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# Notes on Rock Reinforcement Using Threadbar Rockbolts

I grew up in the General Engineering Contracting business. From 1984-2001 I had my general engineering contractor's license in California and was partner in a construction management company that managed a lot of rockbolting jobs that my engineering company designed. So, I probably see contractors in a somewhat different light than most engineers or academics. If you design the job right, it can be built right and the contractor can make money on the job. If the contractor makes money, you'll likely avoid costly construction claims. Changed conditions claims are very common on rockbolt and tieback jobs because they usually involve performance specifications, spelled out in strict specifications for pull testing of the anchors.

That preamble aside, after 25 years of designing rockbolts and managing their installation for a myriad of different situations, I'd summarize my experiences by saying:

> "***good rockbolting is basically a function of personnel experience***"

Wish I could say it's more complicated than that, but I don't know that it is. Either you have the personnel on the job with the requisite experience or you don't. If you don't, the job goes slowly, often runs over budget and frustrates just about everyone connected with it. Unfortunately, contractors can't always find experienced personnel available for their rockbolting jobs. This has been a big problem in places like Hawaii; where they don't do a lot of rockbolting work, so beware. You might want to advertise the job more widely (outside your own state), entertaining bids from subcontractors with a proven track record of recent rockbolting experience (last 5 years).

## Site access is almost always problematic if working on a troubled rock cut slope

Site access and equipment access are almost always problematic, to some degree or fashion. The contactor has to be pretty innovative and have someone steering the job that can make good decisions on-site; without having to call daddy or the company lawyer every 10 minutes. The biggest problems often involve developing a construction access scheme that allows traffic to continue using the highway and oftentimes, securing permission for offsite access. Access agreements often involve passing a document through the hands of several attorneys, none of whom are usually in a hurry (they charge by the hour). In most states, you can exert police powers (eminent domain) to force site access to complete a repair or stabilization job that is in the public interest. Some jurisdictions have competent attorneys who willingly draft up eminent domain orders to force site access, while other agencies do not. The property has to be restored to its original condition, absent replacement in-kind of destroyed vegetation (the area would need to be re-vegetated using an approved erosion control and landscaping plan).

## What are the biggest problems I have observed?

I've numbered the most common problems I encountered over the 25 years of private sector experience below, with the most common first, and so on.

The **Number 1** problem I observed was **drilling in broken ground with the WRONG kind of drill rig.** Most companies will tend to use whatever rigs they have "available". That usually leads to problems. It takes a pretty expensive rig to successfully penetrate broken fractured ground and maintain cuttings circulation. Not many contractors own such rigs. Broken ground (fractured rock) is normally expected if you are attacking a rock slope failure, whether incipient or already occurred. If we expect broken fractured rock, we also expect drilling problems with loss of circulation and jamming (the more brittle the rock fragments, the more jamming). In such cases we would usually specify **overburden drilling systems** using eccentric pilot bits (ODEX) and reamers with advancing casing (to insure drilling circulation) or Dual Energy Percussion Systems (DEPS). Most of these systems have been absorbed by Atlas-Copco and are commonly referred to as ODEX, DEPS or BOODEX overburden drilling systems. The BOODEX system is becoming the dominant horizontal rockbolt emplacement system in underground work, and it uses perforated casing tubes to keep holes open in caving ground, while allowing for penetration grouting of the rockbolt. From my perspective, this is the first viable competitor for the Williams hollow core bolts we've been using in broken ground the past 25 years.

**Number 2** was getting the **non-shrink grout mixes** correctly proportioned and placed within the manufacturer's specifications/recommendations. Doing this correctly on a difficult access site takes a lot of experience. If the contractor doesn't have someone experienced with non-shrink grout directing that portion of the work, watch out; you're probably headed for problems. The core issue is non-shrink grout is very expensive. If the contractor spills it, mixes it incorrectly or uses more grout than he estimated for the job, you're usually looking at trouble brewing, usually in the form of construction claims for the additional grout. Be ready to pay for some extra grout if the takes really are unusually high, but make the contractor justify such expenditures as well, or he'll try to drive a truck though that issue all the way to his bank.

**Number 3** is **early pull testing**. Be sure to specify proper test holes right at onset of job, e.g. make it a contract spec to observe and test the **first, second or third** bolt installation, if at all possible. Many contractors like to drill 6 to 12 bolt holes before they grout them as a group. This can be problematic if the first pull test fails. A test program is always advisable on larger jobs (more than 50 bolts). Be sure to observe the grout take, grout shrinkage at the collar of the bolt before embarking on the actual pull test. The grout take usually correlates with anchorage strength. Make careful measurements during the pull-test for anchorage and note the creep during lock-down. If you're using segmented bolts (more than one bolt, screwed together with a joiner), you will measure quite a bit more creep, because the joints will extend.

After the first pull test sit down with the contractor's site foreman and discuss whether the project specs appear realistic for the site. If the contractor isn't using the specified drilling system, you can't do this (see item No. 1 above). See what kind of reaction you get to this suggestion. If the foreman is green, he will balk, wanting the boss man or company attorney to sit in on the meeting. That's a warning sign you aren't dealing with a seasoned or experienced foreman. Nevertheless, this meeting is crucial to avoid construction claims actions down the line. Get the problems worked out as soon as practicable. In most instances, I would spec a certain type of drill rig if I suspected we were dealing with broken ground and the likely loss-of-circulation during drilling. Invariably, the contractor would ask for a variance to see if a "lighter" (less expensive) drill rig would work "to our satisfaction" on the job. We might allow him to try an alternative rig on the first hole to see if it worked, but always reserved the right to request one of the specified drill rigs in the bid documents at any time we wished while the job was progressing. This places the risk on the contractor, because he shouldn't be given start-up and mobilization fees for moving another drill rig onto the site if his non-specified rig doesn't work out. About 2 out of 3 times we'd have to insist on changing to a "specified rig" because the contractor's available rig couldn't do the job adequately. This makes the contractor mad because it chews into his margins on the job. Be ready to stand your ground on the project specifications, but work just as hard to find ways to accommodate the contractor's problems.

**Number 4** is watching out for **fly rocks** falling on the workers or the highway. It only takes one rock to ruin a job. All loose blocks should be scaled first; but contractors are often reticent to scale then slopes effectively because they either forgot that item in their bid take-off, or they underestimated the difficulty/cost associated with thorough scaling. Most of the scaling I witnessed was of a preliminary and ineffective nature, carried out by laborers hanging from boatswain chairs with 6-feet long pry bars; not very scientific. **Scaling should be carried out throughout the course of a job**, prying off any loose blocks as they appear. In a perfect world **we like to initiate rockbolting from the top down**, because that should provide the greatest safety for the workers on the face. **Most raveling emanates from the upper 10 to 15 feet of the rock cut**, where the rock is most weathered and dilated. That is the area that demands the most attention to safety. If I had my way, we would always trim back rock cuts in the weathered zone to something much flatter than the rest of the cut and thereby avoid many problems with erosion and raveling that typically occur later.

Sometimes we were asked to bolt loose blocks in-place, to prevent their rolling down onto the highway. That can be a cost-effective alternative, but then so can busting the problem rock up into smaller pieces so that it can be safely carried away. It is often a judgment call that might better be addressed by the rockbolting contractor than the office engineer.

**Number 5** is watching out for **traffic safety problems** BEFORE they occur. This was always a major concern in California, where the public demands that right-of-ways remain open to traffic, especially during commute hours. Sometimes there are also limitations on time of day work can be accomplished. This factor ties in with No. 4 above, in that **fly rock problems are usually tied to a lack of ongoing scaling**, during the course of the job. Most contractors see scaling as an initial activity and only give it a casual attention in their bid. The problem is block movements can be triggered during construction by any number of stimuli, such as equipment or traffic-induced vibration, earthquakes, localized excavations for equipment access and rainstorms. Every time we had a major rainstorm during a rock bolting job we had to keep a careful eye on the project, because new problems inevitably surfaced which none of us had foreseen. Keep a close eye on the rockbolting projects during and just after major storm events.

## What were my biggest worries on rockbolting jobs?

Always be careful whenever you specify anything "unusual". Over the years I came to prefer the Williams hollow core bolts when I was working with actively raveling cuts, topples or rock slides because these bolts have a phenomenal ability to "stitch" broken rock because of their superior grout penetration under pressure. Hollow core bolts (Detail 1) are grouted from the head of the bolt downward, and forced out through the top at the bottom of the drill hole. **The grout take on Williams bolts would typically be 3 times to 8 times the annular space between the bolt and the borehole!!**

This superior grout penetration allowed the hollow core bolts to develop fantastic anchorage, far beyond what can be developed using solid threadbar bolts or conventional tiebacks in broken rock. But, this increased anchorage is usually accompanied by two complications:

Problem 1: The superior grout penetration means the contractor uses a LOT more non-shrink grout, which is VERY expensive. The winning contactor (lowest bid) NEVER seems to account for that increased grout take in their bid. The grout volume should always be listed as an extra materials item with an agreed-upon unit price, in-place. Remember that if you are specifying non-shrink grout, it is VERY expensive (high unit cost). Unit costs are included in standard contract docs in many states now.

Problem 2) Every time I specified the hollow bolts, the staff engineer preparing the take-offs for the contractor usually assumed solid threadbar DSI [Dywidag] threadbar bolts, **because that's what they are USED to seeing and using on other rockbolt jobs**. So their winning bid would be $70K or $120K deficient on basic materials costs, right at the start of the job. That always leads to trouble. These jobs would quickly devolve into claims nightmares, as the frustrated contractor sought desperately to reclaim the money they left on the table when they signed the contract.

## Pre-bid conferences necessary if specifying anything “unusual”

If you are specifying anything “unusual” on a rockbolt job, it is wise to use pre-bid conferences, where you or your CM firm can highlight the unusual aspects and give the contractors suggestions on sources of suppliers. The two most common “specialty items” were the dual energy percussion systems (DEPS) or overburden drilling systems with advancing casing (ODEX) for broken and fractured ground and any kind of rockbolt that wasn’t a solid Dywidag threadbar, or Grade 120 steel. I don’t like using 120 ksi steel in active rock slides or raveling rock cuts because it has very little ductility. We investigated several rockbolt failures where 120 ksi bars suffered failures through hydrogen embrittlement because the annealing was broken by massive straining under load (creep).

Two new types of bolts which are coming into use are **Super Swellex** and **Self-drilling rockbolts** (SDRs), both marketed by Atlas-Copco. Swellex rockbolts are made from circular steel tubes, which have been folded to reduce the diameter. The deformed tube is placed in a drilled hole and expanded with water using a high pressure pump. Their big advantage is speed and ability to be used in mixed ground conditions (soil or rock). SDRs use a threaded bolt, a sacrificial drill bit, a coupler, a face plate and a hex nut. Both of these can be employed with rod adding systems (RAS), which allow bolts up to 40 m/131 ft to be used. Any of these newer products would need to be spelled out clearly to the contractors before they submit their bids.

Whenever we tried to implement new technologies or construction products, we generally suffered from the contractors "learning curve". That is why we encouraged government agencies to allow us to use our own construction management (CM) firm to manage those kinds of "specialty jobs". The CM can be given the responsibility to go over the "unusual items" at a pre-bid conference with all the bidders. Pre-bid conferences are VERY important in avoiding unnecessary construction claims later on "specialty jobs".

## Typical details

DSI [Dywidag] Systems International produces a series of standard details that are commonly used for ground anchors and rockbolts across the nation. These can be downloaded from their website at www.dywidag-systems.com

I am attaching some of the most common rockbolt details exclusive of the Dywidag website. These include the following:

**Detail 1 is for a Hollow Core rockbolt**. The Williams 1-3/8-inch diameter bar is structurally equivalent to a Dywidag 1-inch diameter solid threadbar, of equal steel grade (60 or 120 ksi). Thrust rings at the tip of the bar are optional, but a good idea in broken ground. The tensioning length of prestressed bolts needs to be spelled out and shown how it is to be cased, to prevent initial bonding with the threadbar. We usually used PVC casing with lithium grease and duct taped the transition carefully. A vent tube is crucial to the system working properly if grouting from the inside of a hollow core bolt.

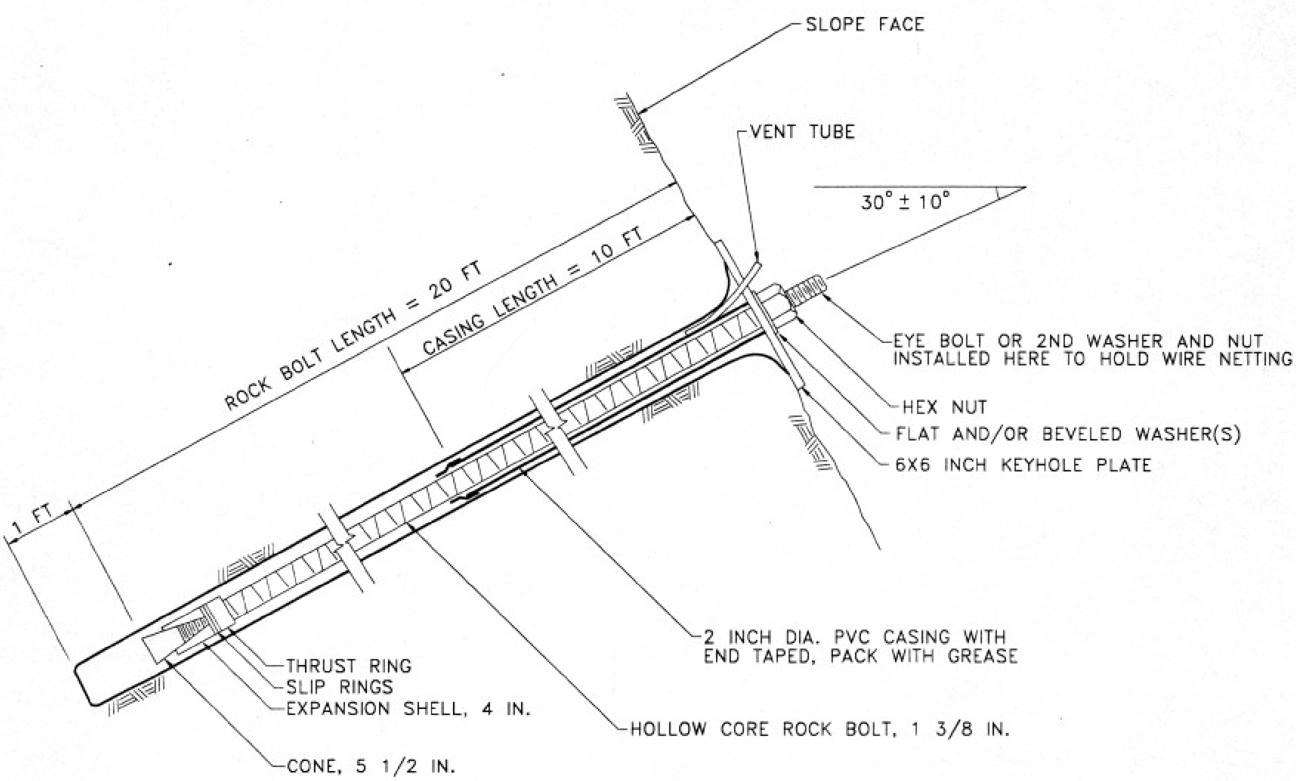
Details 2, 3, 4 and 5 deal with **wire netting** being placed over the face of a broken slope. This prevents blocks from the rugged face pulling away from the exposed face between the rockbolt anchors and prevents fly rock from falling on anyone or anything later. We much preferred the Maccaferri triple twisted galvanized wire gabion mesh to galvanized chain link for a number of reasons, including: 1) it can't unravel if it is ever inadvertently cut (chain link will unravel because it's links are not twisted); 2) the gabion mesh has a much more aesthetic appearance (because hexagonal cells are three times further apart than chain link, so it does not form a "reflective surface"; people tend to see what's beneath the mesh instead of just seeing the galvanized chain link); 3) the gabion mesh comes in large rolls (4 m wide) and is easier to cover large slopes; and 4) the gabion mesh can be ordered with protective PVC coating (in grey or black) to provide increased corrosion protection, important in salt air environments. The chain link can corrode badly giving an awful appearance. See Maccaferri's website at www.maccaferri-usa.com and their case studies at www.maccaferri-usa.com/casestud.shtml

**Detail 2** [no number] shows a typical detail for stitching/weaving two gabion mesh sheets together, using galvanized wire.

**Detail 3** shows a top edge detail for the wire netting attachment to the upper rockbolts, using an eye bolt attached to the end of the rockbolt.

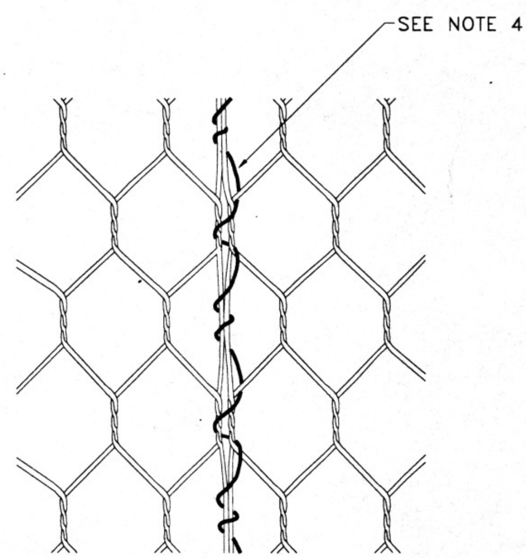
**Detail 4** shows the wire netting attachment detail on the bottom and sides of the rockbolted area. This arraignment allows the ties to be unscrewed so the netting can be lifted off the face as much as needed for periodic cleaning.

**Detail 5** is a bolt-down detail for the wire netting. This is a simple arraignment using two standard Dywidag 6 x 6 inch face plates sandwiched atop one another.



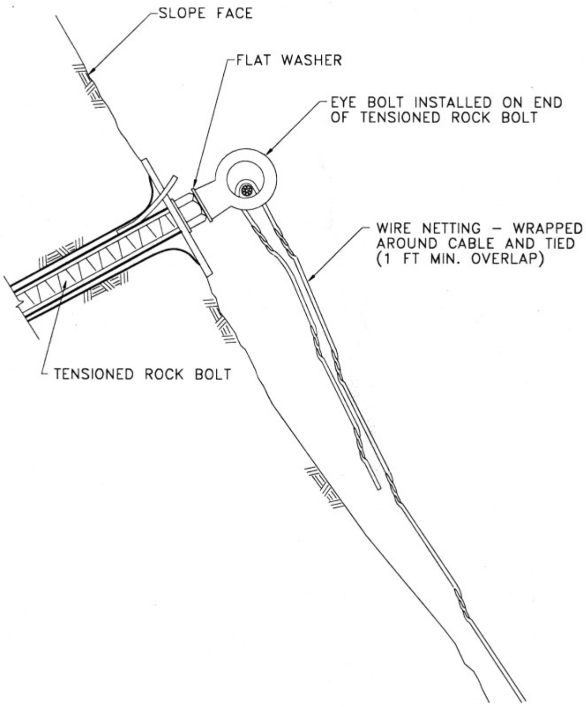

HOLLOW CORE ROCK BOLT DETAIL 1

NOT TO SCALE



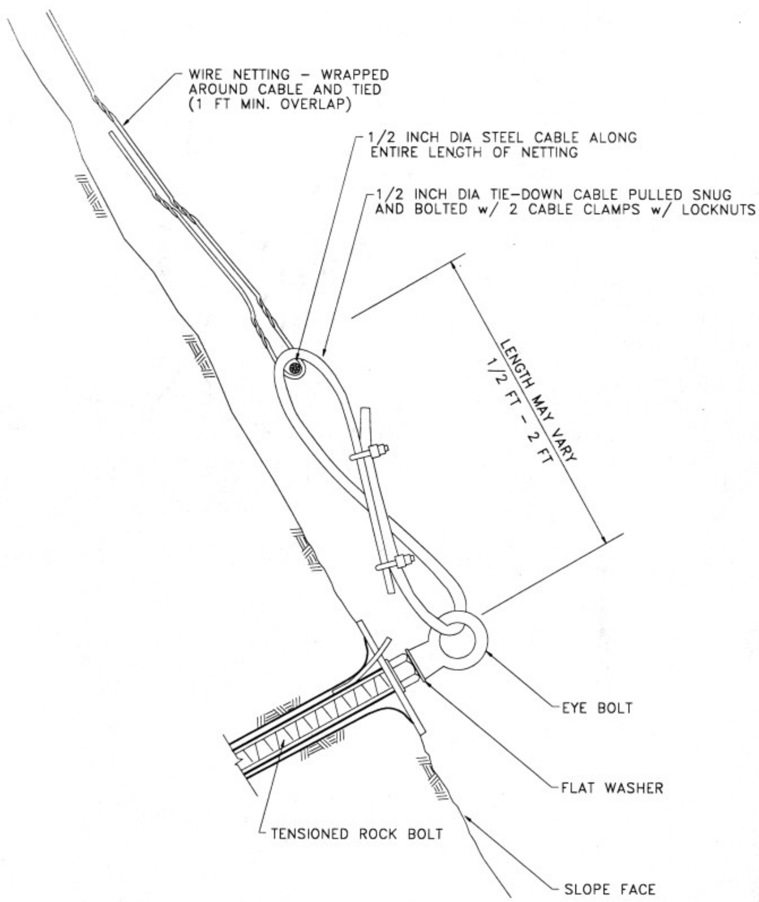

WIRE NETTING VERTICAL SPLICE DETAIL 2

NOT TO SCALE



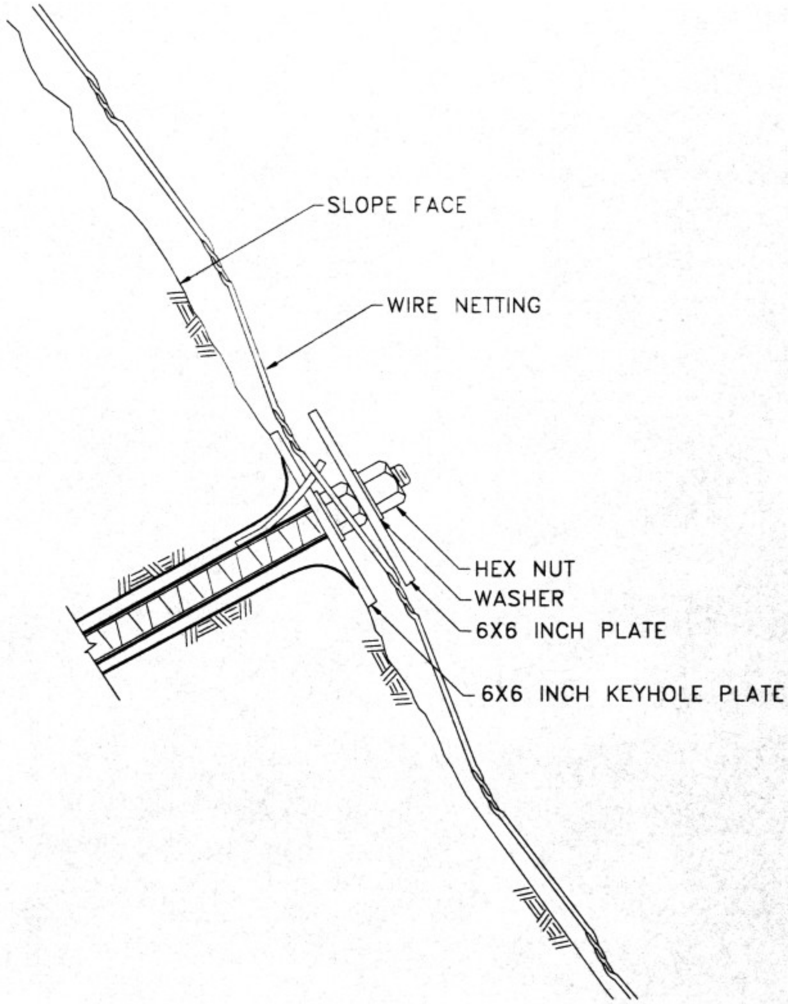

WIRE NETTING TOP EDGE DETAIL (3)

NOT TO SCALE




WIRE NETTING BOTTOM AND SIDE EDGE DETAIL (4)

NOT TO SCALE




WIRE NETTING BOLT–DOWN DETAIL 5

NOT TO SCALE