The Foundation
Anchor Solution for Wind Turbines

The Macalloy Bar
Advantages of the Macalloy Bar over an 8.8 anchor bolt

**SAVE TIME & MONEY**
- Reduced number of bars and/or smaller bar diameter required
- Reduced on-site installation and stressing time
- Reduced fabrication time on flange plates
- Larger spacing between bars facilitate cable entry
- Reduced maintenance due to greater stressing loads and low relaxation

**IMPROVED PERFORMANCE**
- Better fatigue & strength
- Higher detail category Kerbgruppe 80
- Higher load-bearing capacity
- CE Approval
- Independently tested to DIN EN 1993-1-9:2010-12
- Factory installed solution
- Less susceptible to damage from water ingress
- No need for a duct and grout
- Less susceptible to damage during installation

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Up to 35% savings in material and cost

Independent research comparing the use of Macalloy bar with 8.8 bolts for wind turbine foundations has proven the use of Macalloy bars can achieve up to 35% savings in both material and cost. The wind turbine foundation design group; Professor Bellmer Ingenieurgruppe, compared the required number and diameter of Macalloy bolts against 8.8 bolts. Two projects were compared to calculate the data, with actual measurements and loads used. The tables below demonstrate Macalloy bar can be used as a direct replacement for the Grade 8.8 bolt giving up to a 35% material saving.

Example 1 – 35% materials saving compared to the 8.8 bolt
Calculations for a 3.0 MW Turbine with 100 metre high tower – 4.66 metre diameter at the base

<table>
<thead>
<tr>
<th>Bolt Type</th>
<th>Thread</th>
<th>Bar Ø</th>
<th>Quantity</th>
<th>Length (m)</th>
<th>Weight (kg)</th>
<th>Stressing capacity (kN) per bolt</th>
<th>Total compressive load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 8.8 Bolt</td>
<td>M48</td>
<td>45</td>
<td>136</td>
<td>6.20</td>
<td>10,500</td>
<td>615</td>
<td>89,440</td>
</tr>
<tr>
<td>Macalloy Bar</td>
<td>FT40</td>
<td>40</td>
<td>104</td>
<td>6.20</td>
<td>6,700</td>
<td>840</td>
<td>89,440</td>
</tr>
</tbody>
</table>

Example 2 – 30% materials saving compared to the 8.8 bolt
Calculations for a 2.7 MW Turbine with 100 metre high tower - 3.99 metre diameter at the base.

<table>
<thead>
<tr>
<th>Bolt Type</th>
<th>Thread</th>
<th>Bar Ø</th>
<th>Quantity</th>
<th>Length (m)</th>
<th>Weight (kg)</th>
<th>Stressing capacity (kN) per bolt</th>
<th>Total compressive load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 8.8 Bolt</td>
<td>M45</td>
<td>42</td>
<td>164</td>
<td>3.50</td>
<td>6,400</td>
<td>615</td>
<td>100,800</td>
</tr>
<tr>
<td>Macalloy Bar</td>
<td>FT40</td>
<td>40</td>
<td>120</td>
<td>3.50</td>
<td>4,400</td>
<td>840</td>
<td>100,800</td>
</tr>
</tbody>
</table>

Fatigue strength of Macalloy Bar
To demonstrate its outstanding qualities, the Macalloy Bar has undergone extensive fatigue resistance testing by the Technical University of Munich, at stress ranges much higher than those given in the ETA post-tensioning guidelines. The tests showed that the Macalloy Bar has a fatigue detail category of 80, a number significantly higher than 8.8 bolts.

Full details of the fatigue testing are available upon request.

Save time & money on-site too!
- Using less bars reduces on-site installation time and stressing time (up to 25 percent!)
- Using less bars helps facilitate cable entry to the cage
Superior fatigue performance

The fatigue strength of the Macalloy Bar system has been independently assessed by Prof Dr.-Ing Martin Mensinger of Büchting + Streit B+S Beratende Ingenieure VBI. The full report can be viewed on request.

The fatigue strength of post tensioning bars under dynamic loading is mainly influenced by the profile of the thread. The Macalloy Bar has a unique fatigue resistance thread form. Dynamic tension tests on 24 nut-thread connections have been conducted.

The resulting SN-Curve (Wöhler curve) is given below. The fatigue stress range achieved at 2 million cycles is 84 MPa. In case of centric loading the components can therefore be classed into detail category 80.

If the post tensioning bars are subjected to tension forces and bending moments, as is the case in ring flange joints of a wind turbine, then a lower detail category should be considered. With grade 8.8/10.9 bolts a blanket reduction is applied which reduces their detail category from 50 to 36. By applying the same principal, it is reasonable and consistent with current practice to reduce the detail category for the Macalloy Bar from 80 to 56.

The higher detail category of the Macalloy Bar in itself is an advantage over the traditional 8.8/10.9 grade bolts. When coupled with the higher capacity for reduced bar diameters it offers a huge improvement over current practices.

Graph 1 - Macalloy Bar SN Curve
The Macalloy thread

The Macalloy Bar has a unique rolled thread. The Macalloy thread has unique twin peaks which provides an improved fatigue performance compared with standard metric threads.

In rolling the Macalloy thread the grain structure of the material is aligned with the peaks and troughs of the thread, providing a smooth running thread form. As the threading operation is a cold working operation, it results in a local increase of the tensile properties to the surface of the bar.

With a cut metric thread material is removed, creating dislocations within the grain structure. These dislocations are potential areas of crack propagation. It has been proved via extensive testing that a Macalloy rolled thread, with its smooth thread form and increased strength, results in improved fatigue performance.

Low Lock Off Losses and Bar Relaxation

The Macalloy thread helps the bar achieve low lock off losses and relaxation properties. Lock off losses are typically less than 0.7mm after two stressing cycles. The Macalloy bar has been independently tested against European regulations for post-tensioning bar and achieves well under the maximum 3.5% relaxation under a 70% load.

Approvals

Quality Approvals

Macalloy operates a quality assurance system complying with the provisions of BS EN ISO 9001:2008. The Macalloy system has been ETA approved by the UK Certification Authority for Reinforcing Steels (CARES), as well as having approvals to the National Standards in both Germany and France.

More recently, the Macalloy system has been approved by Germanischer Lloyd (GL) under the requirements of the “Guideline for the Certification of Wind Turbines.”

Copies of the ETA approval for the Macalloy 1030 Post Tensioning System, the EC-Certificate of Conformity and the GL Letter of Conformity are available on request.
Steel Quality
The Macalloy Bar is a carbon-chrome steel with a composition designed to give the desired specified properties. All bars are hot rolled. Diameters from 25mm to 40mm are further cold worked by stretching. The stretching load and permanent elongation are predetermined by preliminary tests and the properties are monitored carefully during production to ensure that the bars comply with all the quality standards.

Bars of 50mm and 75mm diameter are heat treated after initial rolling at a controlled temperature to ensure that the steel achieves the mechanical properties stated in table 3. Rigorous inspection and testing is carried out, both during and after treatment, to ensure consistent tensile properties. The mechanical performance of the bar is monitored through the tensile testing of machined specimens rather than section testing.

Strength
The specified characteristic failing loads and 0.1% proof loads for the Macalloy Bar and the stainless Macalloy Bar are given in table 4.
Denso Corrosion Protection

**Denso Tape**
Denso Tape is a grease impregnated synthetic tape and can be supplied pre-applied to the Macalloy bar. The grease is transferred to the bar and kept in place by the tape. The grease provides protection from water based corrosion and the system is guaranteed for 60 years. The bar can still move and stretch within the tape allowing for onsite stressing to take place even though the solution is factory applied.

**Less Susceptible to Damage**
The Denso Tape solution is less susceptible to fatal damage than duct and grout systems. Light damage during installation does not require repatriation as the greased bar retains its corrosion protection properties.

**Reduce Installation Time and On-site Errors**
The Denso tape solution significantly reduces installation time compared to a standard duct and grout system. As the tape is pre-applied there is no need for separate installation of bar, duct and grouting after stressing and less chance of onsite errors taking place.

**Why Choose Macalloy?**

- Up to 35% in material savings
- Independently tested and approved system
- Reduced on-site installation and stressing time
- Higher load-bearing capacity
- Significantly improved fatigue strength
- Factory installed Denso Tape corrosion protection
- Larger spacing between bars facilitates cable entry

EXPERIENCE   INNOVATION   QUALITY
Wind Farm Applications

Uljabuouda - Sweden
The wind farm at Uljabuouda in Sweden consists of a total of 10 3MW WinWinD turbines. Macalloy 40mm bars were installed as part of the foundation system. 136 bars at approximately 2.6 metres long were supplied to each wind turbine, using Denso/PVC tape for corrosion protection.

Sodra Karra and Blekhem
Sodra Karra and Blekhem are two neighbouring wind farms, each consisting of 6 Vestas 1.8MW V100 turbines. Macalloy bars, with Denso tape protection, are used as anchor bolts for the turbines.

This publication provides the technical details currently used by Macalloy in the manufacture of its components. The company reserves the right to amend technical details as and where necessary in line with its policy of continuous development.

Macalloy, Caxton Way, Dinnington, Sheffield S25 3QE, U.K. Tel: +44 (0)1909 519200. Fax: +44 (0)1909 519201
Website: www.macalloy.com Email: sales@macalloy.com