

SCOSS ALERT Tension cable and rod connectors

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WHO SHOULD READ THIS ALERT?

This Alert is aimed at those who own or commission or design or construct structures which contain steel tension elements with end connectors.

INTRODUCTION



Figure 1 Typical tension rod with end connector used on a bridge (**not** from a CROSS report)

Tension rods provide an efficient means of transferring large forces over long distances with a minimal quantity of material. They are now commonplace and Figures 1 and 2 illustrate such systems on a bridge and a building. Tension systems often work at high proportions of their tensile strength and a single failure on one of the connectors raises the possibility of progressive collapse.

Reports to CROSS have highlighted a number of instances where suspension fork connectors for high strength steel bars (cables or rods) acting in tension have failed at loads well below the intended design capacity or have been found to be substandard either during construction or in service.

The failures can be attributed to a number of factors, either in isolation or combination. These include:

- Issues with the material quality and dimensional accuracy of components manufactured by casting (defects and lack of toughness), compounded by inadequate or misleading records.
- A lack of understanding of the behaviour of pinned joints in service.
- Misalignment, both in the connection to a gusset or fin plate and in the geometrical accuracy in the holes bored in the forks of the connector and the degree of tolerance required.

It is important to ascertain that the documentation accompanying safety critical components is accurate and genuine.

It is considered that most failures have been observed in tension rod connectors because they are generally loaded to a significant proportion of their capacity on installation. Furthermore, they can be sensitive to secondary stresses if the end connections are not aligned correctly.

Tension rods and their connectors are usually sold as proprietary products. There is a concern that they can be accepted into a design based on generic information provided by the manufacturer, rather than by verification against the specific performance requirements of a project. In view of this, it is recommended that the following factors are taken into account when procuring end connectors for tension rods.



Figure 2 Typical tension rod with end connector used on a building. (**not** from a CROSS report)

KEY CONSIDERATIONS

Specification

A well-defined specification should be prepared that sets out the requirements for materials, procedures and operations in manufacture, testing, examination, transportation and delivery as well as in service. It should take account of the specific requirements of the project in addition to more generic requirements. Manufacturers will have their own procedures and specifications, so it is important to establish that a particular project specification takes precedence in the event of differences or ambiguities arising.

The key properties are strength, ductility and toughness. The role of strength is obvious. Ductility is required in addition to strength to permit redistribution of the stress concentrations which are inevitable from a number of causes. Toughness (Charpy value) is essential to limit the risk of fracture and crack propagation. Having adequate toughness is particularly essential in thick steel sections – see 'Size matters for Structural Engineers' ^[1]. Fracture arises consequent on low toughness, tensile stress and stress concentrations from defects. It is more likely to occur in cold temperatures. Controlling defects is important in assuring fracture toughness in all products. If special end connectors are made it is essential to preserve a significant ratio between ultimate tensile strength and yield and to have sufficient ductility and toughness. The example shown in Figure 3 involves fracture rather than just yield.



Figure 3 Failed connector (not associated with the structures shown in Figures 1 and 2 or taken from a CROSS report)

End connectors for tension rods are relatively specialist products so it may be necessary in part to rely on the manufacturer's specialist knowledge and bespoke procedures. It is expected that manufacturers will wish to protect their specialist 'know-how'; however, their products should be subject to reasonable independent scrutiny prior to acceptance. Manufacturers may be asked to advise on defining specification requirements and acceptance criteria. However, in such circumstances, requirements should be established and agreed in advance of manufacture and supply. For example, it should be agreed what tests will be undertaken; the extent of such tests and what records will be provided, and when, and what acceptance criteria will apply; preferably with reference to published standards.

Testing

Consideration should be given to independent third party validation and this should be agreed with the manufacturer prior to manufacture and supply. Such validation may include witnessing manufacturing operations, selection of samples of raw materials and manufactured components, and testing at different temperatures. Testing may consist of non-destructive examination of components to be accepted into the works or destructive testing of samples selected specifically for this purpose. It is particularly important for those specifying the various tests to understand their role and limitations.

Consideration should also be given to proof testing prior to incorporation of a connector into the works. The extent of proof testing may be set to suit the nature of the project. For example, where connectors are critical to the integrity of the structure (with little or no structural redundancy) and highly utilised, consideration should be given to proof testing them all. Where 100% proof testing is not appropriate, a sufficiently large sample should be tested to be representative. Confidence in the appropriate design strength for the connector should be obtained by statistical analysis and the derivation of a suitable factor of safety. Where proof testing is not carried out, larger factors of safety should be adopted to compensate for the greater degree of uncertainty. With such tension systems quality of every key item is critical, and if there is a defect in one component there may be defects in others due to the repetitive nature of the manufacturing process.

Caution should be exercised where historical test records are offered as proof of compliance with specified requirements. It should be established that the design tested is identical to that being offered and was manufactured using exactly the same materials, process, tolerances and specification. Material variability should also be taken into account when considering acceptance on this basis. In these circumstances quality assurance may not provide the assurance that is desired due to the variability that can exist between components.

Defect acceptance

End connectors for tension rods are often manufactured by casting. While casting is an established technique, it is an imperfect science. Attention is drawn to SCOSS Topic Paper SC/10/029 - Major Cast Metal Components^[2]. It may be necessary to repair cast components after initial manufacture to bring them to a standard where they may be accepted into the works. Acceptable methods of repair and defect acceptance criteria in accordance with published standards should be agreed with the manufacturer prior to manufacture and supply. It should be noted that the acceptance of a defect may depend on its location in the cast component and the effect this may have on capacity. Thus different criteria may apply to different parts of a single component.

Tolerances

Careful consideration should be given to dimensional tolerances and the effect these may have on assumptions made in the design. For example misalignment or imperfect fit may give rise to severe stress concentrations. It is expected that general steel tolerances will be defined for the project (for example, in accordance with one of the execution classes given in EN1090-2). However, these may not be sufficient for the specific requirements of tension rod end connectors. For example, it is usually assumed that fork type connectors carry half of the tension in the rod on each side. For this to be achieved, the holes in the plates must be bored square and true, within tight pre-defined tolerances. Additional requirements may also be necessary for the general steelwork to which the forks connect, for example to ensure correct alignment and a concentric arrangement that effectively eliminates secondary bending effects.

EXISTING STRUCTURES

The chronology of the reports received to date suggests that sub-standard components may have been included in UK structures. Therefore, a retrospective assessment of the risks may be appropriate. To keep this in proportion, it is recommended that any assessment targets the most critical (i.e. significant to structural safety in the event of failure) and most vulnerable (i.e. greatest propensity to high load or damage) components. As a first step, likelihood of occurrence could be gauged by establishing the place of manufacture and the rigour applied to quality control at the time of construction and the design load and resistance factors. If, following this exercise, the residual risk is deemed too high, limited testing on a sample of components in the structure should be carried out. This may necessitate removal rather than in-situ testing. Consideration may also be given to structural redundancy; this could reduce the extent or remove the need for testing.

SUMMARY

Tension rods can provide highly efficient structural members and have found favour in the architectural and engineering design of bridges and buildings. However, it is important to recognise that these products, including connectors, need to meet the particular requirements of each project. This Alert is intended to raise awareness of some of the problems encountered by the construction industry to date and provide some suggestions on key issues. The particular concern is the possibility of steel section fracture setting off a chain reaction of progressive collapse. Section fracture risk is heightened when sections are 'thick'; where the material lacks toughness and where inadequate quality control or anomalous records might have permitted in-service use with casting defects. The risk is heightened further where the product is in service with severe stress concentrations and when in service in cold temperatures. Information on concerns or failures may be sent to Structural-Safety^[3].

REFERENCES

1. FM Burdekin: Size matters for Structural Engineers, Journal of ISE Vol 77 issue 21 1999
2. SCOSS Topic Paper SC/10/029 - Major Cast Metal Components
3. Structural-Safety web site www.structural-safety.org

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