

• TIMBER FRAME •
ENGINEERING COUNCIL

First Release: July 2016	Revised:
Prepared by: Daniel Hindman, P.E., Ph.D. & Jim DeStefano, P.E., AIA, F.SEI	
Title: Keyed Through Tenon Joints	

Introduction

Keyed Through Tenon (KTT) joints use a protruding tenon secured by a series of trapezoidal keys on the back side of the mortise. KTT joints are commonly used on timber Howe trusses to join the king post to the bottom chord (Figure 1) and also commonly used in New World Dutch Barns to join the anchor beam to the post (Figure 2).

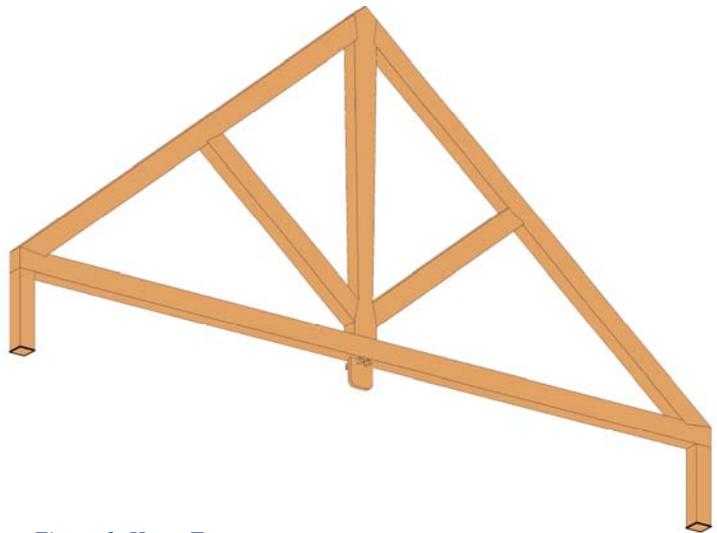


Figure 1 Howe Truss

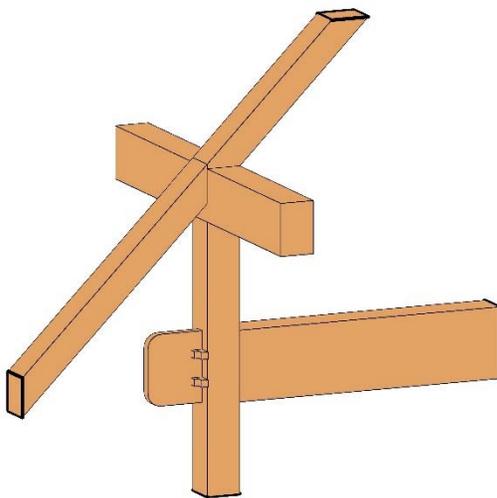


Figure 2 Anchor Beam

KTT joints are typically loaded in tension. An advantage of KTT joints compared to pegged joints is the elimination of tension perpendicular to grain failure in the mortise because the keys are placed on the back of the mortise causing compression forces.

Currently, there is little guidance or design literature for KTT joints. The purpose of this technical bulletin is to explain recent work done to quantify the strength of KTT joints.

Research

The research was conducted by Lance Shields as a part of his Master's thesis under the supervision of Professor Daniel Hindman at Virginia Tech, Blacksburg, Virginia.

Test specimens were fabricated from Douglas Fir and White Oak and tested to failure to identify potential failure modes (Figure 3). Specimens with different tenon lengths (4 inches and 11 inches) were tested, as well as specimens with 1 key and 2 keys.

Test results indicated that proper detailing and proportioning of KTT joints is crucial to their structural performance. Some of the joints failed prematurely in a brittle fashion while others demonstrated ductile behavior. It is desirable to have structural joints exhibit ductility.



Figure 3 Test Setup



Figure 4 Relish Failure

KTT joints with short tenons (4 inch projection) tended to fail when the relish below the key mortises sheared off. KTT joints with long tenons (11 inch projection) did not exhibit this failure mode.

Relish shear failures are a brittle failure mode and should be avoided. It is crucial that tenons be long enough to preclude this failure mode.

Another brittle failure mode that was observed was splitting of the tenon. Splitting was caused by tensile stress perpendicular to the grain of the tenon. This failure mode was only observed in joints that contained a single key. KTT joints with two keys did not exhibit splitting failures.

It is advisable to use two keys in KTT joints as a precaution against a brittle splitting failure.



Figure 5 Tenon Split



Figure 6 Crushing and Bending of Key Wedges

KTT joints that did not experience brittle shear or splitting failures behaved in a ductile fashion. The key wedges first crushed at their bearing surfaces and then progressed to a bending failure. Even after the keys fractured in bending, the joint continued to resist load, exhibiting ductile behavior.

All of the joints tested had a single wedge for each key. If opposing wedges are used for keys, it is anticipated that the key bending resistance will be improved.

Detailing Guidelines

The following guidelines for proportioning KTT joints is intended to minimize the likelihood of a brittle joint failure. The dimensions indicated are minimum dimensions and may need to be increased where required by structural calculations.

- The end distance at the key mortise should not be less than 10 inches.
- A minimum of two keys, each consisting of opposing wedges.
- Tenon thickness should be not less than 2 inches.
- Key mortise should be sized to allow for seasoning of the timbers and subsequent tightening of keys.

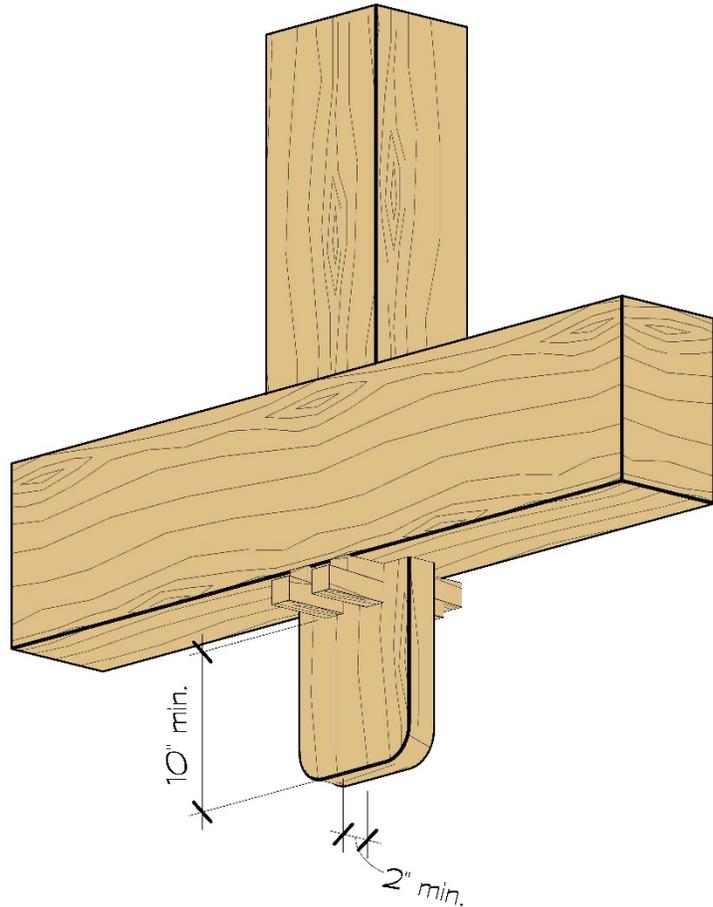
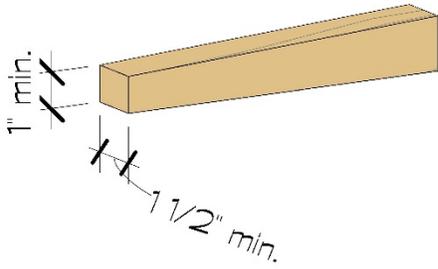


Figure 7 KTT Joint Detail



Key wedges should be made from seasoned hardwood with a specific gravity not less than that of the timber.

Seasoning effects must be considered. As the timbers season and shrink, it is crucial that the key wedges be tightened. Failure to do so could have dire consequences.

Figure 8 Key Wedge

Structural Design

In analyzing the structural capacity of a KTT joint loaded in tension, the following failure modes should be evaluated.

- Net tension strength of the tenon
- Relish shear resistance of the tenon
- Crushing strength of keys

Reference

Investigation of Trough Tenon Keys on the Tensile Strength of Mortise and Tenon Joints by Lance Shields, Virginia Tech, Blacksburg, VA, June 10, 2011

Daniel Hindman, P.E., Ph.D. is an Associate Professor in the Department of Sustainable Biomaterials at Virginia Tech, Blacksburg, VA

Jim DeStefano, P.E., AIA, F.SEI is president of DeStefano & Chamberlain, Inc., Fairfield, CT