MACALLOY 1030 POST TENSIONING SYSTEM

DESIGN DATA

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CONTENTS

1. INTRODUCTION

Macalloy 1030 bars complying with BS4486: 1980, grade 1030, are supplied in 25, 26.5, 32, 36 and 40 mm nominal diameters.

Bars having the same mechanical properties are available in both 50 mm and 75 mm diameters; other diameters can be supplied by arrangement. (Note: BS4486 only covers specific bar diameters up to 40mm). The 50mm diameter bar has been independently tested to the extrapolated requirements of BS4486 and independently approved to be in compliance.

The Macalloy 1030 Post Tensioning (PT) system has been tested to and complies with ETAG 013, European Technical Approval of Post Tensioning Kits for Prestressing of Structures (commonly called Post Tensioning Systems) for fully threaded and end threaded bar systems, in diameters 25, 26.5, 32, 36, 40 and 50 mm. (Note: 50mm nominal bar diameter system has been tested end threaded only).

A prerequisite of ETAG013 compliance, is that the bar element complies with the preliminary European Standard prEN 10138. The current European Standard Eurocode 2: Design of concrete structures BS EN 1992-1-1:2004 also makes reference to prEN 10138. However, prEN 10138 by its very nature may be subject to changes. In the UK the structural use of concrete is covered by BS 8110-1:1997.

The data contained within this document is in accordance with Macalloy's own recommendations and product data, BS4486: 1980, BS8110: 1997 and ETA013. Where there is a conflict between the recommendations of BS8110 and ETAG013, data in accordance with ETA013 has been given.

All bar diameters are offered smooth with threaded ends or fully threaded. Bars can be supplied from stock in lengths up to 11.8m. The 75 mm diameter bar can be supplied in lengths up to 8.4 m.

The bar thread form is of a course pitch and is cold rolled.

Bars can be connected with couplers or anchored using nuts.

The standard range of bars and the related characteristic failing load and design forces are given in Table 1 - DESIGN DATA.

BS8110 and BS5400 state that at load transfer, the initial prestress force should not normally exceed 70% of the characteristic strength of the tendon.

Table 1 - DESIGN DATA

Diameter mm	25	26.5	32	36	40	50	75
Characteristic Failing Load kN	506	569	828	1049	1295	2022	4310
Prestress Load (at 70% of Characteristic Failing Load KN)	354	398	580	734	906	1415	3017

If necessary please make reference to the Macalloy 1030 Post Tensioning System brochure for minimum 0.1% proof loads, nominal cross sectional area, mass and maximum major thread diameter for each bar diameter. The brochure also details the full mechanical properties of the material.

The following sections detail factors that must be considered in the design and detailing of a structure.

2. LOSS OF PRESTRESS

The effective prestressing force in service is often less than the force applied by the jack. The various sources of loss are as follows:

(1) Relaxation of the steel.

(2) Elastic deformation of the concrete.

(3) Concrete shrinkage.

(4) Concrete creep.

(5) Loss at the anchorage on transfer of load from the jack.

(6) Friction in the jacks.

(7) Friction in the anchorage.

(8) Friction due to wobble (unintentional variation in profile) of the duct.

(9) Friction due to curvature of the tendon profile.

2.1 RELAXATION OF THE STEEL

BS4486 specifies a maximum relaxation at 1000 hours for initial loads of 60%, 70% and 80% of the characteristic failure load. For a load of 70%, the requirement is for maximum of 3.5% relaxation. Macalloy 1030 bars perform comfortably within this requirement, with typical values less than 3%. A typical relaxation curve is shown below:

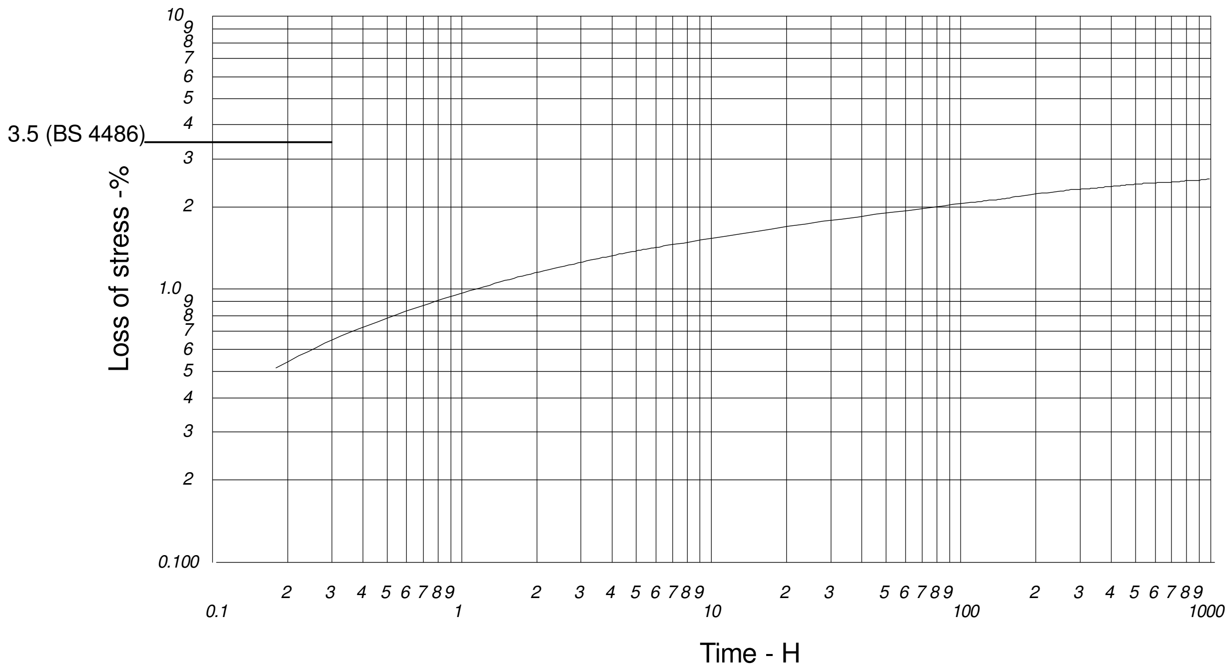


Figure 1 - TYPICAL STRESS RELAXATION CURVE FOR 40MM DIA BAR AT 70% UTS

Data for stress relaxation at 60% and 80% of the characteristic failure load is available upon request.

2.2 ELASTIC DEFORMATION OF THE CONCRETE

There is no loss of force in a tendon due to elastic deformation of the concrete when that particular tendon is being stressed, as the 'shortening' of the concrete is included in the travel of the jack ram and subsequent bar extension after lock off.

When several tendons are stressed in succession, there can be a progressive loss of prestress. This can be calculated on the basis of half the product of the modular ratio and the stress in the concrete adjacent to the tendons averaged along their length. Alternatively, the loss of prestress may be exactly computed on the basis of the sequence of tensioning. It is usually sufficiently accurate to assume that the tendons are located at their centroid.

For most applications, it is sufficient to calculate the total movement of the jack ram, ie. the sum of the theoretical bar extension and the concrete 'shortening', based on the full prestressing force. For multiple tendons in close proximity, this may result in a force in the bars slightly greater than the design value, when the 'concrete shortening' is based on full load in all tendons. However, the force in the first tendons to be stresses will falling to the design value as subsequent bars are stressed.

2.3 SHRINKAGE OF THE CONCTETE

The loss of prestress in the tendon is obtained from the product of the concrete shrinkage per unit length of the concrete and the modulus of elasticity of the tendon.

In the UK shrinkage strain values of 100×10^{-6} for outdoors and 300×10^{-6} for indoors may generally be used.

2.4 CONCRETE CREEP

The loss of prestress in the tendon as a result of concrete creep is the product of the creep per unit length of the concrete and the modulus of elasticity of the tendon. The creep per unit length, per unit applied stress, may be obtained by dividing the creep coefficient by the modulus of elasticity of the concrete at transfer. For UK outdoor conditions creep coefficients of 1.8, for transfer within 3 days and 1.4 for transfer after 28 days may be used. The stress in the concrete should be taken as the value immediately after load transfer.

2.5 LOSS AT THE ANCHORAGE ON TRANSFER OF LOAD FROM THE JACK

Any loss of stress at the anchorage on transfer of load from the jack to the nut is due to dirt or angularity between the bearing faces of the plate, washer and nut, to the take up of the thread tolerances between the bar thread and the nut and to the deformation of the bearing surfaces under load. The loss of stress, as a result of losses due to load transfer (lock off losses) is proportional to the tendon length. The greater the tendon length, the more it will stretch under load and therefore any given lock of loss will result in a proportionally smaller loss of load.

Lock off losses can be minimises by ensuring that the bearing surfaces between nut washer, bearing plate and concrete / grout are smooth, clean and parallel. Cycling the applied load several times from zero to full load to ensure that all bearing surfaces are bedded down will also help to minimise the lock off losses before finally releasing the jack. For single or multiple load cycling, the resultant lock off losses can be assumed to be as below:

Table 2 – LOCK OFF LOSES AFTER LOAD CYCLING

Dar Diameter (mm)	Single stressing	Two or more stressing cycles
25 – 36 inclusive	1.5mm	0.6mm
40 – 75 inclusive	2.0mm	0.7mm

Lock off losses can be reduced further by inducing a torque to the nut prior to the release of the jack and transfer of load.

2.6 FRICTION IN THE JACKS

All jacks supplied by Macalloy are calibrated against a master gauge before despatch and the loads exerted by the ram are tabulated against the pressure gauge readings. Any friction on the jack is therefore allowed for if the calibration readings are used to control the applied load.

Electrical or mechanical load cells are available for the recalibration of jacks and gauges on site, or to control loading with greater accuracy than that provided by commercial pressure gauges.

Loads calculated from pressure gauge readings based on the jacks ram areas do not include an allowance for friction in the jack. Values should be obtained be obtained from the jack supplier.

2.7 FRICTION IN THE ANCHORAGE

There is no friction loss in single bar anchorages.

2.8 FRICTION DUE TO VARIATIONS IN THE DUCT PROFILE OR WOBBLE OF THE DUCT

Friction of the bar relative to the duct due to unintentional variations in the profile or wobble of the duct relative to the bar may occur. These losses can be calculated in accordance with:

(a) BS8110 Part 1: 1997, as stated below.

The prestressing force P_x at any distance *x* from the jack may be calculated from

$$P_x = P_o e^{-kx}$$

where:

P_o is the prestressing force in the bar at the jacking end.

e is the base of Naperian logarithms = 2.718

K is a constant depending on the type of duct or sheath employed, the nature and condition of the inside surface and the degree of vibration employed in placing the concrete.

The value of *K* per metre length for Macalloy bars in closely supported strong rigid sheaths or ducts may be taken as 12 x 10^{-4} . Otherwise, a value not less than 33 x 10^{-4} should be used.

(b) Eurocode 2, EN 1992-1-1: 2004, as described below.

$$\Delta P_{\mu}(x) = P_{\max}(1 - e^{-\mu(\theta + kx)})$$

where:

$\Delta P_{\mu}(x)$ (kN)	is the loss of load due to friction at distance x from the anchorage.
$P_{\max}$ (kN)	is the prestressing force immediately after the anchorage (ie at diatance x=0).
μ	is the coefficient of friction between bar and duct. μ = 0.33 for smooth bars (unthreaded). μ = 0.65 for fully threaded bars.
θ (rad)	is the sum of angular displacements over a distance x (irrespective of direction or sign).
k (rad/m)	is the unintentional angular displacement per unit length. The value of *k* is greater than 0.005 and less than 0.01.
x (m)	is the distance along the tendon from where the prestressing force is at a maximum (ie distance from P_o).

2.9 FRICTION DUE TO CURVATURE OF THE TENDON PROFILE

Macalloy 1030 bars are designed to be used as straight bars / tendons. There is therefore no friction loss due to curvature of the tendon profile, when the tendon is placed straight. Unintentional variations in the tendon profile can be assumed to be in the range 0.005 to 0.01 radians per metre. Losses as a result of unintentional variations in the tendon profile can be calculated as above.

3. TENDON AND ANCHORAGE ARRANGEMENT

In all prestressed members, there should be sufficient gaps between the tendons or groups of tendons to allow the largest size of aggregate used to move, under vibration, to all parts of the mould.

For tendons in ducts, the clear distance between ducts and other tendons should not be less than the following, whichever is the greatest:

(a) h_{agg} + 5 mm, where h_{agg} is the nominal maximum size of the course aggregate (in mm).
(b) In the vertical direction, the vertical internal dimension of the duct.
(c) In the horizontal direction, the horizontal internal dimension of the duct; where internal vibrations are used, sufficient space should be provided between ducts to enable the vibrator to be inserted.

Where two or more rows of ducts are used, the horizontal gaps between the ducts should be vertically in line whenever possible, for ease of construction.

For single tendons (ie single bars within a duct with one single end bearing plate per bar), the recommended duct and end plate sizes are shown in Table . To suit particular requirements, the dimensions can be varied provided that concrete cover, load transfer and stress conditions are satisfactory.

Table 3 - DUCT AND END PLATE SIZES

Tendon Diameter	25	26.5	32	36	40	50	75
Recommended Duct Inside Diameter around Bar	38	40	48	54	60	75	109
End plate length	100	110	125	140	160	200	300
End plate width	100	110	125	140	160	200	300
End plate thickness	40	40	50	50	60	60	75

All dimensions in mm

The above recommended duct inside diameter dimensions are based on a tendon to duct area ratio of 0.4 to 0.45 as specified in The Concrete Society Technical Report 47.

Example – 36mm bar:
$\sqrt{(36^2 / 0.45)}$ = 53.66mm therefore 54mm

For short tendons the duct inside diameter can be decreased provided that grouting trials show that the duct can be satisfactorily grouted. Larger diameter ducts will be required locally around couplers.

For further information on ducts, please make reference to the document ‘Site Practice Guidance Notes for Macalloy 1030 Post Tensioning Bar System’.

For single tendons (ie single bars within a duct with one single end bearing plate per bar), the suggested minimum edge distances and spacings of tendons are set out in Figure 2.

Figure 2 - TENDON SPACING (SINGLE TENDONS)

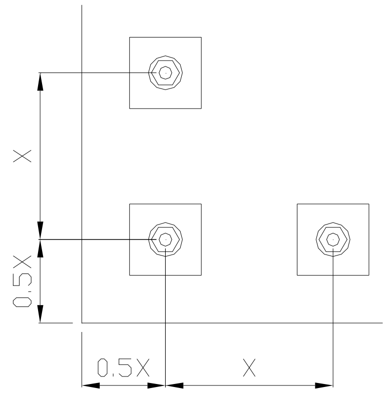


Table 4 – TENDON SPACING AND EDGE DISTANCE (SINGLE TENDONS)

Nominal Bar Diameter (mm)	X (mm)
25	220
26.5	230
32	240
36	260
40	290
50	355
75	515

Notes:

1. The above Figure 2 and Table 4 data is suitable for single bar tendons with reinforcement as per Section 4, Table 6.
2. If required, it may be modified in accordance with national regulations and relevant approval of the local authority to provide equivalent performance. For example, larger bearing plates could be used to accommodate more that one bar tendon.

4. ANCHORAGE ZONE REINFORCEMENT

Bursting tensile forces are induced in the concrete immediately behind the anchorage end plates due to the compressive load applied through the end plates. Reinforcement in the form of links, helices or a combination of these may be required to adequately resist these forces. When designing the end blocks, consideration should be given to (a) bursting forces around individual anchorages, (b) the overall equilibrium of the end block, (c) spalling of the concrete from the loaded face around anchorages.

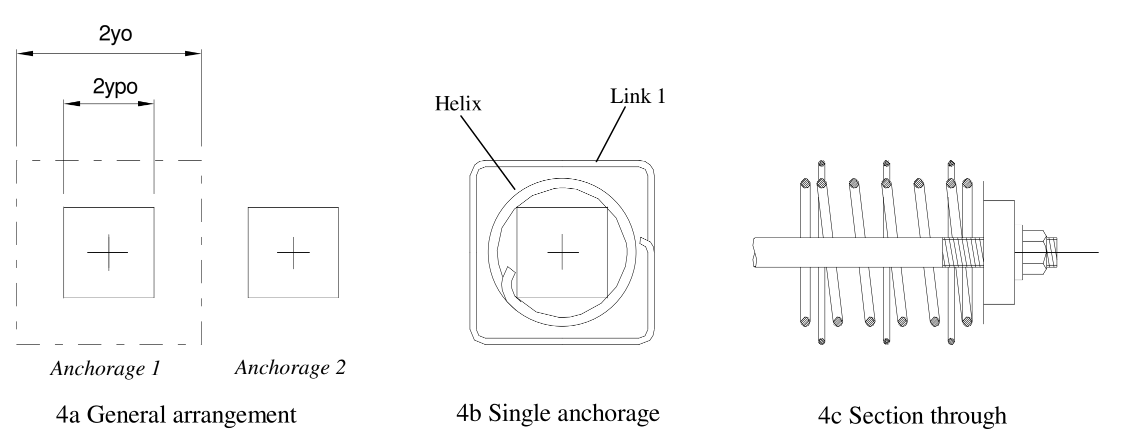
The design of the anchorage reinforcement is covered by Section 4.11 of BS8110 and described in greater detail by CIRIA GUIDE 1- June 1976. The bursting tensile force F_{bst} in an individual end block loaded by a symmetrically placed end plate may be calculated from Table 5 where:

$2yo$	is the side of the end block
$2ypo$	is the side of the end plate
P_k	is the tendon jacking load

Table 5 - BURSTING TENSILE FORCE

$\frac{ypo}{yo}$	0.2	0.3	0.4	0.5	0.6	0.7
$\frac{F_{bst}}{P_k}$	0.23	0.23	0.20	0.17	0.14	0.11

Figure 3 - ANCHORAGE ZONE REINFORCEMENT



The force F_{bst} will be distributed in the zone extending from $0.2yo$ to $2yo$ from the loaded face of the end block and should be resisted by the reinforcement, which should be uniformly distributed throughout this region and acting at a stress of 200 N/mm^2.

Helical and link reinforcement which is adequate for use with a standard Macalloy end plate and in compliance with Etag 013, is detailed in Figure 4 and Table 6 – Anchor Zone Reinforcement.

Figure 4 – ANCHORAGE ZONE REINFORCEMENT

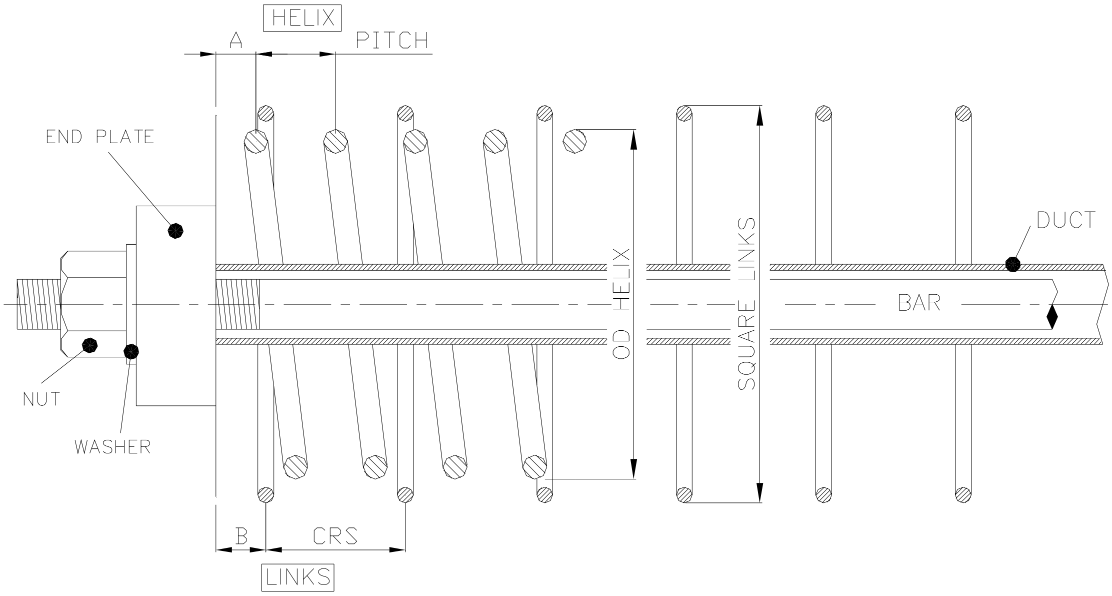


Table 6 - ANCHORAGE ZONE REINFORCEMENT

(Helix And Links Used Together - See Figure 4)

Nominal Bar Diameter (mm)	Helix Shape code 77 to BS EN ISO 3766: 2003 or BS8666: 2005					Links Shape code 51 to BS EN ISO 3766: 2003 or BS8666: 2005, where length A=B				
	Bar Dia (mm)	A (mm)	Pitch (mm)	OD (mm)	Turns	Bar Dia (mm)	B (mm)	CRS (mm)	SQUARE (mm)	No.
25	12	20	40	175	4	8	25	70	199	6
26.5	12	20	40	180	4	8	25	70	205	6
32	12	20	40	190	5	8	30	70	216	7
36	12	20	40	210	6	8	30	70	235	7
40	12	20	40	240	7	10	35	75	265	8
50	12	20	40	300	8	12	40	80	330	9
75	16	30	50	450	8	16	50	100	490	10

Note :

All reinforcement to BS EN 100890: 2005, Grade 460 to BS4449: 1997 or Grade 500 to BS449: 2005.

A longitudinal length of rod may be used to attach the links together, but it is not required as part of the reinforcement.

The above reinforcement may be modified in accordance with national regulations and relevant approval of the local authority to provide equivalent performance.

5 CALCULATION OF BAR AND THREAD LENGTHS

5.1 BAR LENGTHS

Calculation of the overall length of bar is by measurement along the tendon profile and adding the thickness of both end plates plus an allowance for the nuts, washers and attaching the prestressing jack at one or both ends of the bar. Table 7 provides details of all necessary allowances.

Figure 5 - BAR LENGTH CALCULATION

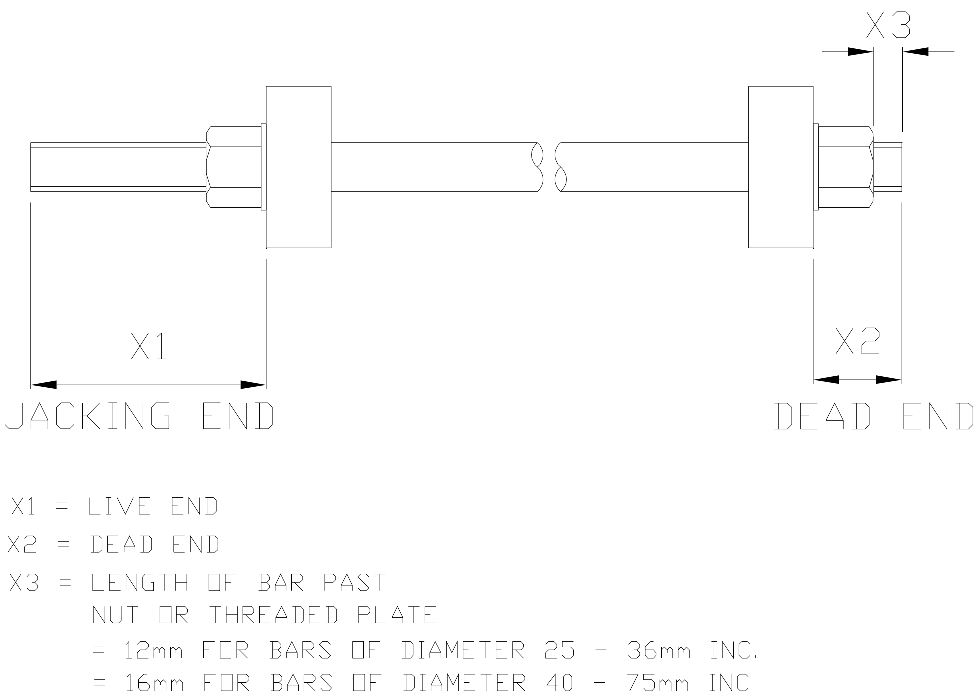


Table 7 - JACKING ALLOWANCE

Tendon	25	26.5	32	36	40	50	75
X1 (mm)	82	91	105	115	130	165	235
X2 (mm)	49	53	57	62	71	91	116
X3 (mm)	12	12	12	12	16	16	16

5.2 THREAD LENGTHS

The thread length at a jacking end must allow for attaching the jack plus elongation of the bar under the prestress load.

Standard thread lengths for jacking ends, dead ends and coupled joints are listed in Table 8. Longer thread lengths may be required for long tendons. The required thread length will be partially dependent on the amount the bar, stretches and the amount the concrete compresses under the jacking load – see Sections 2 and 6.

Table 8 - STANDARD THREAD LENGTHS

Bar dia mm	25	26.5	32	36	40	50	75
Jacking End mm	250	250	250	250	250	250	350
Dead End mm	100	100	100	100	100	100	150
Coupled Joint mm	45	50	60	65	75	85	150

Alternatively, the manufacturing details may be stated as follows:

"*x*" No. of Macalloy bars "*d* " diameter x "*l* " overall length with end threads of length *S1* and *S2*.

6. CALCULATION OF TENDON EXTENSION

Assuming the bar extension is measured relative to the end plate then the extension measured during jacking is the sum of the elongation of the bar and the shortening of the concrete under load. The total extension is given by the following formula

$$\text{Elongation} = L\left[\frac{f_s}{E_s} + \frac{f_c}{E_c}\right]$$

where L is the stressed length of the bar

f_s is the steel stress based on actual bar area

f_c is the average concrete stress along the line of the bar

E_s is the modulus of elasticity of the steel at the applied stress

E_c is the modulus of elasticity of the concrete at the time of stressing.

For usual stress conditions:

E_s = 170 kN/mm^2 (approximately) for 25-50 mm bars and 205 kN/mm^2 (approximately) for 75 mm bars. Measurements of E_s are obtained during routine tensile testing and the value appropriate to the Macalloy bars supplied on any particular consignment can be supplied upon request at time of order.

E_c = 30 kN/mm^2

As an approximate guide, the extension of a bar (25 - 50mm) stressed to 70% of the ultimate stress will be $\frac{L}{220}$ mm approximately when L is given in millimetres.

7. STRESSING RECORD

It is useful to set out a project data and stressing sheet as a means of producing a permanent record of the work carried out. A suggested data and stressing record sheet can be found in the document 'Site Practice Guidance Notes for Macalloy 1030 Post Tensioning Bar System'.

8. TORQUE LOADING

Macalloy and other threaded bars are also used for applications where the load required is small and does not need to be measured accurately, e.g. temporary works or to induce a small compressive stress to control cracking of new concrete.

For these applications, it is possible to develop a load in a Macalloy bar up to approximately 25% of the characteristic failure load by applying a pre-determined torque to the nut. Torque wrenches are available which have a dial indicating the torque value, or which can be preset to 'slip' or 'break' at a specified torque value.

The axial tension induced by a given torque depends upon the diameter and pitch of the threads, and upon the friction within the threads and between nut, washer and end plate. Accuracy of the tensile force cannot be expected to be more than ±20%.

The formula for calculation the approximate resultant load in a Macalloy 1030 bar when a torque is applied to a nut bearing onto a standard washer, is as follows:

$$\text{Torque} = \frac{PD}{K_t}\ \text{Nm}$$

Where P is the desired axial force in kN
D is the nominal bar diameter in mm
K_t is constant measured by test

Table 9 - - K_t VALUES FOR MACALLOY COARSE THREADS

BAR DIAMETER	K_t
25	4.1
26.5	4.3
32	4.7
36	4.9
40	4.5
50	4.1

9. MISCELLANEOUS DATA

9.1 MODULUS OF ELASTICITY

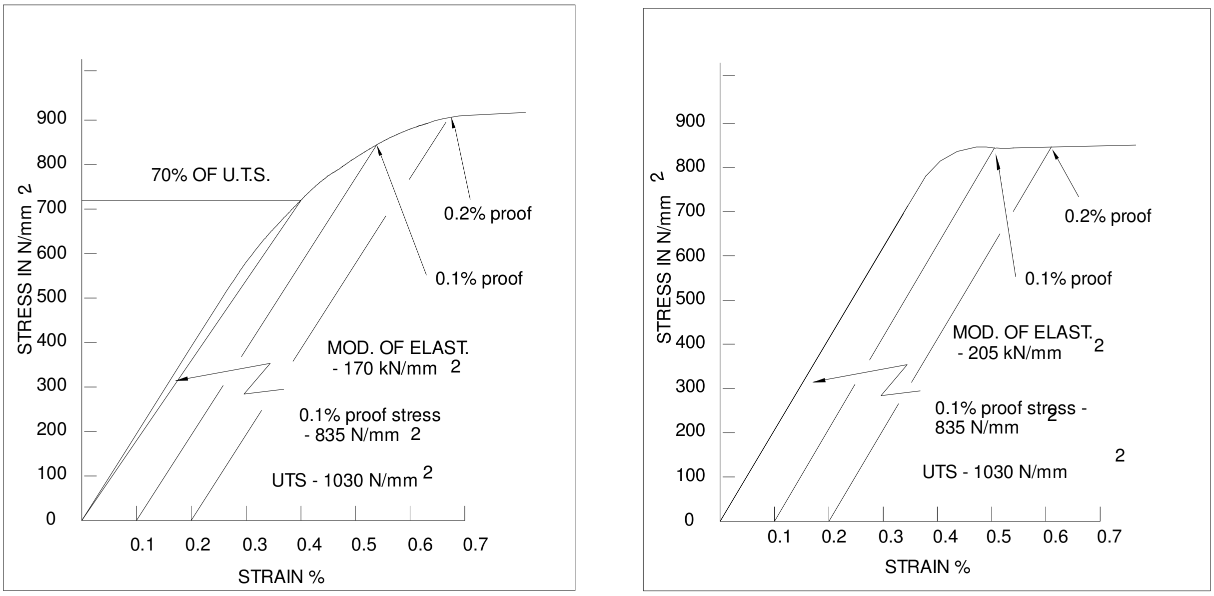
Macalloy bars of 25 mm to 50 mm diameter are cold worked by stretching to a load of approximately 90% of the ultimate tensile strength. After processing, there is no discernible yield point in a tensile test (see Fig 6i). The stress necessary to produce a strain of 0.1% (0.1% proof stress), is taken as an alternative to the yield stress. In a post tensioned concrete application, it is usual to stress the bar to achieve 70% UTS at transfer of load. The Modulus of Elasticity figures that are generally quoted are therefore secant values, calculated between 50 N/mm² (approximately 5% UTS) and 720 N/mm² (approximately 70% of UTS). The average value is 170 kN/mm². The precise value can be supplied at time of despatch, if requested at time of order.

Modulus of Elasticity figures for the straight line portion of the stress strain graph (elastic range) are typically 12 kN/mm² higher than secant Modulus values. The precise value can be supplied at time of despatch, if requested at time of order.

75 mm diameter bars are processed by quenching and tempering the steel to achieve the desired properties. The Modulus of Elasticity value is typically 205 kN/mm². Note that the bar is still within its purely elastic range at 70% UTS. See Fig 6ii.

When the Modulus of Elasticity is calculated it is done so on plain, unthreaded bars. The effect of the bedding of components may contribute to the perceived bar stretch under load. However, this bedding movement is relatively small and can be significantly reduced (often to less than 0.5mm) by cycling the stressing operation (see Section 2.5).

Routine testing for all mechanical properties is carried out on every 5 tonne batch of steel.



(i) 40 mm Macalloy bar (typical of 25-50 mm bar) (ii) 75mm Macalloy bar

Figure 6 - TYPICAL STRESS/STRAIN CURVES FOR MACALLOY 1030 BAR

9.2 FATIGUE RESISTANCE

In accordance with ETAG 013 Macalloy 1030 tendons have a fatigue performance in excess of 2 million load cycles when loaded to an upper limit of 65% UTS and amplitude of 80 N/mm².

9.3 TOUGHNESS

Charpy “V” notch impact results at 20^o Centigrade are typically 5 Joules for Cold worked steels (25-50mm dia) and 18 Joules for Quenched and tempered steels (75mm dia).

Transverse impact tests on full section un-notched cold worked bars (25-50mm diameter), show excellent impact resistance down to -115°C. In the tests, the bars behaved in a ductile manor, exhibiting considerable bending with no surface cracking.

See also section 9.9.

9.4 EFFECT OF TEMPERATURE CHANGE

The coefficient of linear expansion of Macalloy steel is 11 x 10^{-6} per 1 degree Centigrade.

9.5 ELECTRICAL RESISTIVITY

Table gives the values of electrical resistivity at various temperatures measured on the Absolute (Kelvin) scale.

Table 10 - ELECTRICAL RESISTIVITY

TEMPERATURE ^{o}K	RESISTIVITY ohm/m
273.2	17
373.2	23.2
573.2	39.8
973.2	93.5

9.6 TRANSVERSE STRESSES

Poisson’s ratio for Macalloy steel is 0.29.

9.7 CUTTING OFF EXCESS BAR THREAD

Excess bar thread may be cut off after stressing by sawing or disc cutting.

When disc cutting, a liberal supply of water is needed over the bar during the operation to limit the heat developed and surrounding bars should be protected from sparks or spatter.

Flame cutting is not recommended as the heat generated can affect the properties of the bar. If a bar is flame cut, extreme caution should be used in order to prevent permanently effecting the properties of the bar or tendon. An asbestos shield must be provided over the nut, and the cut must not take longer than 10 seconds. Bars must not be cut closer than 120 mm to the nut, and adjoining bars must be protected from the effects of heat.

9.8 SHEAR STRENGTH and SHEAR CAPACITY

Where Macalloy is subject to shear loads, an *approximation* of the shear strength of the steel can be assumed to be half its tensile stress, i.e.

Yield = 50% of 835N/mm^2 = 417 N/mm^2
Ultimate = 50% of 1030N/mm^2 = 515 N/mm^2

Alternatively the following formula can be used:

Shear Capacity $Pv = 0.6Py \times Av$ kN

Where:-
Py is the design strength of the steel in N/mm^2
Av is the Shear Area in mm^2

For Solid bars Av = 0.9 x CSA of bar where shear is applied

Combined shear and tension should be checked using an appropriate formula with the above values used as the shear strength.

9.9 MACALLOY AT CRYOGENIC TEMPERATURES

Test data is available for the Macalloy bar at temperatures down to -196^{o}C. This shows that its strength increases by 17% between room temperature and -100 ^{o}C, but thereafter it declines slightly to give a residual increase of 11% at -196 ^{o}C. The results for elongation and reduction of area show a sharp drop at around -75 ^{o}C; this corresponds with a change in the nature of the fracture from partially brittle to wholly brittle at this temperature.

Charpy impact tests average 4J at -160 ^{o}C compared to 5J at ambient temperature.

9.10 WELDING

Macalloy prestressing bar must not be welded, subjected to high local heating or splashed with weld metal.