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Review of timber construction manual in designing traditional building

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ABSTRACT

Traditional timber joints have been one of the popular connection types for its good seismic resistance and rotation performance. However, many design provisions are not applicable to traditional joints because of complicated shape. National Design Specification for Wood Construction (NDS) and Eurocode 5 for design of timber structures (EU5) are the popular timber structure design provisions from American and European countries, respectively. Based on material strength and structure conditions, both design provisions regulate timber structures and connection members, especially metal-based mechanical connections. This study discussed design manual or provision of timber connections of NDS and EU5 to find a rational approach in designing traditional timber joints. Connection types, design values, failure theory, and strength equations were elaborated. The analysis on both provisions showed that EU5 has more connection types but fewer adjustment factors than NDS. Nevertheless, NDS and EU5 have the same failure modes to calculate load-carrying capacity of the fastener.

1. INTRODUCTION

The strength of connections determines the strength of the whole structure in a building. In traditional timber structures, the rigidity of connections usually depends on joint shape and additional dowels (e.g., mortise-tenon joints, dovetail joints, spline connections, and wood peg dowels). Recent studies found that dowel has great influences on rotational performance of traditional joints. As an additional connector, the number and physical characteristics of dowels are largely influenced by member size rather than material strength requirements (Porteous & Kermani, 2004). However, designers must provide rational approaches to determine the capacity of all-wood joinery because design provisions are often restrictive or not applicable to traditional joints (AITC, 2005).

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National Design Specification (NDS) for Wood Construction and Eurocode 5 for design of timber structures (EU5) are two common standards that regulate timber connection design. Although traditional joints or carpentry joints, glued connections, and mechanical connections are the prevalent wood connections, only mechanical connections are ruled in EU5 and NDS (Fonseca et al., 2022). In this study, timber connection design provisions from NDS and EU5 are compared to find potential development of mechanical connections in traditional joints. The type of timber connectors, design values, failure theory, and strength equation for dowel-type connections are elaborated.

2. TYPE OF TIMBER CONNECTORS

The NDS classifies mechanical connection into three types: dowel-type fasteners, split ring & shear plate connectors, and timber rivets. Meanwhile, mechanical connection in EU5 is divided into two main groups: metal dowel-type fasteners and bearing-type connectors. Split ring and shear plate connections are included in bearing type connectors in EU5. The comparison of the connector types from NDS and EU5 is shown in Table 1.

Table 1. Type of timber connectors

No	Type of connections	NDS	EU5
1	Dowel type fasteners	• Bolts • Screws (Lag and wood screws) • Nails or spikes • Drift bolts and drift pins	• Nails • Screws • Dowels • Bolts • Staples
2	Split ring and shear plate connectors (EU5: bearing type connectors)	• Split ring connectors • Shear plate connectors	• Toothed plate connectors • Split-ring connectors • Shear-plate connectors • Punched metal plate fasteners
3	Timber rivets	• Rivet connectors with steel side plates	(None)

Porteous and Kermani (2004) define dowel as the generic term for a fastener that transfers load between connected members by a combination of flexure and shear in the dowel and shear and bearing in the timber (referred to as embedment in EU5). This definition is compatible with dowel-type fasteners in NDS and EU5. NDS has fewer types of connections compared to EU5. The EU5 has dowels and staples, punched metal plate fasteners, and toothed plate. Nevertheless, NDS has timber rivets type that EU5 does not have.

In traditional joints, connection usually depends on mortises, notching, and housing. The only additional connector is using wooden dowels (square or round). In EU5, most of the design provisions for the dowel have a similar concept to bolt connection. The difference emerges from the calculation of washer strength which affects the overall strength of the connection.

3. DESIGN VALUES FOR CONNECTIONS

The NDS and EU5 consider the effect of actions and environmental factors during the design working life. Different structure conditions impact adjustment factors in calculating design value. NDS's adjustment factors contain load duration factor, wet service factor, temperature factor, group action factor, geometry factor, penetration depth factor, end grain factor, metal side plate factor, diaphragm factor, and toe-nail factor. The EU5 divides the adjustment factors into three main factors: partial safety, action, and modification factors.

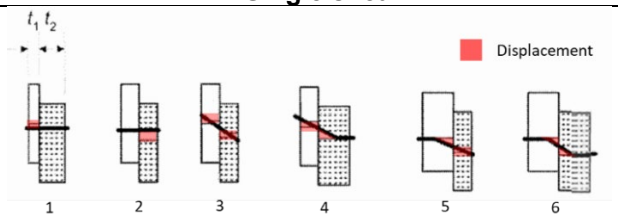
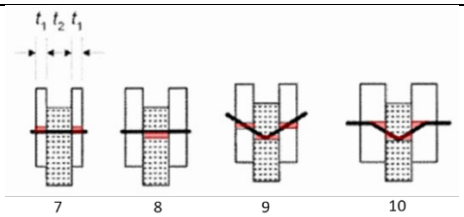
The NDS applies adjustment factors based on two methods: Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD). Meanwhile, the calculation of design value in EU5 depends on ultimate limit states (ULS) and serviceability limit states (SLS). Timber connection employs ultimate limit states to find load-carrying capacity. In calculating load-carrying capacity, NDS uses US customary unit, while EU5 uses the standard international (SI) unit. These differences may not directly impact the calculations but the size of fastener availability.

4. FAILURE THEORY AND STRENGTH EQUATION FOR DOWEL-TYPE CONNECTIONS

The essential parameters of timber connection are the load-carrying capacity and the stiffness material of the connections (Fonseca et al., 2022). NDS and EU5 provide the load-carrying capacity equations for single-shear and double-shear connections based on failure modes. These equations were proposed by Johansen in 1949 and adopted by the EU5 European Standard (Gonzales Fueyo et al., 2009). Wood species density, angle of load to grain, spacing between mechanical fasteners, and edge and end distances influence the strength of mechanical fasteners. Subsequently, the density of wood mainly influences the friction between the dowel and the wood.

Both design provisions generally employ the same failure mode shapes, but the order and terms are slightly different. Due to different recognition of the main wood member, single shear failure on general modes 4 and 5 for NDS is swapped with general modes 5 and 4 for EU5. The general modes 1 and 2 are single shear in one shear plane per fastener. In NDS, it is called as Mode I_m (main) and Mode I_s (side), while Mode (a) and Mode (b) in EU5. In Table 3, failure modes in NDS have been adjusted to compare with EU5 equivalently.

Table 2. Failure modes in NDS and EU5

	Single shear						Double shear			
										
General	1	2	3	4	5	6	7	8	9	10
NDS	Mode I_m	Mode I_s	Mode II	Mode III_s	Mode III_m	Mode IV	Mode I_m	Mode I_s	Mode III_s	Mode IV
EU5	Mode (a)	Mode (b)	Mode (c)	Mode (d)	Mode (e)	Mode (f)	Mode (g)	Mode (h)	Mode (j)	Mode (k)

The NDS and EU5 use different adjustment factors and constants to determine load-carrying capacity from each mode. Both provisions provide equations for various failure modes. The NDS uses reduction factor and dowel bearing strength based on specific gravity from wood oven-dry volume. Meanwhile, EU5 uses embedment strength of timber, yield moment of connectors, and withdrawal resistance which are required to calculate separately. These values are stated in the NDS standards based on structural conditions and wood species.

5. CONCLUSION

In this paper, the comparison between National Design Specification (NDS) and Eurocode 5 (EU5) in timber connection was conducted. By scrutinizing the type of joints, design values, and failure modes, the following conclusions were obtained:

- EU5 deals with more types of joints than NDS, but only NDS has provisions of timber rivets. The EU5 and NDS do not cover wooden dowels that are used in traditional joint. Only EU5 includes metal dowel type that has a similar concept to a wooden dowel. It reveals that the calculation of metal dowel is similar to bolt connection without washers.
- Both provisions consider the effect of actions and environmental factors in a different approach. NDS has a reduction factor (R_d) impacted from the fastener diameter, whereas EU5 does not apply it to fastener strength equations.
- Both provisions have the same failure mode shapes for single and double shear connections in a different order. NSD recognizes the main member in a double shear connection as the inner member (l_m), and the side member as the outer member (l_s). While, EU5 recognizes the inner member as the side member (t_2) and the outer member as the main member (t_1). Thus, the failure mode of the single shear connection in Mode IV and Mode V in NDS is the opposite in EU5.

Since the load-carrying capacity calculation of metal dowel type in EU5 has a similar calculation to bolt connection, the calculation of wooden dowel could be adjusted from bolt-connection provisions. Further research is expected to have a better comparison between NDS and EU5 in timber connection design.

REFERENCES

American Institute of Timber Construction (AITC) (2005), "Timber construction manual", New Jersey: *John Wiley & Sons, Inc*.

American Wood Council (2018), "National Design Specification (NDS) for wood construction with commentary", Virginia: *American Wood Council*.

Fonseca, E.M.M., Liete, P.A.S., Silva, L.D.S., Silva, V.S.B., Lopes, H.M. (2022). "Parametric study of three types of timber connections with metal fasteners using Eurocode 5", *Appl. Sci.*, 12, 1701.

Gocal, J. (2014), "Load carrying capacity of metal dowel type connections of timber structures", *Civ. Environ. Eng.*, 10, 51-60.

Gonzales Fueyo J.L., Dominguez, M., Cabezas, J.A., Rubio, M.P. (2008), "Design of connections with metal dowel-type fasteners in double shear", *Materials and Structures*, 42, 385-397c.

Porteous, J. and Kermani, A. (2007), "Structural timber design to Eurocode 5", Malden: Blackwell Publishing Ltd.