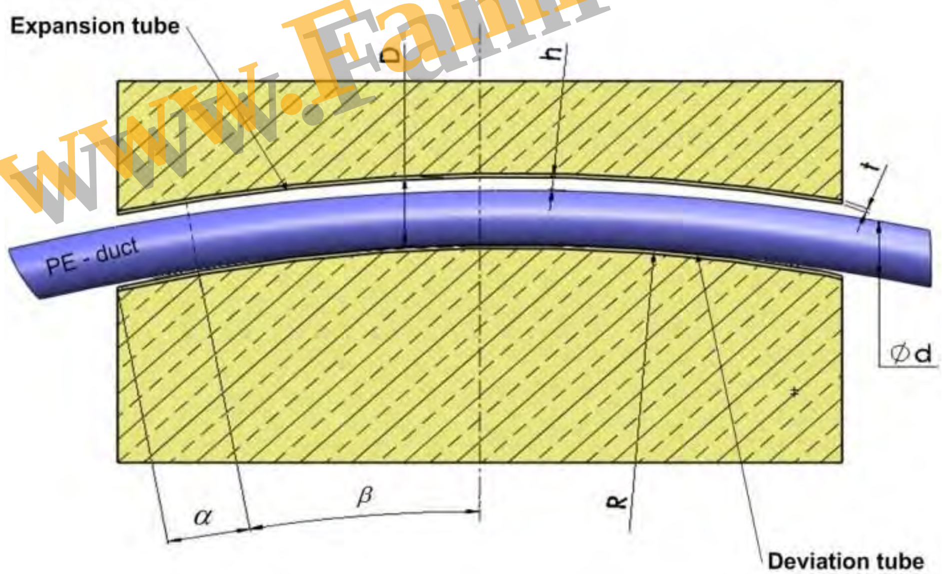
$$R_{min} = 3 \times \sqrt{P_0\{MN\}} \leq 2MN$$
$$L_{min} = 0.8\, m\, for\, P_0 \leq 2MN$$
$$= 0.1\, m\, for\, 2MN \leq P_0 \leq 7MN$$
$$= 1.5\, m\, for\, P_0 \geq 7MN$$



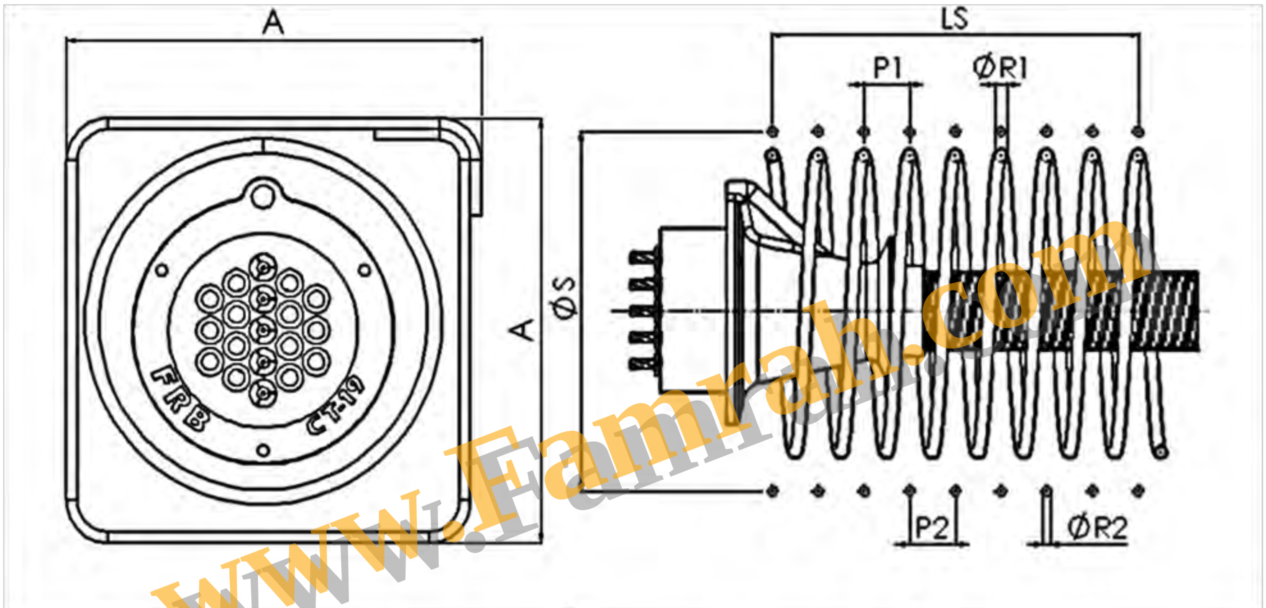
Minimum radius of tendon curvature & specifications for external tendons

α = Designed deviation angle
β = Deviation angle in reserve
β ≥ 3° at each end in all directions required, R ≥ Rmin

Tendon	R min (m)	Ø duct min	d_o min	t	h
all dimensions are mm except for R_{min}					
306	2	50	70	3.6	12.8
506	2	63	82.5	3.6	12.8
706	2	75	95	3.6	12.8
906	2.25	75	95	3.6	12.8
1206	2.5	90	108	3.6	10.8
1506	2.75	110	133	4	15
1906	3	110	133	4	15
2406	3.35	125	152.4	4.5	18.4
2706	3.5	125	152.4	4.5	18.4
3106	3.75	140	168.3	5	18.3
3706	4	140	168.3	5	18.3

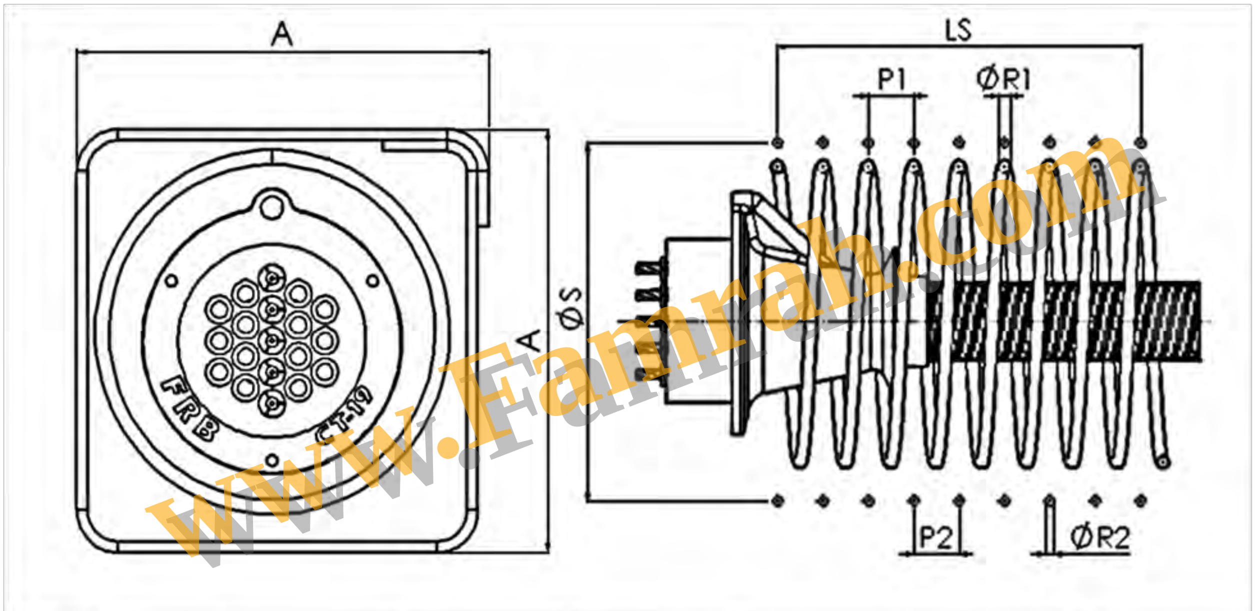


Bursting and additional reinforcement



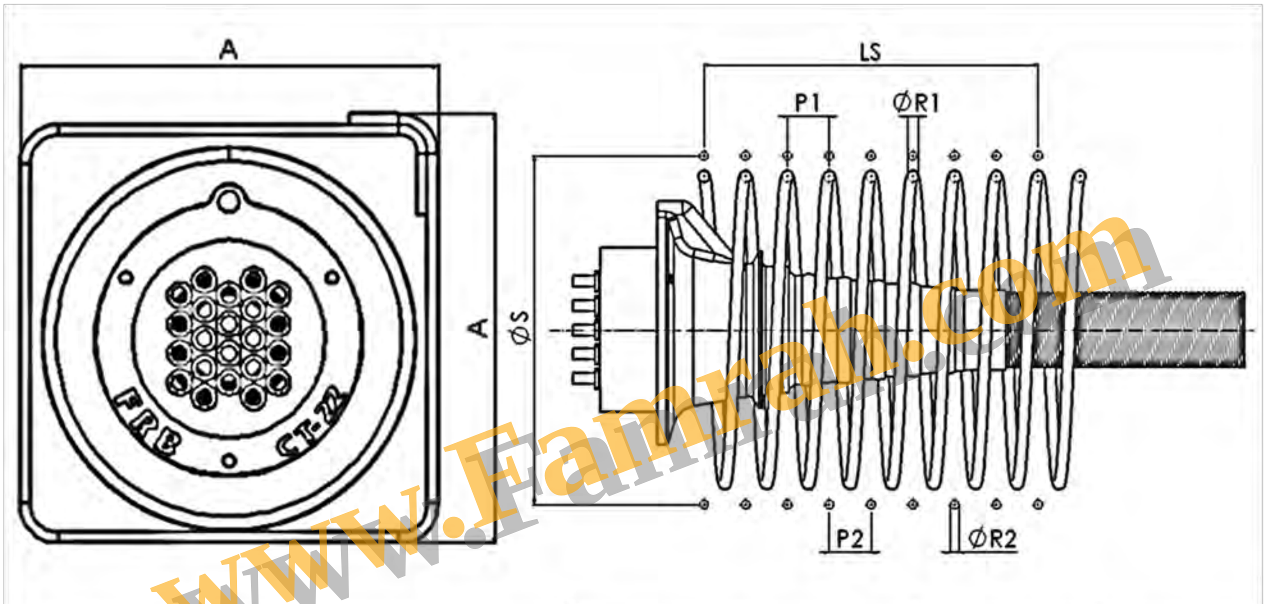
System size	5			7			9		
Bursting reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
Øs(mm)	220	190	170	250	210	180			
ØR1(mm)	12			12			12		
LS(mm)	300	275	250	360	300	270	420	360	330
p1(mm)	50			60					
No.of turns	5	4.5	4	6	5	4.5	7	6	5.5
Additional reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
ØR2(mm)	8			10			10		
P2(mm)	50			55			55		
A(mm)	230	180	170	310	260	230	380	320	280
No.of turns	4	4	4	6	6	5	6	6	6

Bursting and additional reinforcement



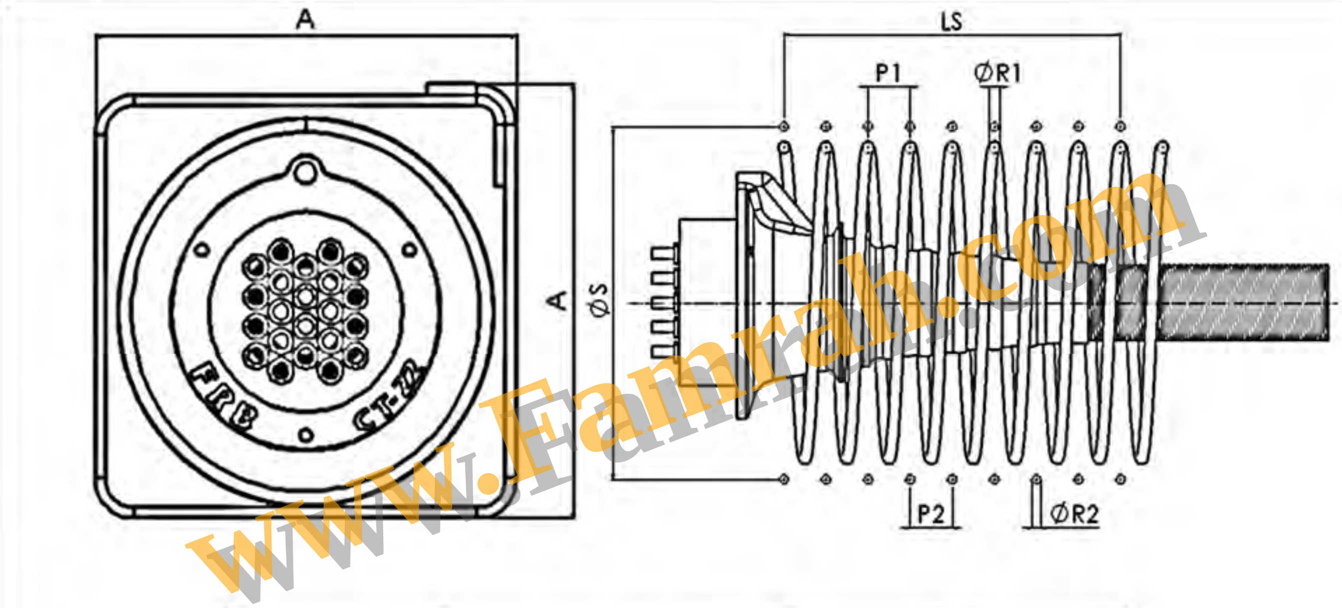
System size	12			15			19		
Bursting reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
Øs(mm)	340	310	280	380	350	315	410	380	360
ØR1(mm)	14			14			16		
LS(mm)	480	420	360	510	450	420	570	510	450
p1(mm)	60			60			60		
No.of turns	8	7	6	8.5	7.5	7	9.5	8.5	7.5
Additional reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
ØR2(mm)	10			12			12		
P2(mm)	55			60			60		
A(mm)	440	360	320	490	420	360	540	460	410
No.of turns	7	6	6	9	8	8	9	9	8

Bursting and additional reinforcement



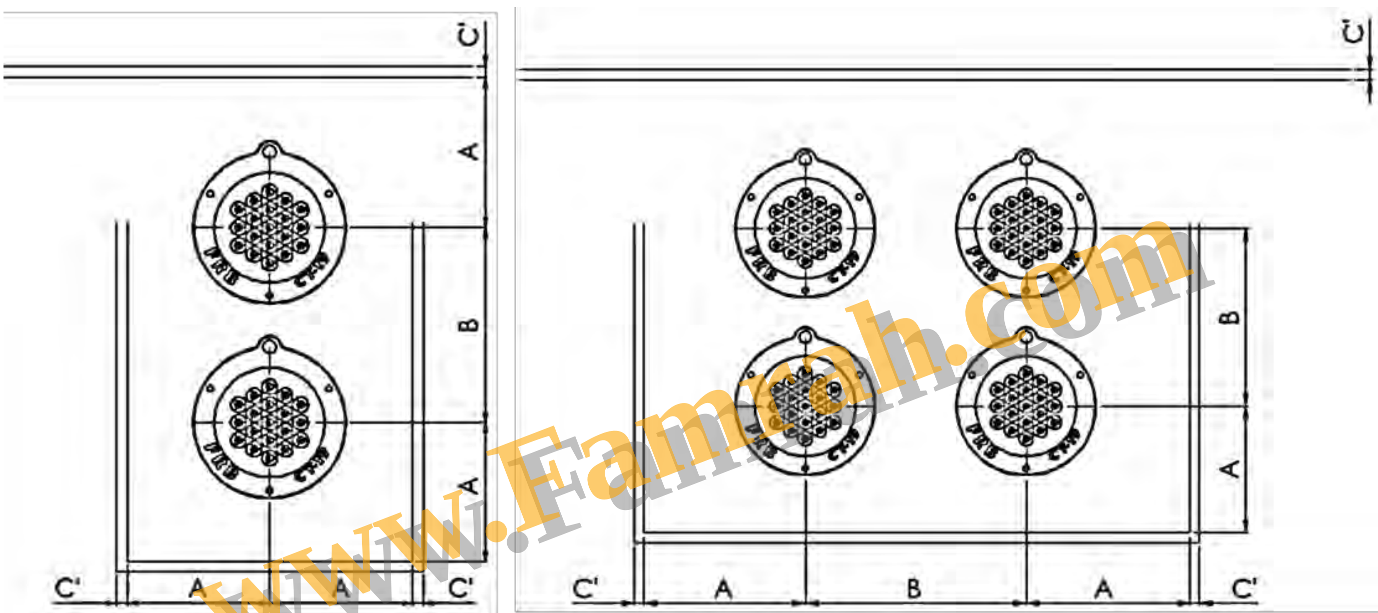
System size	22			24			27		
Bursting reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
Øs(mm)	470	430	500	470	440	400	500	470	440
ØR1(mm)	16			20			20		
LS(mm)	660	540	480	720	600	540	720	600	540
p1(mm)	60			60			60		
No.of turns									
Additional reinforcement									
concrete strength	25	33	45	25	33	45	25	33	45
ØR2(mm)	12			14			14		
P2(mm)	60			65			65		
A(mm)	610	500	450	680	580	490	680	580	490
No.of turns	9	9	8	11	11	10	11	11	10

Bursting and additional reinforcement



System size	31			37		
Bursting reinforcement						
concrete strength	25	33	45	25	33	45
Øs(mm)	540	500	470	560	530	500
ØR1(mm)	20			20		
LS(mm)	750	630	570	780	720	630
p1(mm)	60			60		
No.of turns	12.5	10.5	9.5	13	12	10.5
Additional reinforcement						
concrete strength	25	33	45	25	33	45
ØR2(mm)	14			16		
P2(mm)	65			65		
A(mm)	720	600	530	800	680	600
No.of turns	11	11	10	14	13	13

Center and edge distance



System size	5	7	9	12	15	19	22	24	27	31	37
Minimum edge distance (A)(mm)not including cover											
f=25MP	135	165	190	220	250	280	305	340	340	365	410
f=33MP	120	145	165	195	220	245	265	300	300	325	360
f=45MP	105	130	144	170	190	215	230	260	260	280	310
Minimum center distance (B)(mm)											
f=25MP	280	355	400	465	520	580	630	700	700	755	840
f=33MP	250	315	355	410	460	515	555	620	620	670	740
f=45MP	220	280	315	360	405	450	485	540	540	585	640

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