Timber engineering hardware and connectors

The term ‘timber engineering hardware’ encompasses a diverse range of metal components, made of steel plate, sheet or strip, which are used to connect timber members together, usually in conjunction with dowel-type metal fasteners.

Timber engineering components have widely replaced traditional carpentry joints, due to their ease of use, ready availability and the avoidance of complex machining of timber members. Examples of common types include joist hangers, framing anchors, truss clips and wall ties. Mass-produced timber engineering hardware is usually made from pre-galvanized mild steel, from 1 - 3 mm thick. However, heavier components are also made for large structures in thicknesses up to 12 mm, sometimes in proprietary forms. These thicker components are usually galvanized after manufacture; this has the advantage that the edges, which are otherwise exposed by cutting or drilling, are fully protected. Some manufacturers also supply stainless steel components to order.

Timber connectors improve the transfer of loads by increasing the bearing area between the fasteners and the timber. They are of two broad types – those which use bolts to draw and or hold the members together and metal plate types which allow members to remain in the same plane. Metal plate fasteners rely on a number of nails, or other dowel-type fasteners, or upon integral teeth.

Dowel-type metal fasteners are not covered here, for further information see Wood Information Sheet 2/3 – 52 *Fasteners for structural timber: nails, screws, bolts and dowels*.

Metal plate fasteners

Metal plate fasteners can be divided into two main groups:

- Two-dimensional plates ie punched metal plates or nail plates, used to join two or more pieces of timber of the same thickness, in the same plane
- Three-dimensional nail plates such as joist hangers, framing anchors, truss clips and wall ties.

Two-dimensional plates:

Punched metal plates

A punched metal plate (Figure 1) is defined in BS EN 1075 as a fastener made of metal plate, having integral projections punched out in one direction and bent perpendicular to the base of the plate. They are generally manufactured from pre-galvanised mild steel strip or stainless steel strips, with thicknesses ranging from 0.9 to 2.5 mm.

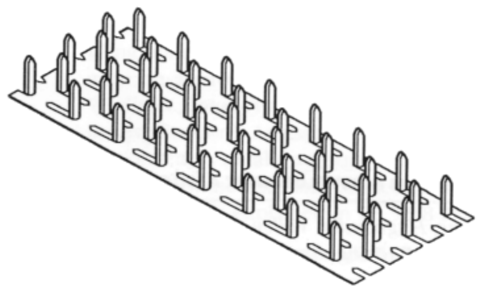

Figure 1 Punched plate metal fastener

Punched metal plate fasteners are suited to factory prefabrication and are able to transfer member forces with smaller connection areas than are possible with hand-nailed plates. They are widely used in trussed rafters designed and manufactured in accordance with BS 5268-3 and BS EN 1059, but also for in-plane joints in other components. Care should be taken in handling such components since the joints are flexible out-of-plane and can be damaged during erection. Guidance on handling timber trussed rafters is given in BS 5268-3.

Different forms of proprietary punched metal plates have been developed, involving a variety of nailing patterns, nail lengths and nail shapes. A common design approach is being established in Eurocode 5 and design procedures are well defined in BS 5268-3 and accompanying documents. Most design of punched metal plate joints is undertaken by specialist fabrication companies, using purpose-written Computer Aided Design packages.

Load carrying behaviour

The load is transferred in a punched metal plate fastener from the timber member into the plate teeth, then from the teeth into the steel plate and across the joint interface, then back down into the teeth in the other member. Joints are designed and fabricated with pairs of plates on opposite faces of the members.

BS 5268-3 gives positioning rules and rules for load capacity for punched metal plates. Permissible loads, for use with the Code, were determined by testing and are given in Technical Approvals, (see Product Approvals and Certification).

Eurocode 5 includes a number of formulae, which predict the strength of joints based on certain key characteristic plate strength properties. These plate properties should be established from standard tests whose basis is given in BS EN 1075. In addition to calculation rules, Eurocode 5 includes certain ad-hoc rules for dimensioning punched metal plate fasteners.

Joint slip may be allowed for in truss deflection calculations either by the use of values prescribed in Codes or by slip moduli established from joint tests in accordance with BS EN 26891.

Nail plates

Nail plates are usually manufactured from galvanised mild steel capable of receiving hand-placed nails. A typical thickness is 1 mm, with pre-formed holes for nails (Figure 2). Manufacturers recommend the use of improved nails, eg square twisted types. The nails should be a tight driving fit in the plate holes.

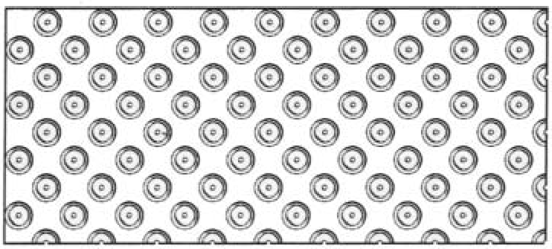

Figure 2 Nail plate

Three-dimensional plates:

Figures 3, 4 and 5 show examples of three-dimensional nail plates.

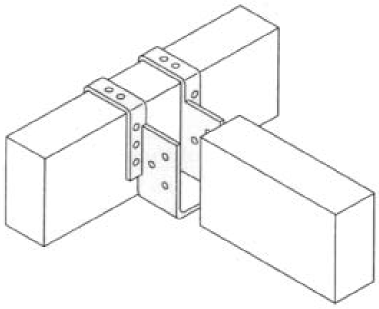

Figure 3 Joist hanger or shoe for principal beam

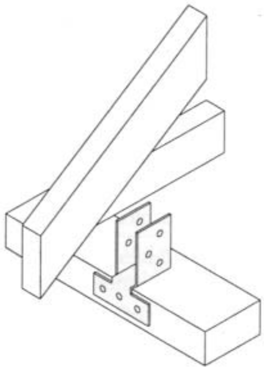

Figure 4 Truss clip

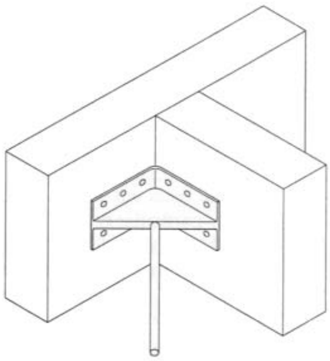

Figure 5 Anchorage for steel tie member

The strength and stiffness properties of engineering hardware products are most commonly derived through testing but, despite the range of 'off-the-shelf' components available from a number of manufacturers, until recently there has been little standardisation in the industry.

Currently no British Standard exists for testing/assessing three-dimensional nailing plates for timber-to-timber joints, however the European Organisation for Technical Approvals (EOTA) has issued a *Guideline for European Technical Approval of Three-dimensional Nailing Plates* (ETAG 015) which can be followed. Test data may be used to calculate characteristic design values for use with Eurocode 5 design procedures. In addition, these characteristic values can be converted to 'Safe Working Loads', which are suitable for the BS 5268 design approach.

Standards covering timber-to-masonry engineering hardware include:

BS 6178-1, for joist hangers built into masonry walls
BS 5268-6: Section 6.1, which includes a test for the strength and stiffness of wall ties for use in timber frame construction
DD 140-1, which proposes a test method for wall ties in masonry-to-masonry and masonry-to-timber frame cavity walls
DD 140-2 for design of wall ties
BS EN 845-1, for ties, straps, hangers and brackets in masonry walls
BS EN 846, for test methods
(See References).

Lack of control on site and lack of understanding on the part of site operatives may result in timber engineering hardware being inadequately fixed. Plasterboard nails, allegedly, are often used on site, instead of the improved nails specified by the manufacturers for fixing timber engineering hardware. Tests conducted by TRADA using plasterboard nails, in place of square twisted nails, showed a 16% reduction in the strength of the joint and an increased deflection.

Another common occurrence is insufficient nails being used. Tests using only 6 nails in a joist hanger, instead of the required 20, resulted in a loss of strength of 28%, although deflection was not increased. These results serve to quantify and reinforce the need for adequate control on site, to ensure the correct installation of timber engineering hardware.

Connectors used with bolts

BS 5268-2 includes three types of bolted connector: toothed-plate connectors, split-ring connectors and shear-plate connectors and refers to BS 1579: 1960 *Connectors for timber for specification*. However, this standard is now withdrawn and has been replaced by BS EN 912 *Timber fasteners - Specifications for connectors for timber*; this uses different terminology, see Table 1.

BS 5268-2 includes rules for the design of joints using bolted timber connectors, together with guidance on appropriate edge and end distances (see WIS 2/3 – 52 *Fasteners for structural timber: Nails, screws, bolts and dowels*). Assessment of the effective cross-sectional area to take account of the timber section removed for the bolts and connectors is also important and this is explained in BS 5268-2.

The ENV version of Eurocode 5, published in 1994, does not provide design procedures for timber connectors. Expressions to derive characteristic load carrying capacities are included in the latest Eurocode 5 draft, however this is still to be published. In the meantime, a TRADA Interim Technical Data Sheet *Design data for timber connectors* for use with DD ENV version of Eurocode 5 provides guidance.

The suitability of the various types of connectors is summarised in Table 1.

Table 1 Connectors for structural timber

Type of connector		Loading		Easily de-mountable	Suitable for use in: Solid timber, glulam etc; density *		Plywood, chipboard, OSB	Steel-to-timber
BS 1579:	BS EN 912	lateral	axial		< 500 kg/m^3	≥ 500 kg/m^3		
Split-ring connectors	Type A Ring connectors	✓	☆	✓	✓	✓	≥ 22mm thick	
Shear-plate connectors	Type B Steel plates	✓	☆	✓	✓	✓	≥ 40mm thick	Single sided
Type C Toothed-plate connectors		✓	☆		✓		≥16mm thick	Single sided

* Characteristic density at 20°C; 65% relative humidity. Less than 500 kg/m^3 corresponds to softwoods in strength classes C14-C40.

☆ Primarily intended for lateral loading, but the bolt can take axial loading if this occurs.

Split-ring and shear-plate connectors

Split-rings and shear-plates may be formed from steel, aluminium cast alloy or cast iron. They are circular, with diameters from 60 to 260mm, and are placed in pre-cut grooves produced by rotary cutters.

In BS EN 912 ring connectors (Figure 6) (known as split-rings in BS 1579 and BS 5268-2) are designated as Type A. Shear-plates (Figure 7) are Type B.

Split-ring connector units consist of one split-ring with bolt, washers and nut, and the ring itself may be of parallel or bevel-sided form. The bevel-sided form is claimed to be easier to insert and to give greater load capacity, although BS 5268-2 does not distinguish between the two in recommending basic loads.

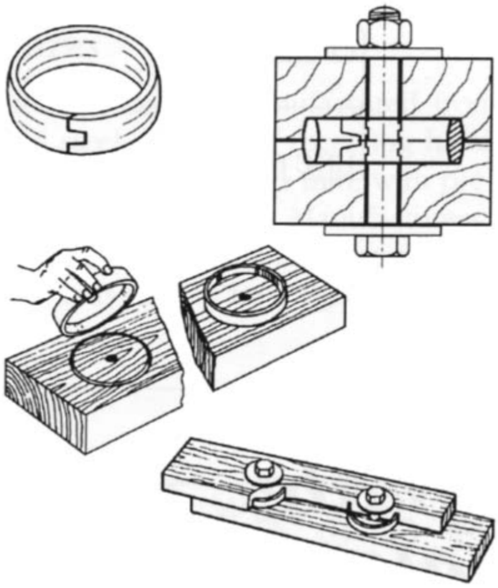

Figure 6 Split-ring connectors

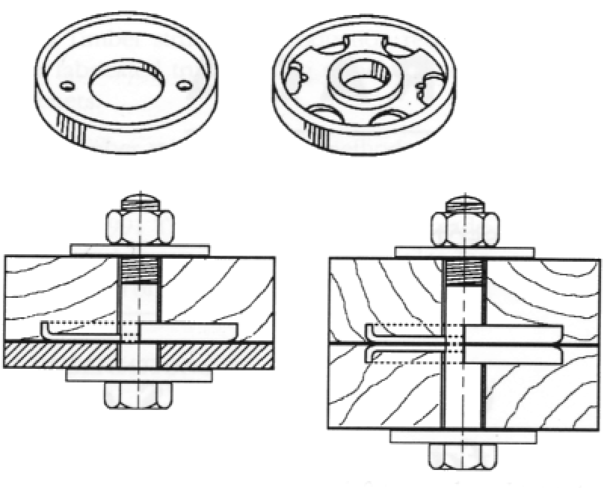

Figure 7 Shear-plate connectors
(top left) pressed steel type, (top right) malleable cast iron type.

BS 5268-2 does not incorporate design values for all of the types and sizes of the ring and shear-plate connectors specified in BS EN 912. It includes only ring connector types A2 and A3 and shear connector types B2 and B3.

Split-ring and shear-plate connectors are used in laterally loaded joints. Split-ring connectors are exclusively applied in timber-to-timber joints, whilst shear-plate connectors may be used for steel-to-timber as well. Shear-plate connectors are normally installed before the assembly of the structure, although the joints are demountable.

The fabrication of split-ring and shear-plate connector joints comprises several steps. First, the hole for the bolt and the connector groove are drilled into the wood. The cutters used to make the grooves should correspond to the shape of the ring cross-section. Then the connectors are placed into the grooves and the timber members to be connected are put together. Finally, the bolts are inserted into the holes and tightened. Alternatively, coach screws may be used to hold the connection together.

Load carrying behaviour

Precision in grooving and boring is essential for the correct installation and satisfactory performance of these types of connector. The load in a split-ring connector joint is transferred from one timber member to another through embedding stresses via the split-ring connector. The connected member must also offer adequate shear resistance.

In shear-plate connections, the load transfer is slightly different: after the transfer of the load into the connector, the bolt is loaded through bearing stresses between the shear-plate and the bolt. The load is then transferred through the shear resistance of the bolt and thereafter to the second shear-plate or a steel member. In shear-plate connections the diameter of the hole in the shear-plate consequently corresponds to the bolt diameter plus a small tolerance. Due to this tolerance, a greater initial slip can be expected in shear-plate connections.

Joint slip always needs to be considered in designs for split-ring and shear-plate connectors whether using BS 5268 or the Eurocode 5 design method.

Toothed-plate connectors

Toothed-plate connectors, denoted as Type C in BS EN 912, are made from cold-rolled uncoated low-carbon narrow steel strips or hot-dipped galvanized mild steel. They are available in a variety of shapes and sizes, with diameters ranging from 38 to 165 mm. Larger connectors are available for use in glued laminated members. They are mostly circular, but square and oval shapes are also available. BS 5268-2 gives design values for types C6, C7 and C8 of BS EN 912.

The joints are normally held together by bolts installed with round or square washers of a size about half the diameter of the connectors used. Like split-ring or shear-plate connectors, toothed-plate connectors are used in laterally loaded timber-to-timber and steel-to-timber joints. They are pressed into the timber members to be connected. Double-sided toothed-plate connectors (Figure 8) are used in timber-to-timber joints; alternatively, pairs of single-sided connectors may be used back-to-back if the joints should be demountable. Single-sided connectors are also used in steel-to-timber joints. Since the teeth are pressed into the timber, toothed-plate connectors can only be used in timber or wood-based panel products with a characteristic density of not more than about 500 kg/m^3.

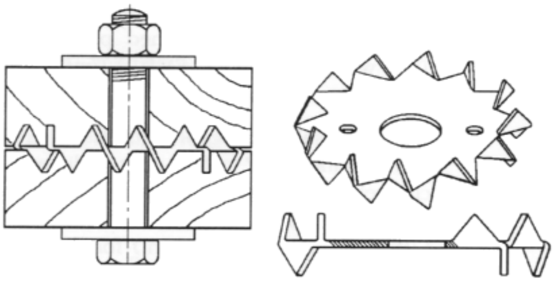

Figure 8 Double sided tooth plate connectors

Toothed-plate connector joints are manufactured in a similar way to bolted joints. First, the hole for the bolt is drilled in the wood, then the connectors are placed between the timber members and the connection is pressed together. Pressing the connector teeth into the timber requires considerable force and either a hydraulic press or a high strength bolt is used. Only for small connector diameters, up to 65 mm, can the permanently installed mild steel bolt be used. If bolts are used to press the connector teeth into the wood, large washers are required because of the otherwise high stresses perpendicular to the grain and the consequent crushing of the timber. After pressing, the high strength bolt is replaced by the permanent mild steel bolt using washers normal for timber structures (see WIS *Fasteners for structural timber: nails, screws, bolts and dowels*). Coach screws may also be used in connection with toothed-plates, as an alternative to bolts.

Load carrying behaviour

The load in a double-sided toothed-plate connector joint is transferred from one timber member to the other through embedding stresses into the teeth of the connector, through the plate and into the teeth on the opposite side. In single-sided toothed-plate connections, the load transfer is slightly different: after the transfer of the load into the connector, the bolt is loaded through embedding stresses between connector and bolt and the load is transferred by shear in the bolt. Then, either the steel member, or the second toothed-plate is loaded by the bolt. In single-sided connections, the diameter of the hole in the toothed-plate consequently corresponds to the bolt diameter plus a small tolerance. Due to this tolerance, a larger initial slip can be expected in single-sided connections.

Summary: Split-rings and shear-plates

- Split-ring connector joints are used in laterally loaded timber-to-timber connections, whilst shear-plate connector joints can also be applied in steel-to-timber connections.
- Timber and connector dimensions, spacing, end distances and density are the primary influence on the connection strength. These are stipulated in design codes.
- Connection stiffness depends mainly on the connector diameter and the timber density.

Summary: Toothed-plates

- Double-sided toothed-plate connector joints are used in laterally loaded timber-to-timber connections, whilst single-sided toothed-plate connector joints can be used in steel-to-timber connections and in demountable timber-to-timber joints.
- Connector and timber dimensions, as well as the load carrying capacity of the bolt are the primary influences on the connection strength.
- Connection stiffness depends mainly on connector diameter and the timber density.
- Toothed-plate connector joints cannot easily be used for timbers with a characteristic density of more than about 500 kg/m^3.

Summary: General

- Split-rings and double-sided toothed-plates are used in a similar way to one another for timber -to-timber joints. They transfer the load directly between the surfaces of the members that are in contact. Assembly can be done on site.
- Shear-plates and single-sided toothed-plates are suitable for steel-to-timber joints as well as for timber-to-timber joints. They allow prefabrication of the joints and only the bolts are installed on site. For these connectors, the load transfer is achieved by the bolt, which is stressed in shear by bearing contact with the connector plates.

Product approval/certification

Currently manufacturers are not obliged to have their products independently tested or certified, or to follow a recognised/standardised method (by testing or calculation) when deriving load bearing capacities. Many manufacturers choose to have their products assessed and certified by an independent third party and this is often in the form of a voluntary National quality mark. In the future manufacturers will be able to CE-mark their products against relevant European harmonised Standards (hEN's) and European Technical Approval Guidelines (ETAG's).

CE marking

After many years of gestation, the Construction Products Directive (CPD) is finally coming to fruition and CE Marking is starting to appear on construction products. In the timber sector, lightweight I-joists, panel products and three-dimensional nailing plates can already be CE-marked, with other products coming on stream.

Generally CE marking should be carried out following the requirements in a harmonised European Standard for the product type. However, if the product is relatively new or innovative and no harmonised European Standard exists, the route to CE Marking is via a European Technical Approval (ETA).

In the case of three-dimensional nailing plates, an ETAG (an ETA Guideline) has been prepared, providing a framework for the ETA Approval Bodies' work. This ETAG has a relatively long transition period until June 2006 for its application.

A harmonized standard in preparation (prEN 14545) *Timber Structures – Connectors – Requirements* will allow CE marking of connectors such as ring connectors, steel plate connectors, toothed-plate connectors, nailing plates and punched metal plates.

The level of attestation for three dimensional nailing plates, shear-plates, toothed-plate connectors, punched metal plates and nailing plates is 2+ "Factory production control (FPC) certification with continuous surveillance". The level of attestation for split-ring connectors is 3 "Initial type testing". This means that the manufacturer and the Notified Body have to undertake the following tasks:

Task	*Manufacturer*		*Notified Body*	
	2+	*3*	*2+*	*3*
Factory production control	✓	✓	-	-
Further testing of samples taken at factory according to prescribed plan	✓	-	-	-
Initial type testing	✓	-	-	✓
Certification of Factory production control	-	-	✓	-
Surveillance of Factory production control	-	-	✓	-

Voluntary National Certification

Timber engineering hardware manufacturers can choose to have their products tested, assessed and certified by an independent body.

BM TRADA Certification operates a Q-Mark Product Certification Scheme for timber engineering hardware. The scheme follows test standard BS 6178-1:1990 for timber-to-masonry products and a TRADA method for timber-to-timber products. The TRADA test method was developed on the basis of a Government-funded research project. It closely matches the method specified in ETAG15 and includes derivation of 'Safe Working Loads' for use in conjunction with British design codes on the basis of the test data. Members of the scheme are subject to ongoing checks on production and performance through regular audit tests and inspections.

Fire resistance

The calculation methods for the performance of timber in fire given in BS 5268-4.1 apply only to timber members where the fasteners are fully protected from the effects of fire. All-round protection with timber or wood-based materials offers insulation from heat, thereby protecting the steel members. Joints are considered protected if the fasteners are covered with adequate protective plugs of timber or wood-based panels. When published, the EN version of Eurocode 5-1-2 will give a series of calculation methods of varying complexity for the fire resistance of timber members and timber components, with the basic method being similar to that contained in BS 5268-4.

Protection / Durability

The performance of a connection in the long term will depend upon the durability of all of its parts ie the metal hardware and fasteners, the timber members and any other materials, eg masonry, which may be involved. It is essential, for example, that the level of protection provided for the hardware should be matched by a similar level of protection for the fasteners, nails, bolts etc, which fix it.

The performance of metal hardware under test will be a measure of its performance in service only if its mechanical properties do not deteriorate through corrosion, embrittlement or fatigue. The choice of hardware must, therefore, relate not only to the loads it must carry, but also to its intended service environment. Different materials and protective treatments may thus be required for different environments. There are several Standards which relate to steel and its protection (see References).

Components for timber-to-masonry joints

BS EN 845-1 *Specification for ancillary components for masonry. Ties, straps, hangers and brackets* recommends corrosion-resistant materials and zinc or organic coating thicknesses for protection of a variety of materials.

Components for timber-to-timber joints

The recommendations for the protection of steel fasteners against corrosion, included in Eurocode 5, are shown in Table 3. The three Service Classes are defined in Table 4. Stainless steel is highly resistant to corrosion and requires no further protection, but certain types have caused problems in swimming pools, due to stress corrosion cracking. Detailed advice is contained in the Nickel Development Institute document *Stainless steel in swimming pool buildings.*

BS EN ISO 3506-1-1998 *Mechanical properties of corrosion-resistant stainless steel fasteners: Bolts, screws and studs* gives guidance on choosing suitable grades of stainless steel fasteners.

Table 3 Eurocode 5 Recommendations for the protection of steel fasteners (related to ISO 2081)

Fastener	Service Class 1	Service Class 2	Service Class 3
Nails, dowels, screws	None	None	Fe / Zn 25c
Bolts	None	Fe / Zn 12c	Fe / Zn 25c
Staples	Fe / Zn 12c	Fe / Zn 12c	Stainless steel
Punched metal plate fasteners and steel plates up to 3 mm thick	Fe / Zn 12c	Fe / Zn 12c	Stainless steel
Steel plates over 3 mm, up to 5 mm in thickness	None	Fe / Zn 12c	Fe / Zn 25c
Steel plates over 5 mm	None	None	Fe / Zn 25c

Notes: If hot-dip zinc coatings are used then Fe / Zn 12c should be replaced by Z 275 and Fe / Zn 25c should be replaced by Z 350, both in accordance with EN 10147.
For especially corrosive conditions consideration should be given to Fe / Zn 40, heavier hot-dip coatings or stainless steel.

Table 4 Service classes defined in EC5

Service Class	Conditions
1	Characterised by a moisture content in the materials corresponding to a temperature of 20°C and the relative humidity of the surrounding air only exceeding 65% for a few weeks per year. In such moisture conditions most timber will attain an average moisture content not exceeding 12%.
2	Characterised by a moisture content in the materials corresponding to a temperature of 20°C and the relative humidity of the surrounding air only exceeding 85% for a few weeks per year. In such moisture conditions most timber will attain an average moisture content not exceeding 20%.
3	Climatic conditions leading to higher moisture contents than in Service Class 2.

References

Standards

BS 5268-2: 2002 Structural use of timber. Code of practice for permissible stress design, materials and workmanship.

BS 5268-3: 1998 Code of practice for trussed rafter roofs.

BS 5268-4.1: 1978 Fire resistance of timber structures. Recommendations for calculating fire resistance of timber members.

BS 5268-4.2: 1990 Fire resistance of timber structures. Recommendations for calculating fire resistance of timber stud walls and joisted floor constructions.

BS 5268-6.1: 1996 Code of practice for timber frame walls. Dwellings not exceeding four storeys.

BS 5268-6.2:2001 Code of practice for timber frame walls. Buildings other than dwellings not exceeding four storeys.

BS 6178-1: 1990 Joist hangers. Specification for joist hangers for building into masonry walls of domestic dwellings.

BS EN 845-1: 2001 Specifications for ancillary components for masonry. Ties, straps, hangers and brackets.

BS EN 846-5:2000 Methods of test for ancillary components for masonry. Determination of tensile and compressive load capacity and load displacement characteristics of wall ties (couplet test).

BS EN 846-6:2000 Determination of tensile and compressive load capacity and load displacement characteristics of wall ties (single end test).

BS EN 846-8: 2000 Determination of load capacity and load-deflection characteristics of joist hangers.

BS EN 846-10: 2000 Determination of load capacity and load deflection characteristics of brackets.

BS EN 912: 2000 Timber fasteners. Specifications for connections for timber.

BS EN 1059: 1999 Timber structures. Product requirements for prefabricated trusses using punched metal plate fasteners.

BS EN 1075: 2000 Timber structures. Test methods. Joints made with punched metal plate fasteners.

BS EN 10142: 2000 Continuously hot-dip zinc coated low carbon steels strip and sheet for cold forming. Technical delivery conditions.

BS EN 10147: 2000 Continuously hot-dip zinc coated structural steels strip and sheet. Technical delivery conditions.

BS EN 10292: 2000 Continuously hot-dip coated strip and sheet of steels with higher yield strength for cold forming. Technical delivery conditions.

BS EN 26891:1991, ISO 6891:1983 Timber structures. Joints made with mechanical fasteners. General principles for the determination of strength and deformation characteristics.

BS EN ISO 3506-1: 1998 Mechanical properties of corrosion-resistant stainless steel fasteners. Bolts, screws and studs.

DD 140-1: 1986 Wall ties. Methods of test for mortar joint and timber frame connection.

DD 140-2:1987 Recommendations for design of wall ties.

DD ENV 1995-1-1: 1994 Eurocode 5: Design of timber structures. General rules and rules for buildings.

ISO 2081: 1986 Metallic coatings. Electroplated coatings of zinc on iron or steel.

Other publications

ETAG 015 Guideline for European Technical Approval of Three-dimensional nailing plates. "CE Marking under the Construction Products Directive" DETR Environment, Transport, Regions. March 2001.

NB-CPD/01/012r3, 6 December 2002 Working Document "Co-ordination of Notified Bodies for the Construction Products (NB-CPD/98/019) on Council Directives 89/106/EEC".

TRADA Interim Technical Data Sheet Design data for timber connectors for use with Eurocode 5. ITD 3. 1994.

TRADA WI Sheet 2/3 - 52 Fasteners for structural timber: nails, screws, bolts and dowels. 2002

Stainless steel in swimming pool buildings. Nickel Development Institute et al. Alvechurch. 1995.

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