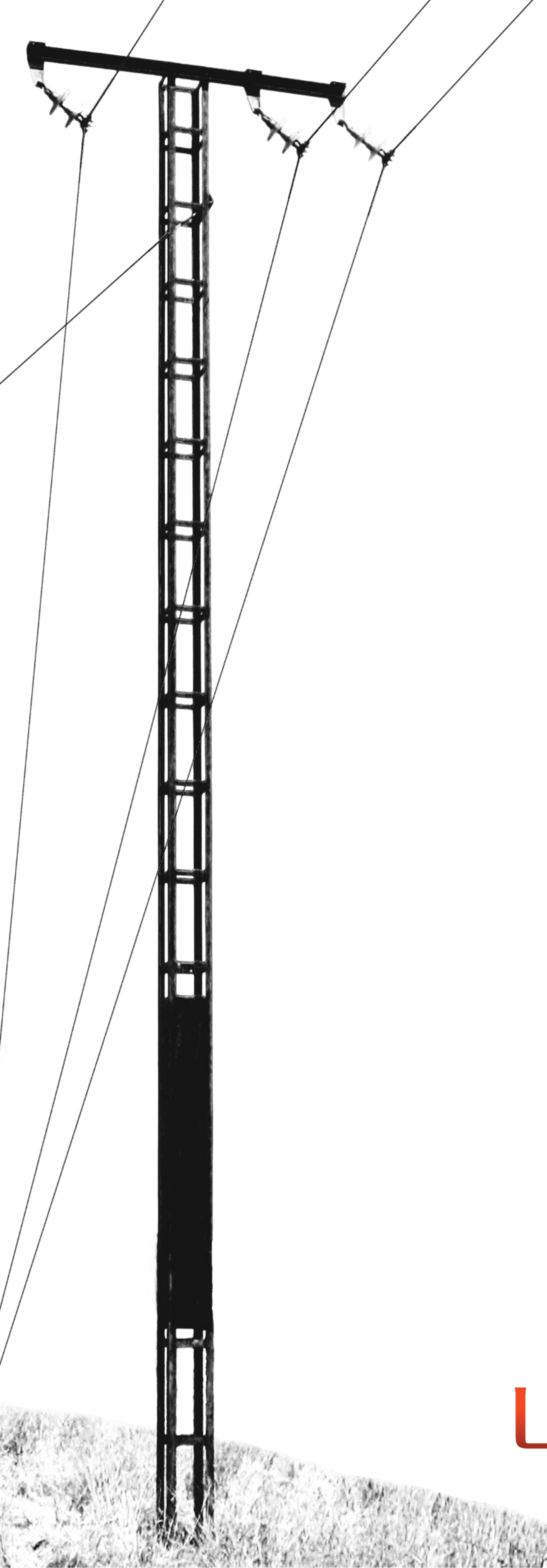

Comparison of Pole Reinforcement Types

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REVISIONS

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1 INTRODUCTION

Essential Energy engaged URI Engineering to undertake a comparison of their current C-Splint reinforcement type with other bolt & ferrule and rebutting types that are currently available in the marketplace. The full range of reinforcement types currently available is categorised into the following groups;

1. **Banded Splints** (i.e. the Ausmose C-Splint and the Osmose C-Truss)
   This reinforcement type uses one or more structural members installed adjacent to the pole, connected to the pole by straps or bands. Examples are shown in Figure 1.

Figure 1: Examples of Banded reinforcement.

2. **Bolted Splints** (i.e. UAM RFD Nails)
   Bolted splints use one or more structural members installed adjacent to the pole, connected to the pole by through-bolts. Examples are shown in Figure 2.

Figure 2: Examples of Bolted reinforcement types.

3. **Rebutting** (i.e. Adapt-a-Pole)
   Rebutting timber poles involves replacing the in-ground and part of the above-ground portion of a pole with another material. The sleeve is normally a concrete-filled steel tube, but the concrete is not always required, and the tube could also be made of fibreglass. Another version uses a pre-fabricated concrete column to replace the bottom section of the timber pole, with a steel tube used to connect the timber to the concrete above ground. An example is shown in Figure 3.

Figure 3: Example of a Rebutted pole.

4. **Wrapping** (i.e. Osmose fibreglass wraps)
   Wraps are also currently available for the reinforcement of poles. They generally use fibreglass wraps impregnated with vinyl ester resins to restore strength to the pole in the ground line region. Examples are shown in Figure 4[1].

Figure 4: Example of a finished and during-application wrapped type reinforcement.

[1] Extracted from an Osmose article at http://www.utilityproducts.com/articles/print/volume-16/issue-3/product-focus/line-construction-maintenance/structural-rehabilitation.html

5. **Strutting**
   Strutting involves the application of one or more (normally at least 2) steel members as temporary supports for the pole just above ground line. Typical application is shown in Figure 5.

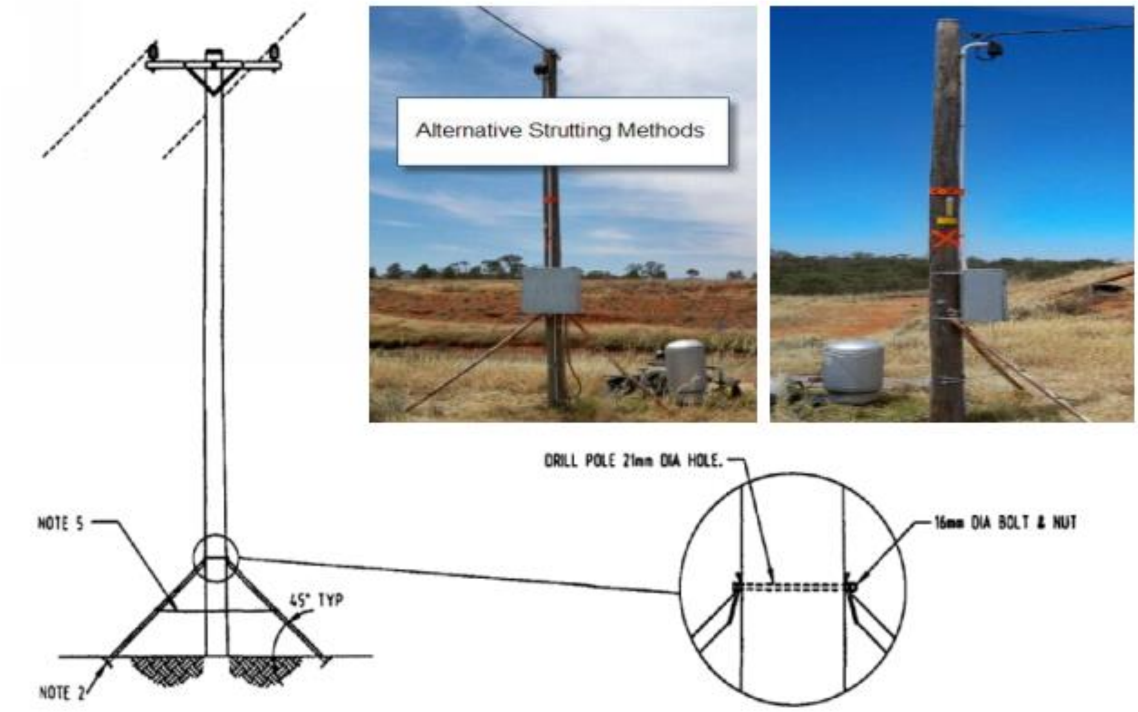

Figure 5: Taken from page 101 of CEOM7005 (1).

This report focusses on the comparison between banded and bolted reinforcements and banded and rebutted reinforcements from a structural and durability performance perspective. Financial and installation/practicality comparisons are not included as part of this report. A review of the applicability of reinforcement to different pole materials such as steel and concrete is also provided.

The information and recommendations in this report are based on the experience and knowledge of the author and are provided mainly as a guide when doing a desktop assessment of different options, and to provide cues for further investigation if Essential Energy wish to assess a particular type further.

Note that the terms reinforcing, splint and nail/nailing are interchangeable in the context of this report and refer to engineered structures, normally made from steel, used to strengthen in-situ poles by bridging degraded sections at ground line. The term 'wall thickness' refers to an annulus of sound wood around the circumference of the pole, as measured by the inspector.

2 BANDED VS. BOLTED REINFORCEMENT

Banded splints are the current preferred reinforcement option used by Essential Energy at the moment, which is the Ausmose OZ-C-Splint system. The Osmose C-Truss and C2-Truss systems are also very similar systems that are used extensively across North America.

2.1 DURABILITY

Some manufacturers claim that the lack of bolts has durability benefits for banded reinforcement because drilling can let in moisture and accelerate decay of the timber pole. We have been involved in many failed pole inspections and pole tests of ex-service reinforced poles and this does not appear to be an issue in reality, but the banding does avoid any risk of this occurring.

One durability benefit that banded reinforcements have is that they do not rely on the pull-through capacity of the decayed timber, either longitudinally or in local crushing near the ground line. Instead, they constrain the annulus of 'good wood', which keeps the timber section in a circular shape and resists local crushing. This gives a better bending resistance to the section and avoids premature failure.

In terms of the durability of the steel below ground, if the different reinforcement types are both steel based materials, they will perform similarly in similar environments. Galvanised steel should perform adequately for around 20 years in most cases, but in areas of high salinity, phosphorus or acid soils the life will be greatly reduced. Driving through angular, gravelly or rocky soils can also damage the galvanising and cause accelerated corrosion in some cases. Refer to the report "*Hillston Feeder Reinforcement Review*" (2) for more information on durability of the steel.

We are aware that one bolted reinforcement type called Powerbeam uses stainless steel bands to help constrain the poles if they have significant checking/splitting at the time of reinforcement. The stainless steel bands are installed before the splint, and the splint will rest against the bands in most cases. This is not a particularly good detail because stainless steel in contact with galvanised steel causes accelerated corrosion of the galvanised steel due to a galvanic reaction. This may not cause any issues in dry environments during the intended life of the reinforcement, but could be an issue in humid, high rainfall environments. The large amount of galvanised steel vs. stainless steel may also mean the galvanic reaction is minimal during the design life. Galvanised bands would be recommended as a better detail.

Note that stray currents and earth leakage with even a small DC offset may cause quite aggressive corrosion of the steel sections, however this appears to be rare in our experience.

2.2 CONNECTION

Banded reinforcement systems rely heavily on the bands remaining tight on the reinforcement so that they can transfer the loads between the pole and the splint member. If the bands loosen and slip down the pole, the reinforcement becomes almost completely ineffective. In our experience, more ad-hoc banding systems that do not have enough tension in the bands can be loosened by the movements in the pole itself, or they can be loosened by livestock rubbing on the reinforcement. To our knowledge this does not appear to be a problem with the tension used in the installation of the C-Splint and C-Truss systems.

Banded systems can have the banding break under some circumstances, but in our experience this tends to be well after the pole has failed and the reinforcement has yielded, and there is some other force continuing to pull the pole to the ground. Figure 6 shows an example of this where the pole is leaning at more than a 45° angle, the steel is heavily deformed and the bottom strap in the top group has broken away. This failure mechanism is more likely to occur when the reinforcement is loaded about its strong axis, and can happen at the bottom or top groups of banding with equal chance, it all depends on the tension in the bands and the geometry of the pole/reinforcement system. If the splint is loaded about its weak axes the bands are far less likely to fail because the reinforcement is weaker and it will buckle in the direction of the load rather than in torsion. Examples of weak axis failure are shown in Figure 7.

Figure 6: An example of the severe deformations that are normally required before bands are overloaded, if they are installed correctly. Typical of banded reinforcement loaded in the strong direction.

Figure 7: Examples of banded reinforcement failure about the weak axes.

It is also important for bolted systems to be installed tight to the pole. If the bolts do not hold the reinforcement tight to the pole, the loose connection will not transfer any appreciable loads between the pole and reinforcement until the pole has fractured. As long as the connection is not too loose and the reinforcement is designed to be able to take the appropriate loads without assistance from the timber, then this is not a problem. However, if the bolts are too loose, or if there is free-length of bolt between the reinforcement and the pole, the effectiveness of the reinforcement can be hindered as it will start to rely on the bending capacity of the bolt rather than the tensile/shear capacity, and bolts have minimal capacity in bending. An example of this is shown in Figure 8.

Having a bolt fail in bending is not necessarily going to cause catastrophic failure, it is more likely to just cause the pole/reinforcement system to deflect further than if the bolt was purely in shear. This may reduce the clearances and hence the safety margin of the system.

Bolted systems can also undergo increased deformation if the bolts start to deform the timber in bearing. An example of this is shown in Figure 9. However, a similar degree of additional deformation will occur when the pole twists relative to the banded reinforcement. An example of this twisting is shown in Figure 6.

Note that the capacity of the bands at the top and the bottom of the reinforcement are equally critical to the performance of the pole in-situ, it isn't only the top bands that undergo high stresses. The distribution of stress in the bands is dependent on pole and reinforcement geometry, band tension, and load direction.

Figure 8: Example of a bolted reinforcement connection in bending.

Figure 9: Example of the timber being deformed by a bolted connection.

2.3 STRENGTH OF THE TIMBER POLE

The main concern with bolted reinforcement is the loss of strength in the timber pole due to the bolts.

Figure 10 and

Figure 11 show examples of failures that have occurred through the top bolts of different reinforcement types. The smaller the pole and the larger the ferrules, the more pronounced the strength reduction. It is important to also note that even if the top 2 bolts are 300mm apart, the failure plane will normally pass through both bolt holes, which reduces the section capacity based on both bolts, not just one. Figure 12 shows examples of this.

The extent of capacity reduction can be more than 50% depending on the size of the pole, the presence and size of ferrules, and the number of bolts. This is significant, because the capacity of the pole at the top of the reinforcement can be quite close to the design bending moment at that location (due to the effects of taper). Hence, if the reinforcement is significantly stronger than the pole at the top bolts, the failure mechanism becomes failure at the top bolts, and this can occur under wind speeds less than the design wind. Figure 13 shows a graphical representation of this. The majority of failures that we have seen for poles with bolted reinforcement occur at the top of the reinforcement, regardless of the type of bolts and reinforcement used.

Figure 10: Failed section of pole through the top bolt & ferrule hole. This would lead to a 9-42% loss of strength depending on the orientation of the bolt hole.

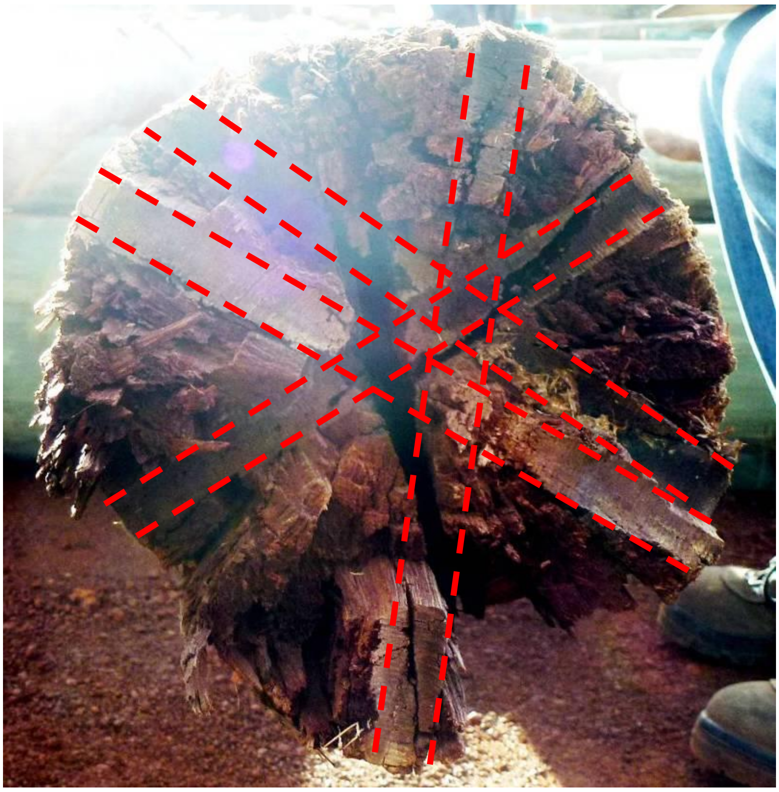

Figure 11: Example of a multiple bolted connection with no ferrules giving an approximate 40% reduction in strength.

Figure 12: Examples of failures being influenced by both top bolts. The top bolt in the right hand image also pulled through the ferrule during failure.

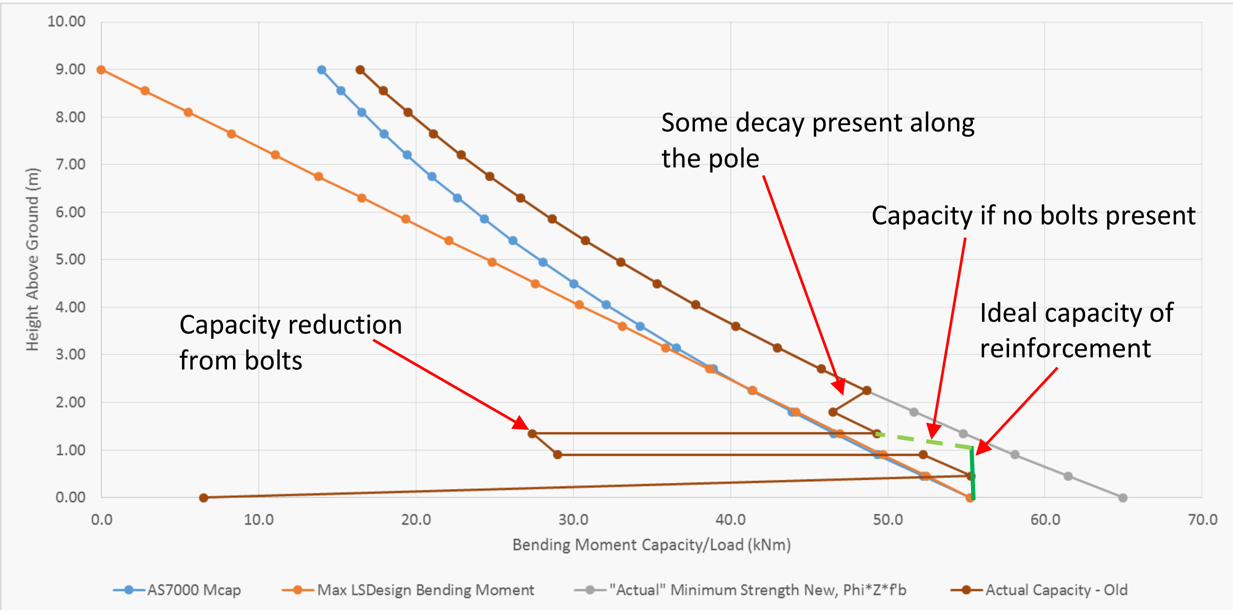

Figure 13: Representation of the effect of bolts on the capacity of a reinforced pole.

Because banded reinforcements do not reduce the section capacity of the pole at the top of the reinforcement, they will ensure that the pole will only fail at the top of the reinforcement if its full capacity is exceeded, which should be greater than the design wind loads (assuming the pole is still in good condition at this point). This greatly reduces the risk of catastrophic failure.

The other benefit of banded reinforcement is that it constrains the timber cross-section and prevents the timber from “barber-chairing”. Barber chairing occurs when the pole splits longitudinally and leaves a segment of the cross-section that is not constrained by the bolts. The un-restrained section fails in tension at the ground line with minimal capacity and splinters outwards. Because the cross-section at the top of the reinforcement is reduced by the unrestrained section plus the bolts, the pole then fails at a reduced capacity at the top of the reinforcement. An example of this failure mechanism is shown in Figure 14.

Figure 14: Example of a barber-chair failure for bolted reinforcement.

2.4 FOUNDATION CAPACITY

Foundation capacity of the reinforcement-pole system is critical to the overall performance of the reinforcement. In terms of the foundation capacity, both bolted and banded reinforcements will be similar. Because most bolted reinforcements have a flat surface against the pole they may not “grip” as well to the pole below ground, but they tend to have ribs that stick out further from the pole which will increase their own capacity to resist foundation failure. Most banded reinforcements have a ‘C’ or ‘3’ shape and sit closer to the pole with minimal protrusions, but most of them will have a sharp edge in contact with the pole surface that effectively grips the pole below ground, and they use this interaction to help them resist foundation failure.

In our experience with plain pole and reinforced pole testing in-situ, foundation failures rarely occur before the pole or reinforcement itself fails. When foundation failure does occur in either case, it is a ductile failure mechanism and only causes the pole to rotate into a dangerous position in very weak, swampy soils. The example shown in Figure 15 was installed in a loose, rounded gravelly sandy soil, and was tested only 2 weeks after installation (i.e. the foundation did not have time to consolidate). The reinforcement had already yielded above ground by the time it started to rotate out of the ground, and continued to slowly yield until it finally pulled fully out of the ground. The test was also done with a slowly applied load and hence the higher strength of the soil under short duration wind loads (due to viscoelastic soil response) would not have been applicable.

Figure 15: Example of a foundation failure of a banded reinforcement type.

2.5 REINFORCEMENT STRENGTH & FAILURE MECHANISM

The strength of the splint member is often not the most influential element in the performance of a reinforced pole (within reason). For the bolted reinforcements it is commonly the timber at the top bolts that is the limiting factor. For banded systems, you are far more likely to have the preferential failure mechanism of reinforcement yield, but the actual strength of the reinforced pole may be less than the calculated capacity of the reinforcement. If the bolted reinforcements were to fail by yielding of the reinforcement they would have similar influencing factors.

Both reinforcement types may not reach the full calculated capacity due to site variables including;

- Soil conditions,
- Installation tolerances,
- Load eccentricities that are not accounted for,
- Variability in the residual strength and cross-section of the timber pole,
- Lean on the pole prior to reinforcement, etc.

In reality, the actual capacity (ignoring the bolt holes at the top of the reinforcement) could be less than 80% of the calculated capacity. However, the variability in ultimate capacity is less important than the failure mechanism provided, in which the reinforcement can hold the pole well off the ground even under significant rotations of 30° or more. Hence, you are better off sizing the reinforcement based on its calculated capacity, because it must fail prior to the failure of the pole above the reinforcement for the system to provide the strength and robustness that is required. This ductile failure mechanism is not provided if the timber fails above the reinforcement (i.e. the reinforcement is too strong). This may only be an issue if the wind speed exceeds the design wind, but it can also occur if there is some decay in the timber above the reinforcement. Hence, it is a balance between having reinforcement that is too week and cannot catch the pole and hold it off the ground if the timber fails at ground line, and having too much capacity in the reinforcement so that the timber above the reinforcement is the weakest section.

In other words, you do not want to assume the reinforcement is only 70% of its calculated capacity just in case it is actually 100% of its calculated capacity, because the reinforcement will then be too strong and will significantly increase the risk of failure of the timber above the reinforcement.

The selection criteria for reinforcement sizes needs to consider the intent of the reinforcement. The two main considerations are;

- Is the reinforcement a risk mitigation device to try and stop the pole – if it should fail – from becoming a safety hazard by keeping the conductors above a temporarily safe clearance level until the pole can be replaced? In this case a lower level of reliability may be allowable as it may be a temporary deferment and the chances of catastrophic failure are minimised until proper replacement measures can be implemented.
- Is the reinforcement required to take the capacity of the pole back up to its original design capacity and provide the same level of reliability as the original pole? In other words, it doesn't matter what fails first, the reinforcement or the pole, as long as it happens above the design loads (i.e. above the design wind speed).

Our recommendation is that reinforcement should only be used as a risk mitigation strategy, with a maximum time between reinforcement and replacement of 20 years, with 15 years or less preferred. There are too many uncontrollable variables involved in determining the capacity of a reinforced pole to be able to have confidence in the reliability of the system to restore full capacity in the long term. This goes for any system, but bolted systems in particular are highly unlikely to be able to provide the latter because of the loss of timber section due to the bolt holes.

Based on previous projects we have been involved in that look at the capacity of various reinforcement types, all the reinforcements seem to have been developed using working stress design principles and a factor of safety of 2 for the steel capacity. Some of the systems have been found to have lower theoretical strengths than claimed, and most systems have been tested on new poles that have been cut at ground line rather than old poles that they will be installed on. In addition, removing the timber pole section at ground line removes the potential failure mechanism of the pole at the top of the reinforcement, and hence does not give a true indication of the performance of the system in a real world situation.

Almost every bolted and banded reinforcement system that has been reviewed has fallen short when comparing the nominated reinforcement capacity to the capacity of the pole that it is being installed on. The reason that this has not shown up as a large number of failures on the east coast, is because the inspection criteria and rules around when a pole is to be reinforced and when the reinforced pole is to be condemned are very conservative. In most cases the timber poles themselves are still capable of carrying the design loads without the reinforcement. Hence, evaluating the performance of a reinforcement system based on the number of reported reinforcement failures vs. the total number of reinforced poles is meaningless.

Both banded and bolted system suppliers will claim that their product is proven because there are 'x' number of poles that have been reinforced with their system, but this should be ignored, and the system assessed on the merits of its design and testing. In addition, if a reinforced pole fails at the top of the reinforcement it should be counted as a reinforcement failure, not just if the reinforcement yields at ground line.

One of the benefits of the bolted systems is that they tend to have a similar bending capacity in any direction, whereas the banded systems tend to be highly direction dependant. This will give the bolted systems (in general) more flexibility in installation orientation around the pole. The direction dependant reinforcements can be chosen to give the required strength based on their installed orientation, but this needs to be considered before the installation crews get to site to reduce the chance of calculation issues on site, and it makes it hard for installation crews if they find an issue that requires a change in orientation once they are on site.

In summary, the reinforcement should be designed and selected to give a capacity within +/-15% of the ultimate design load at ground line (not the pole capacity). If this is done for both bolted and banded reinforcements, the banded reinforcements will provide a greater reduction of risk of catastrophic failure.

3 BANDED VS. REBUTTED REINFORCEMENT

Rebutting as a form of reinforcement became relatively popular about 20 years ago, and is still an option today. One of the biggest benefits of rebutting is that a correctly designed rebutted pole can be used to lift the line and gain additional clearance in the adjacent spans.

3.1 DURABILITY

During the early days of rebutted poles, there were issues with the durability of the timber inside the steel tube. The main problems were;

- There were no drainage holes, or the holes would get blocked and water would collect around the timber in the sleeve and cause decay.
- The sleeves were concrete filled right to the bottom of the timber, which allowed water to pool at the bottom of the timber and cause decay.
- The timber was packed into the sleeve using all sorts of materials including timber offcuts, mortar and concrete. The concrete/mortar can crack and let moisture into the timber-steel interface, which can cause decay.

Decay in the timber at the steel-timber interface contributed to the example failure in Figure 16.

As long as the timber-steel interface is free draining and the concrete is not too close to the butt of the timber, the timber pole should experience minimal decay, and may in fact be more durable than the steel sleeve in which it is placed.

The durability of the galvanised steel rebutting tube will be essentially the same as the galvanised steel splints. If the tube is hollow it will fill up with water over time (the evaporation from within the tube is minimal), unless it has a drain hole at the butt, in which case it may also fill up over time if there is a high groundwater table. If this starts to cause corrosion on the inside of the steel tube it is only likely to reduce the life of the rebutted pole if the water contains corrosion accelerating elements such as salts, which will be more likely if groundwater is allowed into the tube.

The concrete infill may prevent this from happening, and the alkalinity of the concrete will passivate the steel. Similarly to the reinforcing members, the steel tube may be susceptible to stray currents and earth leakage with a DC offset.

Hence, the durability of the rebutted pole system is not expected to differ significantly from the splint type reinforcements if the steel-timber interface is suitably designed.

Note that fibreglass tubes would be even more durable than the galvanised steel tubes, but these do not appear to be commercially available as an option at this time.

Figure 16: Failed rebutted pole at the timber-steel interface due to timber decay and high winds.

3.2 CONNECTION

The connection between the steel and the timber is a critical element of the rebutted pole. Similarly to banded reinforcement, placing the timber inside the tube constrains it and keeps it in the circular form to maintain its full bending strength within the connection zone.

In most cases, the rebutting systems only use 3 or more 8mm or larger coach screws to connect the timber to the steel. With so few screws of such small size, they are only there to support the timber vertically. The bending capacity is provided by friction and bearing between the timber and the steel. This is in effect the same way that the banding systems work.

The key to the performance of the connection between the timber pole and rebutting tube is the condition of the timber section. During the installation process the timber pole is cut above ground and the degraded butt section disposed of. In theory, the remaining timber has little or no decay present. In reality, this may not always be the case. Hence, it is important to check the timber for defects within the connection zone, and to put limits on the extent and type of degradation present.

To avoid the timber being overloaded in shear and bearing, it is also important that the timber be embedded at least 900mm into the steel tube, and further for longer, larger diameter poles.

Strength wise, the connection between the steel and timber for a rebutted pole will be higher than that of a banded nail pole due to the complete containment of the timber.

3.3 STRENGTH OF THE TIMBER POLE

Because of the containment of the timber pole, the coach bolts are unlikely to influence the strength of the timber pole above the rebutting. This has been observed through testing of a relatively small number of new and old rebutted poles.

Therefore, much like the banded reinforcement, the timber pole strength will not be deteriorated by the act of rebutting unless the connection is not free draining and the timber deteriorates. In this case the timber strength just above the steel tube can become the critical section for strength as shown in Figure 16.

If the timber pole is shaved to fit within the steel tube the strength loss is negligible as long as the shaving is no more than 10mm deep (over the diameter) at the top of the steel.

3.4 FOUNDATION CAPACITY

As long as the steel tube is a similar diameter to the original pole diameter below ground the foundation capacity will be similar to that of the original pole. This will be significantly greater than the foundation capacity of the banded reinforcement. As noted in Section 2.4, this may not be a significant advantage unless the pole is in particularly poor soils. Another scenario in which this might be useful is if the pole has some foundation movement at the time of rebutting which can be rectified, and the rebutting installed deeper into the ground to prevent future foundation rotations.

In most cases the foundation capacity will be higher than that of the rebutting steel tube, similarly to the banded reinforcement types.

3.5 REINFORCEMENT STRENGTH & FAILURE MECHANISM

It is recommended that rebutted poles are still considered risk mitigation and temporary life extension products for timber poles. However, due to the use of the steel tube, the variables involved in the actual capacity are minimised. Torsion and load eccentricity issues are effectively removed, foundation capacity issues are minimised, and the connection between the steel and the timber is robust if designed and constructed properly for durability. Hence, disregarding durability of the steel, the risk of catastrophic failure for well-designed rebutted poles would be less than both the banded and bolted reinforcement types.

Because the steel tubes that are used are common structural tube sizes, the design strength is easily calculated and well understood, and hence there is also more surety in the capacity than with some of the proprietary splint systems. This allows the rebutted poles to be easily designed to resist the required design forces.

As with the splint type reinforcements, it is still recommended to size the reinforcement as close as possible to the loads on the pole rather than the original ultimate capacity of the timber pole. This will help ensure that the steel tube is the point of weakness once the design loads are exceeded, rather than the timber above it. Having the steel tube weaker than the timber pole ensures that the failure mechanism is a ductile yield of the steel tube like in Figure 17, rather than a catastrophic failure of the timber.

It is also noted that concrete infill does not necessarily increase the strength of the steel tube, because the tube will fail at the gap between the concrete and the timber. What it will do is move the failure location to the top of the concrete, which may be above ground line at a location that attracts a smaller bending moment than the ground line. The problem is, this will increase the overall capacity of the rebutting system at ground line, and may actually cause the timber to become the weakest point in the system. In our experience, the structural performance of the steel tube without concrete infill is more predictable and more detectable when a failure does occur. The restraint provided by the concrete can also cause a tearing of the steel tube during failure, which will turn an otherwise ductile failure into a catastrophic one.

Figure 17: Failed rebutted pole at ground line due to steel section buckling.

Hence, whilst the capacity of a rebutted pole can be more predictable and have less risk associated with it than banded reinforcement, careful consideration is required to ensure that this is the case in reality.

4 REINFORCING OTHER POLE MATERIALS

The following discussion is an attempt to point out as many foreseeable issues and considerations that would be applicable if Essential Energy were to consider reinforcement of other pole materials such as steel, concrete and fibreglass. The discussion is not guaranteed to be exhaustive, and a more detailed assessment is recommended if Essential Energy wish to pursue this course of action in the future.

Note that rebutting is not considered a plausible option for the reinforcement of poles made of materials other than timber, and maybe fibreglass, so is not considered in the following discussion.

4.1 DURABILITY

In general, the durability of the reinforcement used would be similar to that discussed in Sections 2.1 and 3.1. The only other thing to be careful of would be any risk of galvanic corrosion occurring between the pole material and the reinforcement material (i.e. a steel pole that has been significantly corroded may accelerate the corrosion of the splint by consuming the galvanising).

Once corrosion of materials like steel and concrete starts, it will often continue up the pole at a faster rate than what decay will travel up a timber pole. This makes it important for the corrosion of these materials to be significantly hindered or stopped before reinforcing is used, otherwise the reinforcement may be ineffective in a short period due to the pole weakening beyond its required capacity at the top of the reinforcement.

It is important to remember that for concrete poles, the corrosion may be a few hundred millimetres further along than where the spalling and cracking occurs, as it takes some time for the corrosion to produce these surface indicators (although with the low reinforcement covers typically used in the industry this may be reduced to some extent).

Unfortunately, stopping the spread of corrosion for steel and concrete tends to be a labour intensive and an expensive process in terms of coating and repair materials. If the repairs are not done properly they can actually generate an accelerated corrosion cell between the repaired section and adjacent corrosion that was missed during the repairs.

Hence, the reinforcement of steel and concrete poles that are heavily corroded is not recommended.

On the other hand, if the steel, concrete, fibreglass or other pole material is damaged by impact or other mechanical force, reinforcement is possible. As long as there is minimal corrosion present, the durability of the system may be suitable.

Any holes that are to be drilled in the pole need to be treated to prevent corrosion at those locations.

Not enough is known to the author about degrade of fibreglass poles and propagation of degrade once it starts (i.e. osmosis or UV damage). If these poles are proposed to be reinforced, it is recommended to contact a plastic **durability** expert to obtain advice.

4.2 CONNECTION

Connecting reinforcing members to poles made from materials other than timber needs careful consideration. Bolting through concrete poles is a difficult prospect, even when the reinforcement can be located. If there is any error in the hole location for the through bolts, the reinforcement may be cut, which reduces the pole capacity and ductility, and can completely fail the pre-tensioned reinforcement if present.

If bolted reinforcements are to be used with steel or fibreglass poles, the crushing strength of the hollow section becomes an important consideration for the strength of the system. This will require careful control of bolt tensioning during installation, and may warrant testing to determine the effects of the bolt tension on the overall capacity of the reinforced pole.

Similarly to timber poles, banded reinforcement will provide the least number of issues with regard to reducing the section capacity of the pole at the top of the reinforcement. However, given the uniformity of the surface of many alternative pole materials, the bands may be more prone to slipping down the pole, or slipping under load. This would require further testing.

Some systems used for concrete poles involve a formed steel bracket that is placed around the reinforcement, which is then bolted to a similar bracket on the other side of the pole, similar to the clamp brackets commonly used for concrete pole top constructions. This would allow thicker gauge steel to be used for the bracket, which may allow the bracket to be positively connected to the reinforcement to prevent slipping, without compromising the capacity of the bracket like it can do with banded systems.

4.3 STRENGTH OF THE PARENT POLE

Due to the stress distribution that can occur in steel and fibreglass poles due to their ductility and isotropic[2] material properties, having bolt holes through the poles will only cause minimal loss of strength in the pole. The loss of strength can easily be accounted for using the design rules in AS 4100 (3).

If a concrete pole is drilled and the reinforcement is not damaged during the cut, a significant loss of capacity is unlikely.

If banded reinforcement solutions are used the strength of the pole will be unchanged by the act of reinforcing.

[2] Not quite for fibreglass, but ok for the purposes of this discussion.

4.4 FOUNDATION CAPACITY

The foundation capacity of the reinforced pole system will be almost the same for non-timber reinforced poles as it is for reinforced timber poles. There may be a slight reduction in capacity for the banded reinforcements that rely on their 'grip' on the pole due to differences in friction coefficient for the alternative materials. There may also be less 'grip' provided by poles that are cylindrical rather than tapered because the reinforcement won wedge itself over the butt of the pole as well as with a tapered pole. These differences are likely to be minimal.

If the pole is rectangular, square, or other non-circular shape, the connection between the reinforcement and pole may be more difficult, and sharp corners may cause high localised stresses on the bands or bolts.

4.5 REINFORCEMENT STRENGTH & FAILURE MECHANISM

The strength of the reinforcing splint itself will not change just because the pole is not timber. However, the failure mechanism may change. For lighter poles such as steel and fibreglass, the reinforcement will be far more likely to be able to keep the failed pole from becoming an immediate safety hazard (i.e. rotating to a point where the safety clearance is insufficient), due to a reduction in second order effects.

However, with the heavier concrete poles, the chances of the reinforcing being able to support the additional weight are reduced, and the poles are more likely to come to ground once they have failed. If the reinforcements were to be strengthened to reduce this risk, the risk of the pole failing above the reinforcement would increase.

Intrinsically, steel poles have a relatively ductile failure mechanism, so it may be pointless to add another member that is just designed to provide a ductile failure mechanism if the pole fails. However, concrete, and some fibreglass poles can fail energetically and catastrophically. When this occurs, concrete often fails at two locations, one near ground and one higher up the pole. If the pole was to fail in this manner, then the reinforcement is unlikely to be able to prevent the dual failure locations, and the pole will still fall to the ground from the top failure location.

Hence, when assessing the potential for reinforcing alternative pole materials, these failure mechanisms will need further investigation.

5 SUMMARY

The following rating system is provided to allow Essential Energy to better compare different reinforcement types. Each element of reinforcement performance is given a score from 1 to 5, where;

1 = does not perform
2 = inadequate performance
3 = performs, but not as well as required
4 = performs as required
5 = outperforms requirements without compromising other aspects.

Table 1 shows an example of the rating system based on the Banded, Bolted and Rebutted reinforcement types already discussed in this report. Each element can be weighted by Essential Energy as required to give appropriate emphasis depending on importance. It is assumed that each reinforcement type is correctly sized for the design loads on the pole when determining the ratings.

Table 1: Performance rating system applied to Banded, Bolted and Rebutted reinforcement types on timber poles.

Performance Aspect	Banded Reinforcement	Bolted Reinforcement	Rebutting
Durability	4	4	4
Connection	4	3	4
Pole Strength	5	3	4
Foundation Capacity	4	4	5
Reinforcement Strength	4	4	4
Failure Mechanism	4	2	4
Total (Max 30)	25	20	25

Choosing appropriate reinforcement types and sizing the reinforcement correctly for the pole can involve a complex range of issues that need to be considered. However, based on our experience with the above three reinforcement types, if banded and rebutted poles are correctly designed and installed, they will provide a much more effective risk reduction measure than bolted reinforcements due to the tendency of bolted reinforcements to fail at the top bolts in a catastrophic manner. This is the key consideration from a structural performance perspective.

6 RECOMMENDATIONS

If Essential Energy are going to consider other reinforcement types for timber poles, or if they are going to consider reinforcing poles made out of alternative materials, this document provides a starting point for issues that need to be considered.

Of the three reinforcement types discussed in this report (banded splint, bolted splint and rebutting), our knowledge and experience leads us to recommend that bolted reinforcements are the least favourable reinforcement type in terms of risk mitigation and structural performance. If the banded and rebutted reinforcements are correctly designed for strength and durability, and correctly installed, then there shouldn’t be a considerable difference in their structural performance and risk mitigation performance. The difference will be apparent when considering installation issues and cost.

The performance rating system shown in Table 1 can be expanded to include cost and installation aspects, as well as a weighting system to prioritise each aspect based on Essential Energy’s corporate objectives. It could potentially be expanded to provide more detail within each aspect, but at the very least it should cover the six aspects shown.

7 REFERENCES

1. **Essential Energy.** *Operational Manual: Asset Inspection.* ISSUE 4. Port Macquarie : Essential Energy, 2012. CEOM7005.

2. **Spencer, N. J.** *Hillston Feeder Reinforcement Review.* Newcastle : URI Engineering, 2014.

3. **Standards Australia.** *Steel Structures.* Sydney : SAI Global, 1998. AS 4100.