Testing Scarf Joints in Bending

HISTORICALLY, timber framers have used scarf joints to fabricate long timbers for sills, plates and posts where the local forests no longer could provide them or, in the case of timbers for very long bridges, where they did not exist. Over the centuries, various scarf joints were developed for reasons of function and economy (see TF 60 for some American examples). Resisting loads in bending is one of the more challenging demands made of scarf joints.

Inspired by scarf joint testing at a UK Carpenters Fellowship conference, and renewing a Guild conference joint-busting tradition from the late 1980s, we sacrificed member-donated scarf joints for fun, theatrics and education at 2009 Saratoga (New York), 2010 Coeur d'Alene (Idaho) and, just recently, 2010 Montebello (Québec).

We built a portable bending rig of paired, cambered Douglas fir timber reaction beams, high-strength steel rods and a hand-pumped hydraulic ram. We used a 12-ton ram at first but have since upgraded to a 30-ton model to obtain better results. The tested scarf joints were limited to 24 in. long and cut in nominal 8x8 timbers to produce an assembled length of 96 in. Actual sections varied from 5¾x7½ in. to 8¼ in. square.

We applied a single-point load via a bearing plate at the center of the scarfed beam using the hydraulic ram (Fig. 1). Gradually increasing the load in bending, we brought the sample to failure unless the setup became unsafe or we ran out the 3-in. stroke of our ram. Except for the length and section of the scarfed beam and the length of the scarf, the donated test samples were not restricted. The use of steel and steel connectors was encouraged.

In physics, a *moment* is defined as a tendency to cause rotation about a point or an axis. A point load acting in the middle of a beam, such as applied by our hydraulic ram, creates a moment that bends the beam. To resist the applied load, a beam must develop an internal balancing moment. The internal moment consists of compression in the fibers closest to the loaded face and tension in the fibers opposite the loaded face. The tensile and compressive forces acting within the beam create the internal balancing moment that resists the load.

If the scarf joint is to resist a bending load, this internal moment, consisting of balanced tension and compression zones, must be transferred between the two halves of the scarf. There are two means of this force transfer: by bending both "halves" of the scarf joint equally though shear and bearing forces; or by transferring the compression and tension forces directly in their respective zones between the pieces. The more effectively these forces are transferred, the more effectively a scarfed beam resists a bending moment.

Of course, the scarf joint by its nature interrupts the wood fibers in both the compression and tension zones of the assembled beam. Interruption of fibers in the compression zone is not difficult to address. Compression force easily transfers between the two parts of the scarf through compressed bearing surfaces. Transferring tensile forces is more challenging. Scarf joints do so in numerous ways, most of which we investigated in the variety of joints we tested.

For joints like the simple half lap that transfer the moment across the split between the halves by bending both pieces more or less equally, we can easily define the maximum moment the joint can carry. The moment that a beam can carry is proportional to the width of the beam and to the square of the height of the beam. If the half lap is horizontal (or in traditional terms the scarf is *edge-halved*), the maximum moment it can carry is one-quarter the moment of a solid beam, because the half lap is the width of the beam but one-half the height. For our vertical half lap (in traditional terms, the scarf is *face-halved*), the width is one-half the solid beam but the height of the half lap is equal, so the maximum moment the half lap can carry or transfer is one-half of what a solid beam will transfer.

These assertions assume perfect transfer of forces, an event not likely to occur; the effectiveness of an actual scarf joint will necessarily be less. A reasonable rule of thumb, confirmed by our observations during testing, is that a well-designed and well-executed scarf joint can sustain about one-third the moment sustainable by a solid timber (or glulam) of the same section.

The effect of the reduced section at the scarf joint is even more dramatic in stiffness. Deflection, or curvature, is a measure of stiffness. The greater a beam deflects under a given load, the lesser its stiffness. Stiffness or deflection is proportional to the width of the timber and the cube of its height. A vertically oriented half lap (a simple face-halved scarf) is the height of the beam and one-half as wide, so the maximum theoretical stiffness of the lap is one-half. A horizontally oriented half lap (an edge-halved scarf) is the width of the beam but only one-half as high, so the lap's maximum stiffness is one-eighth (one-half to the third power) as much. Actual performance varies from these limits according to the joint configuration.

WOODEN scarf joint design is limited only by the nature of the material and the imagination and skill of the framer. Many of the joints we tested adapted historical precedent, stimulating us to devise a coding system (preserved in the scarf descriptions and in the table of results on page 13) that allowed us to classify the connections as engineers and draw broad conclusions useful to timber framers.

We found it helpful to characterize scarf joints by their topology and their moment-transfer mechanism. We tested eight layouts in three broad topological categories: butts, laps and what we called *cogs*, giving the term a special meaning as explained below.

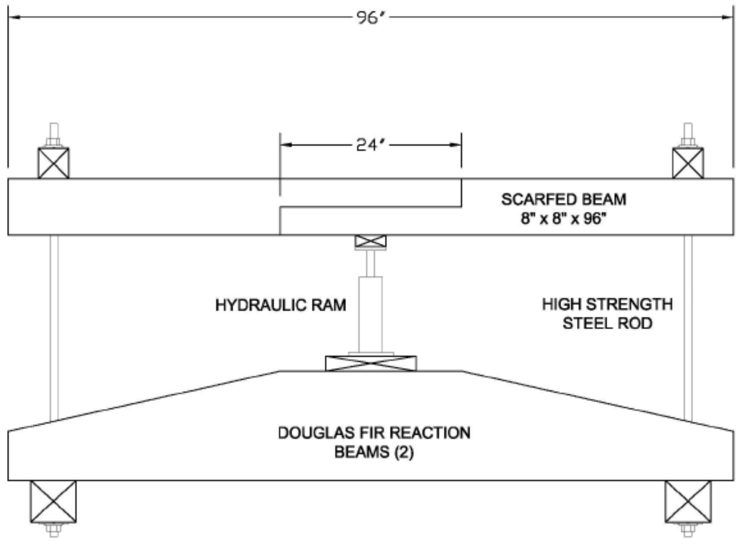
Butt joints can be simply fabricated with tension and compression connectors. While for some observers such connections might not constitute scarf joints, for our purposes a scarf joint is any end-to-end timber joint; thus fastened butt joints qualify.

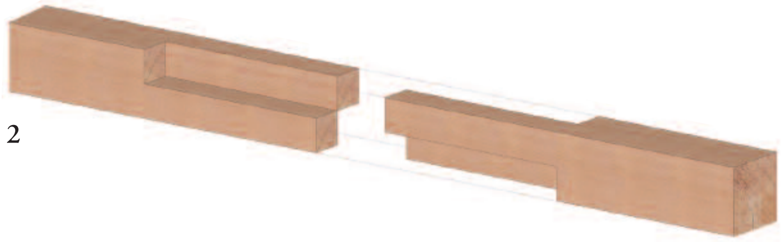
We defined lap joints as the simple lapping of two timbers at a joint. Laps can be aligned vertically, horizontally or at some intermediate slope (splayed). "Cogged" joints lap as well, but they are differentiated by having their lapping parts interleaved across the grain like the teeth of meshing gears. Bridled scarf joints are examples of what in our internal classification we called cogged joints.

Finally, laps or cogs can be modified by "splitting" the lapped sections and mirroring them about the splitting axis, such as shown theoretically in Figs. 2–4. The increasing complexity of a scarf joint correlates well with an increase in bearing faces (if not necessarily *effective* bearing areas) and moment resistance.

The moment-transfer mechanism was equally helpful in categorizing the scarf joints we tested. Many joints relied upon more than one method of moment transfer, though the testing demonstrated that one method predominated in most cases.

The simple face-halved scarf, when pegged, screwed or bolted together, uses shear to transfer the moment from one part of the joint to the other. The simple edge-halved scarf, pegged, screwed or bolted together, uses shear and, to a lesser extent, bearing to transfer the moment. In both instances, connectors work against the separation of the joint through shear. And, in the latter instance, the pressure of the load also induces bearing forces in the lapped portions. (*Bearing* is compressive force transmitted across a discontinuity, such as the interface between the ends of the laps.) An important attribute of these joints is that the connectors crossing the joint are in single shear.

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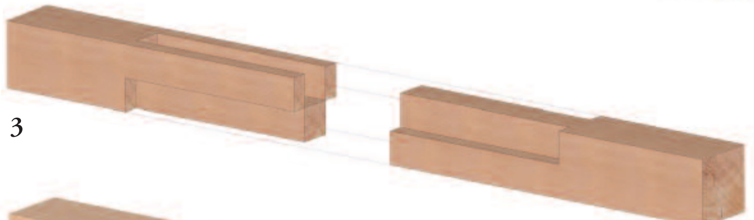
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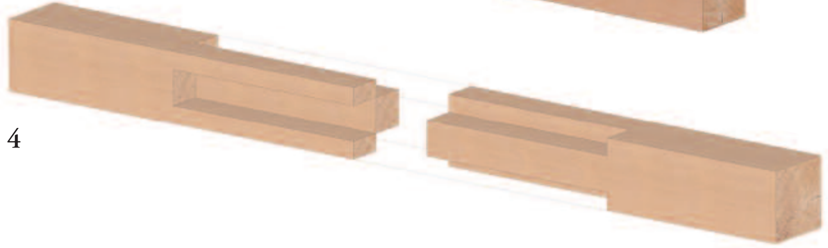
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1 Test rig to bend beams under controlled, monitored force.

2 Top right, simple theoretical "cogged" scarf.

3 Middle right, split and mirrored theoretical edge-halved scarf.

4 Bottom right, split and mirrored theoretical face-halved scarf.

Joints such as bridles in various forms (which we classified internally as "cogged") develop more complicated transfer mechanisms. Joint connectors here typically are in double shear, generally increasing the effectiveness of moment transfer and thus of the joint. Under high loads and significant deflections, face-halved bridled scarfs may develop additional bearing surfaces as trailing edges of lapping extremities, such as bridled abutment corners, interfere with their housings.

In edge-halved bridles, interleaved abutments (cogs in our terms) create more bearing surfaces and contribute to scarf joint effectiveness. Undersquinted abutments have been used historically in the belief that they increase effectiveness, and this was confirmed by our testing. The bearing surface at the undersquint seemed to increase the load capacity of the joint and reduce the deflection, particularly in oak timbers. Anticipated splitting along the grain at the squint did not occur early in the loading despite wood's relatively low strength in tension perpendicular to the grain, thus contributing to the performance of the joint.

"Splitting" and mirroring lapped and bridled scarf joints increase their resistance to twisting. Such joints will likely perform better than straightforward ones in rafter and purlin plates, where vertical and horizontal thrust loads sometimes occur, and they will suffer less indignity under drying stresses. Joint efficiency seems to be improved by increasing the number of active shear planes of the connectors. (But see the last conclusion in the review and conclusions section below.) Unfortunately, elaboration of the joint design also increases difficulty of fabrication.

The Scarf Joints Tested

Mack Magee

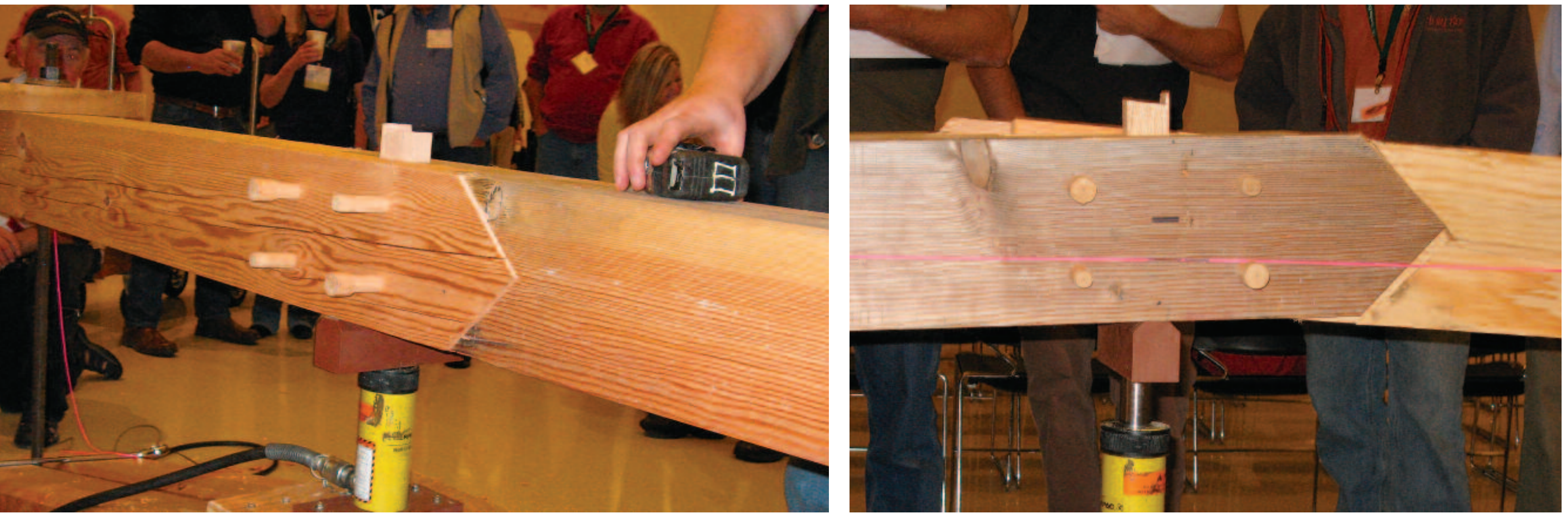
Big Dog Bone Scarf, Bensonwood Homes. Code 1-BJMC. Butted scarf with steel connector and pegged spline for joint alignment. Moment transfer through tension (steel) and compression (bearing surface). Testing stopped upon yielding of steel and incipient lateral buckling and block shear failure in the wood.

Photos this page Mack Magee

SOB (Saratoga or Bust) Scarf, Loyalist Timberframes. Code 2-VCS. Face-halved with sallied and bridled butts. Moment transfer through bearing. Tension perpendicular to the grain failure as load pried joint apart.

Double Deuce Scarf, Timberpeg. Code 3-VLD. Face-halved and tabled with two edge pegs. Moment transfer through bearing and dowel shear. Failure via almost pure block shear. Maker Jesse Kendall, at right, gives pep talk to scarf before testing.

Below, Diamond Dove Scarf, Timberpeg. Code 4-CVLD. Face-halved and keyed with lapped sallied butts and four edge pegs. Moment transfer through squinted bearing surfaces and dowels. Block shear failure.



Mack Magee

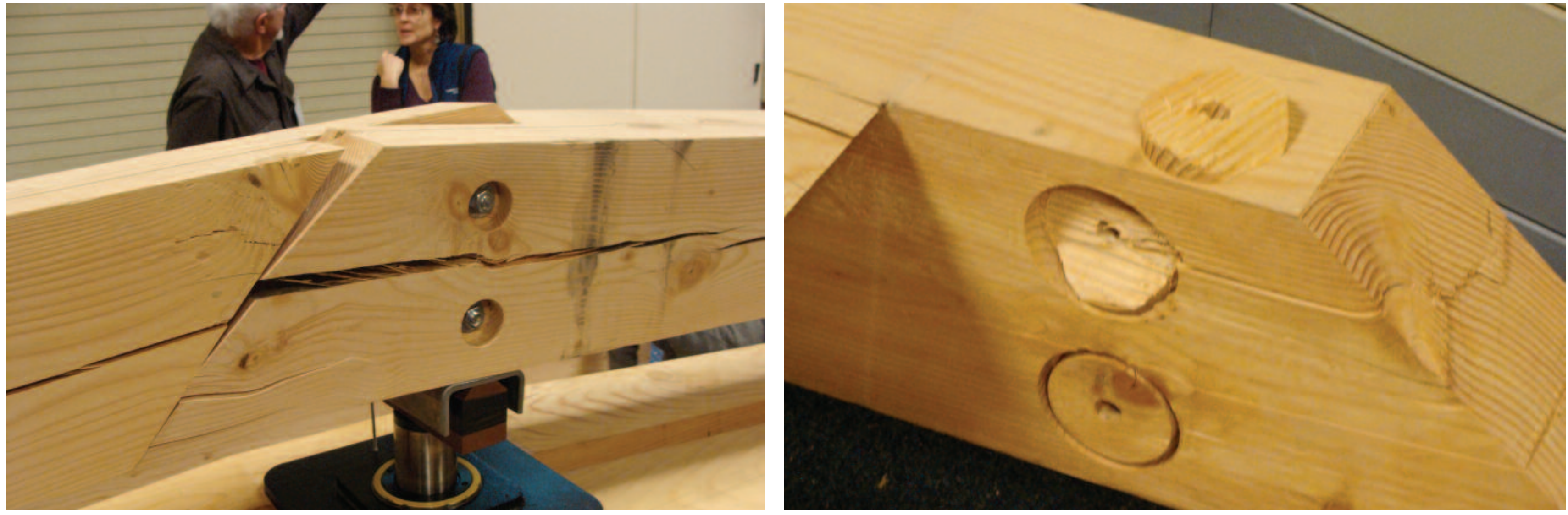
Pop-Sicle Scarf, Timberpeg. Code 5-VLW. Face-halved and keyed with radiused butts. Moment transfer primarily through bearing. Failures via tension perpendicular to grain and key shear. Insert in photo at right shows failure of folding-wedged key.

Mack Magee

Lignatools Scarf, Stefan Richter. Code 6-BJ. Squint-butted with dovetailed bridle. Moment transfer through dovetail tenon. Failure via shear at dovetail. Joint cut impromptu at Saratoga 2009 using machine at hand.

Below, Ringo Scarf, Cornerstone Timberframes. Code 7-VLSP. Face-halved and scissored with steel ring shear plates. Moment transfer through shear and bearing. Failure via tension perpendicular to the grain (split) and plug shear failure.

Greg Stine



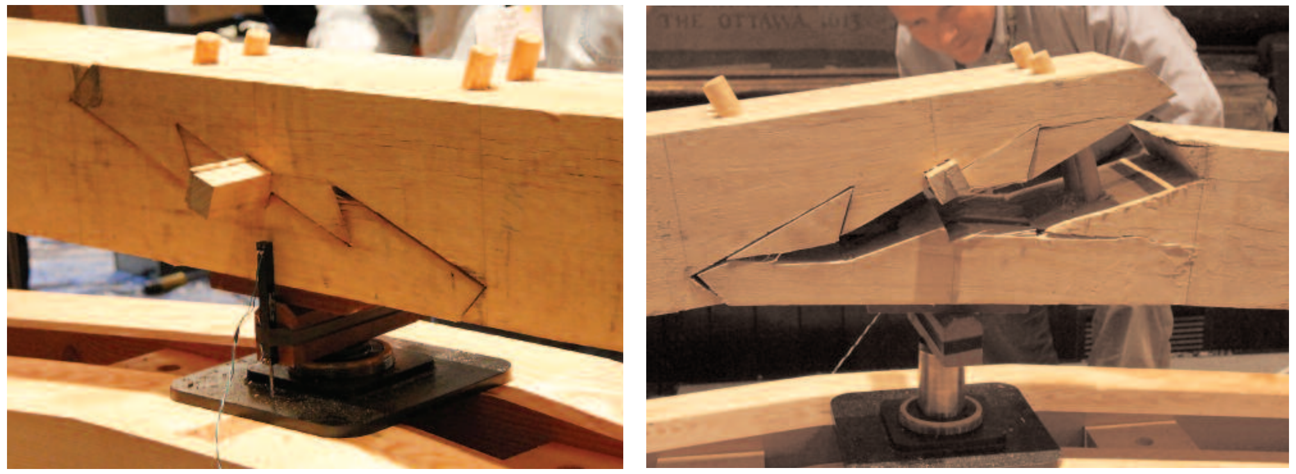
Photos these pages Joe Miller

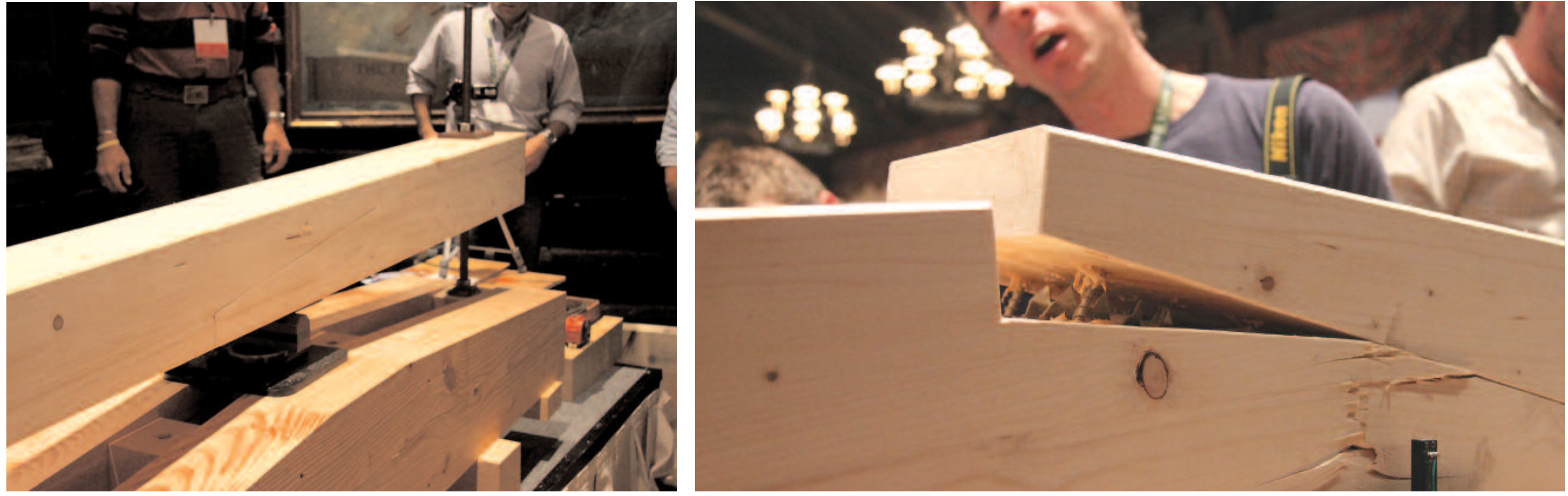
Bates Scarf, Virginia Military Institute (VMI). Code 8-VCSD. Face-halved with sallied butts and four edge pegs. Moment transfer in bearing and dowel shear. Failure in tension perpendicular to grain and dowel shear.

Jarrett Scarf, VMI. Code 9-VCSD. Variant on Bates. Face-halved with asymmetrical sallied butts and three edge pegs. Moment transfer through bearing and dowel shear. Failure in tension perpendicular to the grain (minimum dowel distress).

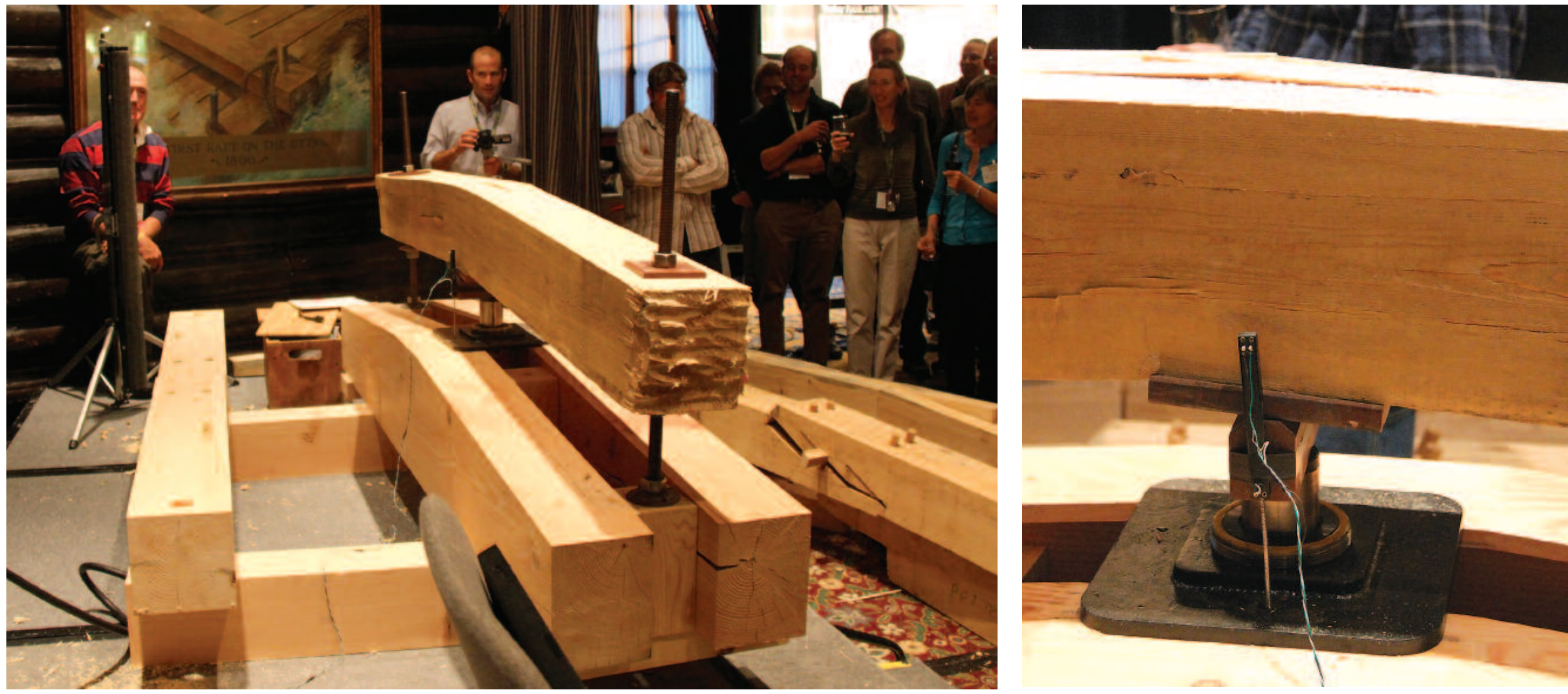
Peck Scarf, VMI. Code 10-VLSD. Face-halved scissor with four edge pegs. Moment transfer through bearing and dowel shear. Failure first through dowels followed by failure in tension perpendicular to grain.

Tunnell Scarf, VMI. Code 11-HLWD. Edge-halved and keyed, stop-splayed and double-tabled with undersquinted abutments and four face pegs. Moment transfer through bearing and dowel shear. Failure in tension perpendicular to the grain.





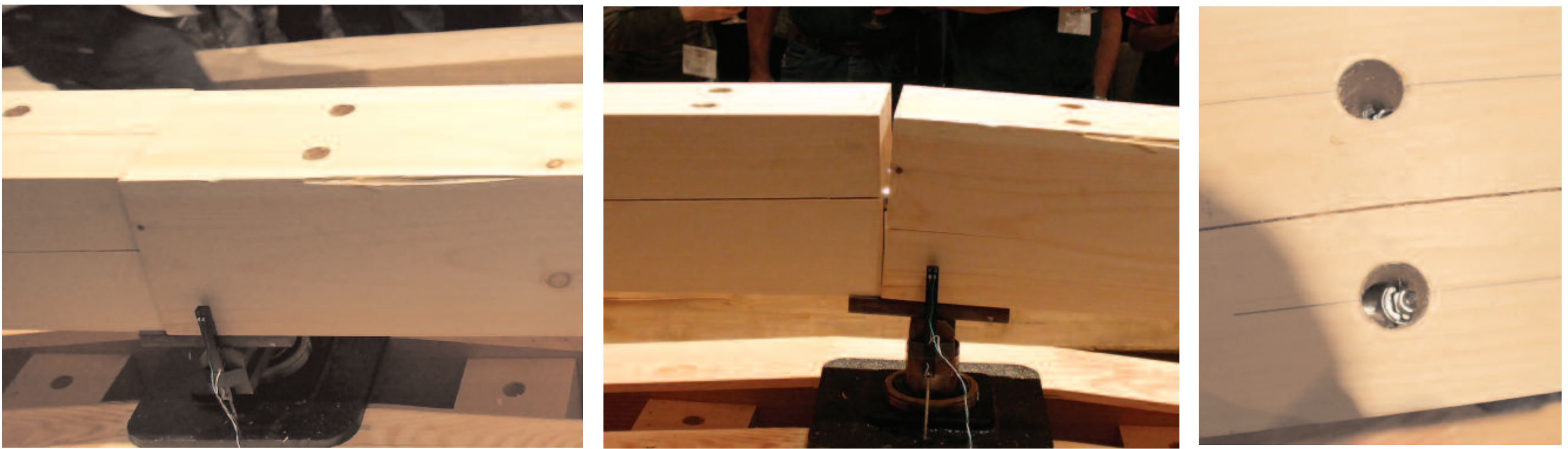
Heco Scarf, Herrmann's Timber Frame Homes. Code 12-HLMC. Edge-halved and stop-splayed with numerous face screws. Moment transfer through axial loading of screws. Failure by withdrawal of screws and breaking of glulam fingerjoint. Toothed connector inside was ineffectual.



Hamlet Hemlock Solid-Sawn Beam, Hamlet Heavy Timberworks. Code 13-MN. Mother Nature's entry. Classic modulus of rupture failure, at 33,840 lbs. Test beam was parted from longer one with drill and auger bit, under desperate conditions.

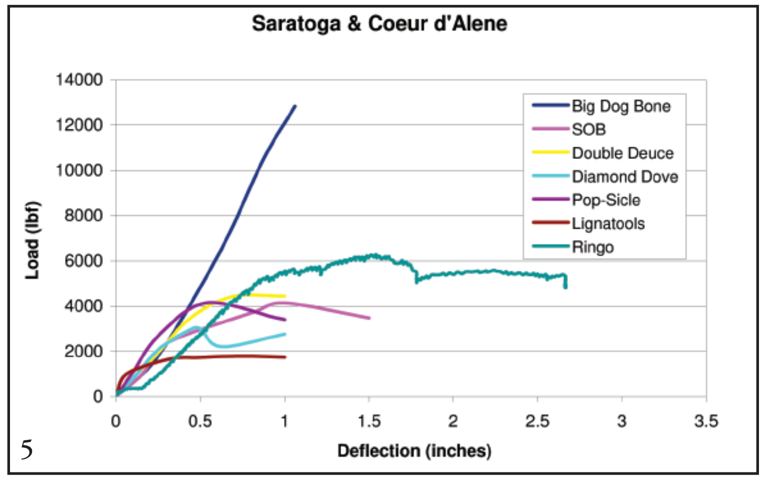
Hamlet Beaver Tail, Hamlet Heavy Timberworks. Code 14-HLMC. Edge-halved with bridled and pegged square abutments and eight face screws. Moment transfer through mechanical connectors and bearing. Failure by withdrawal of mechanical connectors and shearing of dowels. Small square brass plate is ornamental. Insert in photo at right shows shear failure of peg fastening bridled abutment.

Okake Daisen, Adam Zgola. Code 15-VL. Face-halved, stop-splayed, tabled and bladed. Moment transfer through bearing alone. Block shear failure predominated with minor failure in tension perpendicular to grain. Inset shows detail of top view.



Photos and charts this page Joe Miller

Timberlinx 1, Timberlinx. Code 16-BJMC. Square-butted with patent metal connectors. Moment transfer through tension and compression connectors in their respective zones. Failure via dowel bearing. View at right shows bending of (steel) dowels crossing tension connectors.



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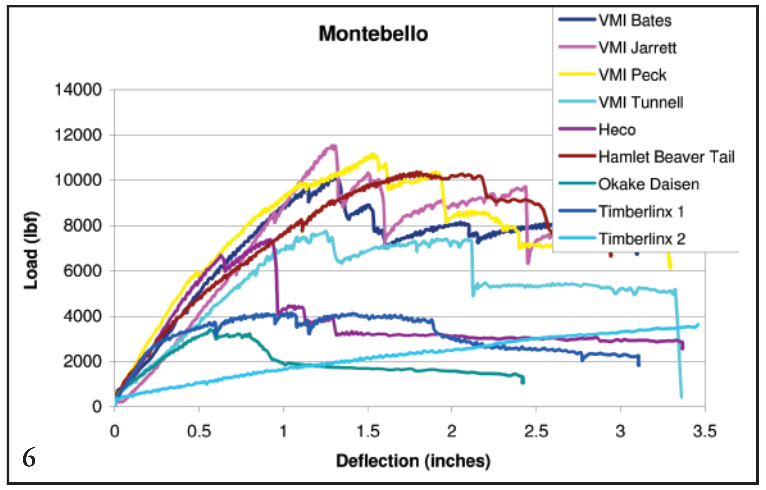
5 Graph of scarf test results at Saratoga 2009 and Coeur d'Alene 2010 conferences. Big Dog Bone test stopped for safety reasons.

6 Graph of scarf test results at Montebello 2010 conferecne.

7 Comparison of solid sawn beam with well-cut conventional edge-halved scarf with bridled abutments and mechanical connectors.



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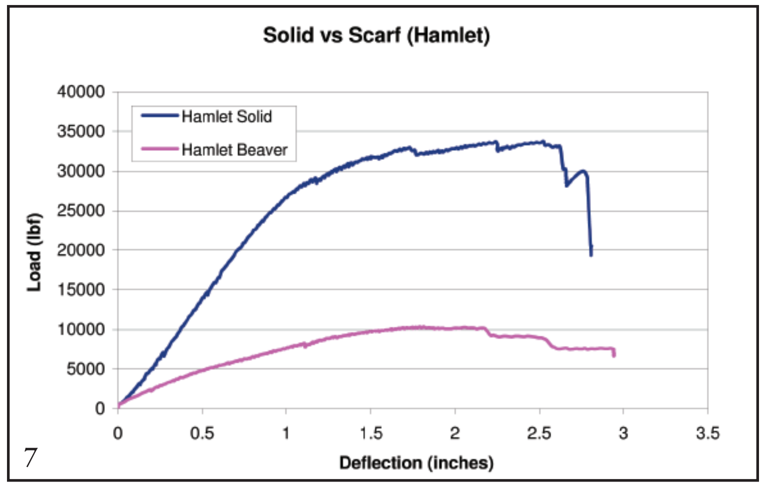

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Table of Results

NAME	TEST	LOCATION	MAKER	SIZE	SPECIES	SCARF TYPE	DEFLECTION at 1000 lb (in.)	LOAD at 1/4 in. (lb)	MAX. LOAD
Big Dog Bone	01:BJMC-BWH	Saratoga	Chris Carbone Bensonwood	8 x 8	Red Oak	Square Butted with Steel Barbell Connector, Spline and 4 Edge Pegs	0.156	1795	12,835
SOB	02:VCS-LTF	Saratoga	Ray Gibbs Loyalist Timberframes	8 x 8	Recl. Doug. fir	Face-Halved with Sallied Butts	0.156	2040	4140
Double Deuce	03:VLD-TP	Saratoga	Jesse Kendall Timberpeg	7½x7½	Doug. fir	Face-Halved and Tabled with 2 Edge Pegs	0.125	1930	4445
Diamond Dove	04:CVLD-TP	Saratoga	Jesse Kendall Timberpeg	7½x7½	Doug. fir	Face-Halved and Keyed Lapped Sallied Butts with 2 Edge Pegs	0.125	2070	3010
Pop-Sicle	05:VLW-TP	Saratoga	Jesse Kendall Timberpeg	7½x7½	Doug. fir	Face-Halved and Keyed with Radiused Butts	0.094	2675	4140
Lignatools	06:BJ-LT	Saratoga	Stefan Richter Timber Tools	8¼x8¼	White Oak	Squint-Butted with Dovetail Bridle	0.063	1625	1795
Ringo	07:VLSP-CTF	Coeurd'Alene	Pete Peters Cornerstone Timberframes	8 x 8	Doug. fir	Face-Halved and Scissored with Steel Shear Plates	0.255	955	6275
VMI Bates	08:VCSD-VMIB	Montebello	Nick Bates Virginia Military Institute	8¼x8¼	White Oak	Face-Halved V-Bridle with 4 Edge Pegs	0.064	2540	10,225
VMI Jarrett	09:VCSD-VMIJ	Montebello	Marshall Jarrett Virginia Military Institute	8¼x8¼	White Oak	Face-Halved V-Bridle with 3 Edge Pegs	0.154	1725	11,535
VMI Peck	10:VLSD-VMIP	Montebello	Jordan Peck Virginia Military Institute	8¼x8¼	White Oak	Face-Halved and Scissored with 4 Edge Pegs	0.050	3405	11,140
VMI Tunnell	11:HLWD-VMIT	Montebello	Andrew Tunnell Virginia Military Institute	8¼x8¼	White Oak	Edge-Halved and Keyed, Stop-Splayed and Tabled, Undersquinted Abutments and 4 Face Pegs	0.087	2005	7760
Heco	12:HLMC-HTFH	Montebello	Andreas Herrmann Herrmann's Timber Frame Homes	7½x7½	Spruce Glulam	Edge-Halved and Stop-Splayed with Face Screws	0.065	3950	7380
Hamlet Solid	13:MN-HHTW	Montebello	Daniel Addey-Jibb Hamlet Heavy Timberworks	7¾x8½	E. Hemlock	Mother Nature's Joint (Solid-Sawn Timber)	0.040	6320	33,840
Hamlet Beaver Tail	14:HLMC-HHTW	Montebello	Daniel Addey-Jibb Hamlet Heavy Timberworks	7¾x8½	E. Hemlock	Edge-halved with Bridled Abutments, 2 Edge Pegs and 8 Face Screws	0.051	2885	10,365
Okake Daisen	15:VL-AZ	Montebello	Adam Zgola	5¾x7¾	E. White Pine	Face-Halved, Stop-Splayed Tabled and Bladed	0.084	1910	3405
Timberlinx 1	16:BJMC-TL1	Montebello	Neil Maclean Timberlinx	7½x7½	E. White Pine	Butted with Patent Steel Connectors	0.070	2715	4140
Timberlinx 2	17:BJMC-TL2	Montebello	Neil Maclean Timberlinx	7½x7½	E. White Pine	Butted with Patent Steel Connectors	0.470	730	3625

8 Table of results. All told, scarf joints perform somewhere in the range of 30 percent of a solid beam.

Review and Conclusions When viewing the results in the table and charts (Figs. 5–8), care should be taken when comparing any two scarf joints. Besides the type of scarf joint, the actual size of the timbers, strength of the wood and other factors have a substantial effect on the assembled member's strength and stiffness.

For the best designs, the theoretical maximum limit for moment capacity of a simple face-halved scarf joint is 50 percent of a like-sized, solid sawn timber. For a simple edge-halved scarf joint, the theoretical maximum is one-quarter. The rule of thumb that a well-designed and well-crafted scarf joint's moment carrying capacity is one-third of a solid-sawn timber's is consistent with our results, assuming the joint orientation is designed for the load orientation.

Stiffness (resistance to deflection) is likewise limited by the reduced section at the scarf joint and the inability to perfectly transfer the forces from one part of the joint to the other through the joinery and the wood and mechanical connectors (threaded and compression fastenings). The theoretical maximum limit is also 50 percent for a vertical half lap and one-eighth for a horizontal half lap. Because there is no stress without strain, there must be some initial give before the wood joinery and the connectors take any load. This initial give also reduces stiffness. Another contributing factor to decreased stiffness in scarf joints is that wood cell structure's efficiency in load transfer cannot be easily matched by dowel type connectors.

Tension perpendicular to the grain was the predominant failure mechanism in the scarf joints we tested. Improvement in scarf joinery can be achieved by augmenting the wood's strength in this critical mode. In that connection, mechanical connectors appear by demonstration to be a very effective way to augment the moment capacity of scarf joints in bending. (Mechanical connectors would appear to be an effective way to augment scarf joints in tension as well.)

The use of bearing, compression force applied across an interface, to transfer moments seems to be more effective than the use of dowels, metal or wooden. Stiffness seems to be greater as well for scarf joints that rely on bearing.

Face-halved mirrored joints appear to have higher tenacity as well as higher ultimate capacity than joints that rely on dowels and other bearing transfer mechanisms.

Finally, with the use of suitable screws, quite simple scarf joints such as Hamlet Heavy Timberworks' Beaver Tail, which might be cut straightforwardly, can prove as strong as far more complex and more-difficult-to-fabricate oak scarf joints such as the group cut at Virginia Military Institute. —Mack Magee

Mack Magee (mack@ftet.biz) is a principal at Fire Tower Engineered Timber in Providence, Rhode Island. Colleagues Joe Miller, Ben Brungraber and Duncan McElroy assisted materially with the preparation of this report, and Miller and Brungraber with the testing at the conferences. Bensonwood Homes and FraserWood Industries kindly supplied the reaction beams for the test rig.