Specification of tension bar components No. 4.05

Scope

This Guidance Note presents model clauses for tension bar components for use in a project specification where execution is to comply with EN 1090-2.

The clauses may be used either as a supplement to clauses taken from the *Model Project Specification* in SCI publication P382 or as clauses to be inserted in an Appendix 18/1 that supplements the *Specification for Highway Works* (as revised in 2014).

Clauses are numbered as 'Section 13 of a document, since EN 1090-2 numbers its sections up to Section 12.

A two column format is given, with clauses in the left-hand column and commentary in the right-hand column.

13 TENSION BAR SYSTEMS

13.1 General

13.101 High strength tension bars, complete with terminations and provision for adjustment of length during installation shall be provided as shown on the drawings listed in 4.101.

Alternatively, "… listed in Appendix 18/1".

13.102 The nominal dimensions of the bars shall be as shown on the drawings

It should be made clear on the drawings whether the length is 'as manufactured' (i.e. unloaded length) or on completion (in which case the forces in the bars at that stage should be stated).

13.103 The tension system, comprising the bars, their terminations and adjusting devices shall be supplied by a specialist supplier who shall design the system such that it complies with the recommendations of EN 1993-1-11 for the tension forces specified in 13.201 and for the fatigue endurance specified in 13.401 to 13.404.

Note that the requirements in EN 1993-1-11, 6.2 apply to tension bars (Group A components) even though the wording of the clause is not always clear.

The recommendations in Annex A of EN 1993-1-11 are relevant but note that in A.2(2) reference to ultimate resistance refers to the design value rather than actual value of the manufactured bar.

13.104 Details of the tension system shown on the drawing are based on the *(insert)* system. Alternative systems may be permitted, subject to the approval of the designer of the permanent works.

The drawings will normally have been developed on the assumption of one particular system. Even where a system has been assumed, the required performance characteristics should still be stated in the specification.

13.2 Design forces in tension bars

13.201 The tension bars shall provide a characteristic value of breaking strength (F_{uk}) at least equal to the following:

Location	Characteristic value of breaking strength, F_{uk} (kN)

The ratio of characteristic value of the proof strength to the characteristic value of the breaking strength (F_k/F_{uk}) shall exceed 0.67.

The design tension resistance for components of tension rod systems is defined in EN 1993-1-11, 6.2. However, EN 1993-1-11, 7.2 requires that the stress be limited at SLS to a value dependent on the characteristic value of the breaking strength; this determines the required breaking strength when the ratio of proof strength to breaking strength exceeds 0.67, which is the usual condition. The designer will calculate the required breaking strength from clause 7.2, and will assume that the ratio exceeds 0.67.

13.202 The anchorages and fittings (nuts, couplers, clevises, pins etc.) shall be designed such that the characteristic value of the breaking strength of the rod can be resisted without exceeding yield stress.
The determination of design resistance of anchorages and fittings shall be based on the appropriate values of mechanical properties or component strengths determined in accordance with the relevant product standards.

For threaded components in tension, the rules for bolts in EN 1993-1-8, 3.6 are appropriate. It is suggested that these rules apply even though EN 1993-1-8 states that the requirements only apply to bolts listed in Table 3.4 of that Standard, which currently manufactured bars would not conform to.
For the design of end connections, the requirements of EN 1993-1-1 may determine the design tension resistance of those components.
For the design of pins, the rules in EN 1993-1-8, 3.13 are appropriate.

13.203 Where the constructor adopts an alternative construction method or sequence, in accordance with 9.304, the design axial forces for the transient design situation shall be evaluated. Where these forces would require a greater breaking strength, determined in accordance with EN 1993-1-11, 7.2, they shall be taken as the required characteristic value of breaking strength design tension resistance.

Note that EN 1993-1-11 permits lower values of partial factor for the construction phase and therefore even if the total characteristic value of tension force is greater during construction than for the persistent situation, the required breaking strength is not necessarily greater.

13.3 Constituent products of tension system

13.301 Constituent products shall comply with the following specifications:

Product	**Standard**
Tension bar	EN 10025 or EN 10083-1
Cast end connectors	EN 10340
Machined end connectors	EN 10025 or EN 10083-1
Forged end connectors	EN 10222-4
Splice connectors (couplers and turnbuckles)	EN 10025, EN10083
Pins	EN 10025, EN10083

Alternative products may be permitted, if appropriate, in order to fulfill the performance requirements of this specification, subject to the approval of the designer of the permanent works

Note that the specifications for cast components generally leave testing requirements to be agreed "between supplier and customer". See GN3.08 for further guidance.

Note that EN 10293 is not suitable for castings used in this context.

13.302 Threaded components in tension shall have ISO metric rolled threads complying with ISO 261 or BS 3643.

Unified or ASTM threads may be accepted as an alternative.
For applications where no consideration of fatigue is needed, cut threads would be acceptable.

13.303	The strength grade of the products shall be chosen in order to fulfil the performance requirements of this specification.	*Because the supplier is to design the system, there's no need to specify the grades.*
13.304	The products shall have a specified minimum toughness appropriate to the dimensions and detailing sufficient to meet the requirements of EN 1993-1-10 for a design steel temperature (defined as the value $T_{md} + \Delta T_r$ in expression (2.2) in EN 1993-1-10, 2.2(5)) of … °C. The supplier shall provide detailed confirmation of determination of required toughness either through: a) fracture toughness calculations in accordance with BS 7910 and associated inspection and test plan that confirms limiting imperfection size has not been exceeded for all components; or, b) through proof load testing at the design steel temperature of *(insert sampling required)* complete assemblies supplied.	*Insert a value for lowest steel temperature, typically −20°C.* *It may be difficult to determine a reference temperature, in accordance with EN 1993-1-10 and its National Annex, for the particular size and shape of a component. In such a case, evaluation by fracture mechanics may be necessary.* *The mechanical properties of castings are determined on separately cast test bars. The Inspection and Test Plan has to ensure that the casting properties stated on the certificate are representative of the casting itself. There is also the risk of casting defects. As such, the castings need to be subjected to NDT using an appropriate defect acceptance standard.* *Proof load testing is both costly and impacts the delivery program. However, for large diameter bars and complex terminations, it is probably more reliable than numerical methods. Sampling should be from the production run and include at least one of each size of bar in the project.*
13.305	A record shall be maintained of the source of, and test certificates for, main structural steel elements in order to provide traceability for each product. Traceability shall be by piece.	
13.306	The supplier shall permit third-party inspection of product tests.	*Third party inspection is not always necessary but it should be possible to request it.*

13.4 Fatigue test on tension bars

13.401 Fatigue tests shall be carried on … (*insert number*) complete tension bar assemblies, of nominal length … pin to pin. The application of load shall be such that the pins are held with a misalignment angle of (*insert angle, typically 0.5 degree*) … (from square to the axis of the bar) at each end.

It is important for a representative fatigue test that the test is performed "as designed", e.g. if proof loading of components is not specified for the project, then proof loading should not be performed before fatigue testing.
The specified angle should allow for both initial tolerances on position and temperature movements.
Fatigue testing is both costly and time consuming. The Designer should consider the necessity of the test on the basis of the fatigue demand on the tension bars.
The manufacturer should be permitted to submit historic tests on the system provided the testing has been carried out on components that are substantively similar to those to be used.

13.402 A constant amplitude fluctuating load shall be applied for 2 million cycles per test, in accordance with EN 1993-1-11, A.4. The value of the constant and fluctuating components of load shall be such that the stresses calculated on the nominal diameter of the bar are as given in Table A.4.1 of EN 1993-1-11.
Fatigue testing shall be carried out under load control and not under extension control

Although the wording in EN 1993-1-11, A.4.1 is not entirely clear, it may be taken that $\sigma_{uk} = f_u$ i.e. that F_{uk} is based on the lesser of the cross sectional area of the bar and the tensile stress area of threads in tension and that the varying axial force reduces the stress below σ_{sup}.

13.403 Finally, the test specimen shall be loaded to fracture and should develop a minimum tensile force equal to 92% of the actual tensile strength of the bar (determined from a sample of bar taken before assembly for the fatigue test) or 95% of the specified minimum ultimate tensile strength of the bar, whichever is greater. The strain under this load should not be less than 1.5%., measured pin to pin. Failure is to occur in the bar and not the anchorage.

13.5 Non destructive tests on cast components

13.501 Magnetic Particle Inspection (MPI) of all castings shall be in accordance with EN 1369, acceptance criteria: SM/LM/AM level, with 100% coverage.

Alternatively, testing to DIN 18800-1:2008-11, acceptance criteria: MS2 would be sufficient.

13.502 Ultrasonic Testing (UT) shall be in accordance with EN 12680-1:2003. Acceptance criteria: severity level 2.

13.503	The reference standard for assessing the quality of cast components shall be ASTM E186 – 10: *Standard Reference Radiographs for Heavy-Walled (2 to 4½-in. (50.8 to 114-mm)) Steel Castings*. Full volumetric coverage during radiographic testing of cast components, primarily terminations, shall be required and must be demonstrated in the Radiographic Technique Sheet. The maximum accepted severity level of graded discontinuities shall be Level 3..	*Note that EN 12681 does cover assessment of castings but ASTM Standard is preferred due to availability of trained radiographers & reference graphs.* *See GN3.08 for guidance on specifying severity levels*
13.504	The extent of MPI and Radiographic testing for cast components shall be 100%.	*100% is appropriate for EXC3 and above. For EXC2, a lesser extent may be specified.*
13.6	*Dimensional irregularities of termination components*	
13.601	The shape and fit up of the termination components for a tension bar system shall not deviate from the specified system dimensions to the extent that detrimental stress concentrations and crack propagation could result. The manufacturer shall provide details of tolerances on shape and fit-up that have been included in the design of the component.	*The dimensional information for the manufacture of termination components should include tolerances and limits relating to fit up.* *This requirement is particularly relevant to castings where the manufacturing process and the criticality of toughness are potentially less readily controlled than for components that are fabricated.*
13.7	*Assembly and Installation*	
13.701	Assembly and installation of the tension rods shall be carried out in accordance with specialist supplier's recommendations. In particular the supplier shall define: • Required engagement of threads in components; • permissible deviations in alignment of seating of anchorage and axis of element; • permissible angular deviation in clevis pin axis; • requirements for lock-off of couplers and adjustment components; and, • fixing devices for pins.	
13.702	The tension rods are to be installed and adjusted such that the final tension is within the larger +/- (*insert*) kN or +/- (*insert*) % of the values shown on the drawings.	*The designer is to insert practical limitations on the variation in initial tension that is permissible within the design. Alternatively, if profile is considered more critical than load, tolerance on length should be defined.*

13.8	*Durability*	*The system shall be designed to be replaceable and typically the design life shall be 60 years.* *A service life verification in accordance with the principles of EN 1990 may be carried out by designer or supplier.*
13.801	The components of the system that are exposed shall be protected from corrosion by ….	*Designer to define choice of allowable corrosion protection systems from SHW Series 1900 Type II, Type IV and/or stainless steel.* *For clevis type connections, detail is required as to how the gap between the fork and clevis is maintained or sealed.* *For galvanized rods, the supplier should be asked to demonstrate how the risk of hydrogen embrittlement and liquid metal assisted cracking is mitigated. This should include limits on hardness and control of surface preparation to avoid the generation of hydrogen.*
13.9	*Measures to limit vibration of cables in service*	
13.901	After completion of steelwork erection, including installation of parapets, and surfacing, but before opening to traffic, the constructor shall measure on site the amplitude of hanger vibration under a wind speed of 15 m/s ±1 m/s. An anemometer shall be set up on the structure and gauges on each hanger for a suitable period of time to enable a full data set to be analysed. If the amplitude of vibration exceeds *L*/500, where *L* is the length of the bar (pin to pin), the adoption of a damper system will be required, such as Stockbridge dampers. The design of the appropriate dampers would need to be determined for the particular case: the designer of the permanent works will design the system at that time. Where dampers are installed the constructor shall re-measure the amplitude of hanger vibrations.	
13.10	*Measures to mitigate environmental effects*	
13.701	*Insert optional clause*	*It may be desirable to specify mitigation measures such as devices to warn large birds of the presence of such slender components as bars.*

References

1. EN 1090-2:2008+A1:2011, Execution of steel structures and aluminium structures. Part 1, Technical requirements for steel structures.
2. Steel Bridge Group: Model project specification for the execution of steelwork in bridge structures, (P382), SCI, 2009.
3. Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, Agency, 2014
4. Manual of Contract Documents for Highway Works, Volume 2, Notes for Guidance on the Specification for Highway Works, Series NG1800, 2014 (*Includes* Sample Appendix 18/1)

Reference Standards to be included in the Project Specification

Some of the Standards referred to above are not in the list of referenced documents for execution in EN 1090-2. The following Standards should be added as referenced documents in the Project Specification.

EN 1369:2012, Founding. Magnetic particle testing.

EN 10083-1:2006, Steels for quenching and tempering. General technical delivery conditions.

EN 10222-4:1999, Steel forgings for pressure purposes. Weldable fine-grain steels with high proof strength.

EN 12680-1:2003, Founding. Ultrasonic examination. Steel castings for general purposes.

ASTM E186 – 10, Standard Reference Radiographs for Heavy-Walled (2 to 4½-in. (50.8 to 114-mm)) Steel Castings.

BS 3643-1:2007, ISO metric screw threads. Principles and basic data

BS 3643-2:2007, ISO metric screw threads. Specification for selected limits of size

ISO 261:1998, ISO general purpose metric screw threads. General plan