The construction crew readied itself to start the day. This morning, the first of March 2013, they would proceed with a final bolt tightening operation, just as they had hundreds of times before. This job wasn't really any different from others, they were tasked with tensioning 96 three-inch diameter, high strength ASTM A354 Grade BD Anchor Bolts to 69% of their Ultimate Tensile Strength. The tightening was being done on several key seismic structures designed into the newly constructed east span of the San Francisco-Oakland Bay Bridge. Everything went well and when they completed this task, they moved onto the next one.

Tensioning large threaded components like these is not as simple a task as throwing a torque wrench onto the nut and turning it until the correct torque is achieved. No, this process is a little more complicated and usually involves a post tensioning inspection to assure that everything is alright and to adjust for any short-term relaxation or tension loss. For this reason a post-assembly inspection was scheduled a week later on March 8th. Inspectors were horrified to find a couple of the Anchor Bolts fractured and broken at the head way down in the concrete. Over the course of the next seven days, additional failures would occur until nearly one-third of the installed Anchor Bolts would fail.

Subsequent forensic analysis of the failure would expose a material that was extremely susceptible to hydrogen embrittlement. When paired with the high tension loads the Anchor Bolts were placed under and exposure to hydrogen from on-going corrosion, these Anchor Bolts were destined to fail from hydrogen embrittlement.

Anchor Bolts and Rods

This makes a very interesting and compelling story all on its own, but this article is not intended to be about fastener failures from hydrogen embrittlement. Instead it is an example of how rarely thought of and humble fastener was propelled into the spot light. For many Californians, Anchor Bolts and fasteners became, for a time, an everyday conversation topic and gave Anchor Bolts some notoriety and importance that they failed to enjoy before this event.

In this article, we will investigate the basics of Anchor Bolts and All-threaded Rod that are used as anchors. We will explore how a product that usually doesn't garner much attention by anyone, is really an important and sophisticated engineered component.

All-Threaded Rod

When a metal rod or bar is continuously threaded over its entire length, it is known as "all-threaded rod" or sometimes as "threaded bar". When the length is relatively short or components are cut-off sections of longer threaded rod, they are referred to as "Studs". **Inch threaded rod is governed by ASME's standard B18.31.3,** "Threaded Rods – Inch Series", which was first published November 10, 2009. B18.31.3 covers threaded rod in the Unified Coarse thread series (UNC) in diameters from #4 to 4", Unified Fine thread series (UNF) in diameters from #4 to 1 ½", 8UN thread series in diameters 1 1/8" to 4" and Acme Threads in diameters from ¼" to 5". These rods usually come in standard lengths of 3, 6, 10, and 12 feet, although they can be produced in other, customized lengths.

Metric threaded rod is currently governed by DIN 976, which replaced withdrawn standard DIN 975. These all threaded rods are one meter long and made of steel or stainless steel. Diameters range from M2 to M48. For the steel options, the standard offers eight different Property Classes (strengths), 4.8, 5.6, 5.8, 6.8, 8.8, 9.8, 10.9, and 12.9. In Stainless Steel they are available in both A2 (UNS 30400) and A4 (UNS 31600) options.

Although almost all standardized threaded products, both inch and metric, are released with a standard Class 2A thread fit, both UNC and UNF all-threaded rod is an exception, specified with a Class 1A thread fit before plating. The 8UN series is specified with the standard Class 2A thread fit. Thread inspection is to System 21 requirements, meaning that acceptance is dependent on passing a GO and NOT GO threaded Ring Gage and exhibit an in-specification Major Diameter. The ends are expected to allow the mating nut to freely assemble, so that both full length rods and smaller length cut-offs often receive a chamfer on both ends.

Dimensionally the product is not complicated. However, because there are so many potential uses and desired applications, there is a broad assortment of material and strength choices.

- **Low Carbon Steel per ASTM A307 Grade A**- This is perhaps the most common material choice and designates a low carbon steel possessing a minimum tensile strength of 60 ksi.
- **Grade 36** – This designates low carbon steel meeting all the requirements for ASTM F1554 Grade 36. A common error is to indicate that the threaded rod should meet "ASTM A36". The A36 standard is only a raw material standard, and thus, not appropriate to refer to the mechanical performance of these products.
- **Medium Carbon Alloy steel per ASTM A193/A193M Grade B7** – This designates a medium Carbon Chromium and Molybdenum alloy that possesses a minimum tensile strength between 100 ksi and 125 ksi depending on the rod diameter size.

Figure 1: Threaded Rod as Hangers

Figure 2: Epoxy Anchor

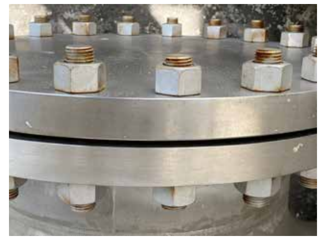

Figure 3: Studs in a Pipe Flange Connection

Figure 4: Double Arming Bolts

- **SAE J429 Grade 1 and Grade 2** – This designates low or medium Carbon steel that possesses a minimum tensile strength of between 60 ksi and 74 ksi depending on the rod diameter size.
- **ASTM A449 Type 1** – This designates plain Carbon, Carbon Boron, or alloy steels that possess minimum tensile strength of 120 ksi, 105 ksi, or 90 ksi depending on the rod diameter size.
- **ASTM F1554 Grade 105**- This designates Carbon steel that possesses tensile strength between 125 ksi and 150 ksi on rods with diameters between ½" and 3".
- **ASTM A354 Grade BC and Grade BD**- This designates alloy steel that possesses a minimum tensile strength of 125 ksi for Grade BC in diameters ¼" to 2 ½" and 115 ksi for diameters over 2 ½" and 150 ksi for Grade BD in diameters up to 4".
- **SAE J429 Grade 8** – This designates medium Carbon and alloy steels that possess a minimum tensile strength of 150 ksi in diameters up to 1 ½".
- **ASTM F593 Alloy Group 1, Condition CW** – This includes stainless steels like 304 and 302HQ.
- **ASTM F593 Alloy Group 2, Condition CW** – This designates 316 stainless steel.
- **Brass per ASTM F468** – This designates that the supplier may choose any brass or naval brass that meets the requirements given in ASTM F468.
- **Aluminum per ASTM F468** – This designates that the supplier may choose any aluminum that meets the requirements given in ASTM F468.
- **Others**- the standard is also open to include any other material specified by the purchaser.

The default finish is plain with light oil; however, the purchaser may specify electroplated zinc per ASTM F1941/F1941M or hot dip galvanize per ASTM F2329. Hot dipped galvanized rods must be processed with a galvanizer accustomed to threaded parts and is capable of spinning off the excess zinc immediately after removal from the galvanization tank. ASTM F2329 was written specifically for fasteners and should replace ASTM A153 Class C specified on products of this type. Other finishes that are permissible by the standard but get applied far less often include Xylan, Black Oxide, and Powder Coating.

Threaded rod is usually exempt from the marking requirements stipulated in the material specifications listed above unless the purchaser specifies the need to do so.

Threaded rod is manufactured in one of two ways; "cut-to-length" and "made-from-scratch".

- **Cut-to-length**: When studs or shorter rod segments are needed, they are routinely cut from longer, stock rods. This is a relatively simple process. The first step involves cutting the parts to length with a band saw. The second step is to use a cutting tool to chamfer both ends. The final process is to stamp the grade identification into the end if it is required.
- **Made-from-scratch:** When a longer rod or a non-stocked item is needed, it is usually made from scratch. This involves several additional steps from the process described immediately above. In the first step a blank is cut a little long from round bar on a band saw. In the second step the threads are created using thread chasers to cut them from full size round bar. In the third step the part is cut-off a second time. There is a small unthreaded stub that is required to hold the part during the threading process. This must be removed. Then the ends are chamfered, one end marked, and sent out for coating, if necessary.

Threaded rod has a wide assortment of different uses in construction and industrial applications. Several of the more common uses include:

- **Hangers**- Threaded rod is commonly employed as part of the hanger system for plumbing, HVAC, and electrical piping and ductwork (Figure 1). A threaded nut or coupling is installed into the ceiling or floor structure on one end and a band or connector installed on or around the item being supported on the other end with a threaded rod in-between suspending the item the proper distance off the ceiling or floor.
- **Epoxy Anchors** – Figure 2 illustrates a threaded rod or stud which is inserted into holes drilled into concrete or masonry and then back filled with epoxy to hold them securely in-place.
- **Extenders** – It is not uncommon, especially during the setting of anchor bolts for them to be set low. The easiest fix is often to extend them with a section of threaded rod. This is accomplished using a coupling nut and an appropriately sized cut-off from the threaded rod.
- **Anchor Bolts** – Threaded rod can quickly be adapted into an "Anchor Bolt". They are not as good as a headed anchor bolt, but they may be a satisfactory alternative and easy and inexpensive to fabricate. To provide the pull-out resistance of an Anchor Bolt when embedded into concrete, the embedded end will receive a nut or nut and washer that have been tack welded into place.
- **Pipe Flange Bolts**- Studs cut from longer threaded rod are commonly utilized on pipe flanges (Figure 3). These usually are manufactured to ASTM A193/A193M Grade B7 or sometimes ASTM A307 Grade b.
- **Double Arming Bolts** – Threaded rod is used in conjunction with four nuts to secure the cross arm on each side of a wooden utility pole (Figure 4).

Anchor Bolts

Anchor Bolts, also known as Anchor Rods, serve as anchoring points for structural members, columns, equipment, and any number of items that need anchoring. Although threaded rod can be used for these purposes, Anchor Bolts are specifically designed for the job. Anchor Bolts are defined as, "… partially or fully threaded, one end of which is intended to be cast in concrete while the opposite end projects from the concrete, for anchoring other material. The end cast in concrete may be either straight or provided with an uplift-resisting feature such as a bent hook, forged head, or a tapped or welded attachment."

Anchor Bolts are governed by ASTM F1554. This standard covers straight, bent, headed, and headless anchor bolts. It does not cover mechanical expansion anchors, powder activated nails, and anchor bolts fabricated from deformed bar. The standard covers four different materials; Carbon, medium Carbon Boron, alloy, and high strength low alloy steels. It designates three different strength grades and two different thread classes. Table 1 below describes the three different strength grades incorporated in this standard.

Table 1: Anchor Bolt Strength Grades	Strength Grade	Tensile Strength, ksi (MPa)	Diameter Range, inches
	Grade 36	58-80 (400-558)	½- 4
	Grade 55	75-95 (517-655)	½ - 4
	Grade 105	125-150 (862- 1034)	½ - 3

The threads shall be either Class 1A or Class 2A Unified Coarse (UNC) thread series per ASME B1.1. Unless they are specifically designated to be Class 1A, the thread fit is understood to be Class 2A. For sizes greater than one inch, the purchaser may choose the 8UN Threads Series. Unlike threaded rod, however, there is no standardized option for the Unified Fine (UNF) threads series. Threads are to be inspected per System 21 requirements, which means that they must pass a dimensional verification of the Major Diameter and a GO and NOT GO threaded ring gage.

Grades 55 and 105 are both intended to be heat treated. To assure that these products have metallurgical toughness restored by tempering, the Grade 55 has a minimum tempering temperature requirement of 800°F and the Grade 105 of 1100°F. These minimum tempering temperatures are quite important because tempering at too low a temperature will result in an Anchor Bolt that is likely still somewhat brittle, a completely unacceptable condition for this type of fastener.

Several other important considerations include:

- Grade 36 must be weldable.
- Bending can be done hot or cold but no cracks are allowed and the reduction of area in the bend region should not dip below 90% of the straight shank.
- Bending temperature for non-heat-treated versions should not exceed 1300°F.
- When bending Grade 55 added heat should be less than 700°F and Grade 105 less than 1000°F.
- Grade 36 and Grade 55 are commonly paired with Grade A nuts per ASTM A563/A563M, either Hex or Heavy Hex depending on the diameter of the Anchor Rod.
- Grade 105 Anchor Bolts should be paired with Heavy Hex Grade DH nuts per ASTM A563/A563M.

Figure 5: Anchor Bolts for Building Column

An important consideration regarding the nut is that other grades of nuts may be substituted using choices from ASTM A194/A194M or ASTM A563/A563M as long as the "Nut Pairing Rule", meaning the Proof Load Stress of the nut should be equal to or greater than the Anchor Bolt's minimum Tensile Strength, is maintained. This will assure that the Anchor Bolt fails in an obvious fashion before the nut.

Much like threaded rods, Anchor Bolts may be supplied plain, zinc plated, hot dip galvanized, or mechanically zinc coated. The bolt and nut must possess the same coating type, but this is not required for any paired washer.

Figure 6: Electrical Substation

Whereas threaded rod does not have specified marking requirements, Anchor Bolts do. The default requirement says that the end protruding from the concrete shall be spray painted blue for Grade 36, Yellow for Grade 55, Yellow on the protruding end and white on the encased end for weldable Grade 55, and red for Grade 105. There is also an alternative or supplemental marking requirement should the purchaser prefer this method. For the protruding ends, Grade 36 shall be stamped with "AB36", Grade 55 with "AB55" and Grade 105 with "AB105". The Supplemental Requirements may also specify the inclusion of the Manufacturer's insignia or ID.

Figure 7: Wind Tower Mast Anchorage

Figure 8: Headed Anchor Bolts Being Set

Figure 9: 90º Anchor Bolts Being Set

Anchor Bolts are used for all types of anchoring applications. Several common applications include:

- **Bridges** – anchoring the bearings, approach slabs, and steel railings
- **Steel Buildings** - anchoring the building columns and bearing plates (Figure 5)
- **Light Poles**
- **Traffic Signals**
- **Industrial Equipment**
- **Water Storage Tanks** –anchoring the leg columns and the standpipe.
- **Electrical** – Substation equipment, buss supports, and poles (Figure 6)
- **Ground Mounted Solar Structures**
- **Wind Tower Masts** (Figure 7)

Headed Anchor Bolts have a formed head that gets embedded into the concrete and serves to provide uplift-resistance. These are often used in concrete foundations to secure structural steel columns, light poles, bridge rails, substation structures, and wind tower masts.

90° Anchor Bolts have a bent portion called the "Leg" that is embedded in the concrete and serves to provide uplift-resistance. These are commonly used to support structural steel columns, light poles, highway sign structures, bridge rails, and industrial equipment.

Anchor Rods may be made from threaded rod with a nut or nut and washer tack welded onto one end. Although these are probably not as good as a Headed Anchor Bolt, they are commonly used and are particularly advantageous when timing or availability is an issue.

Swedged Rod Bolts are an alternative design to an Epoxy Anchor and have indentations for pull-out resistance on the embedded end. These commonly get used in highway work.

Summary

These products are very important fasteners used in many different applications. Although they generally don't garner a lot of attention, as this article has illustrated, there is a great deal to know about them. Fortunately, there are standards which help assure that the quality and performance are maintained.

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