Quality.Together

SPIB Technical Committee
June 27, 2014

Update on Southern Pine Design Values

History

- Original IGT Published: 1991
- Monitoring: 1994-2010
- Destructive Testing: 2011
  - #2 2x4
  - MOE, MOR, UTS
- Significant decreases observed

2012

- Reduced 2x4 #2 & lower design values
- Conducted New IGT
  - 2 grades, 3 sizes
  - MOE, MOR, UTS, UCS

2013-2014

- New design values published

- Monitoring:
  - #1 2x6 in 2013
  - #2 2x4 in 2014

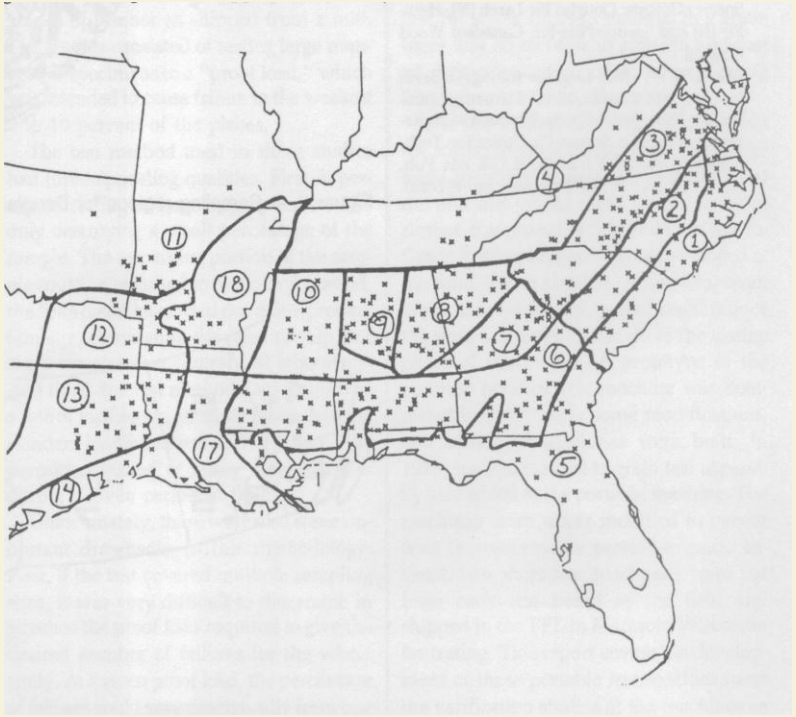
InGrade Testing Protocol

- Test 2 grades, in each of 3 sizes
- Nondestructively evaluate stiffness (MOE)
- Destructively test for:
  - Bending Strength (MOR)
  - Tension Strength (UTS)
  - Compression Parallel to Grain (UCS)

Sampling

- Mills assigned to one of 16 homogeneous Southern Pine growing regions
- Includes SPIB and TP mills
- Randomly select mills in proportion to regional production
- Target sample size: 360 pieces per “cell”
- Test 10-12 pieces from each selected mill

Southern Pine Regions



Data Collected

- Grade
- Defect – grade controlling, msrd
- Dimensions – width, thickness, length
- MC
- Temperature
- Growth Characteristics – rpi, %sw

Data Collected

- Bending Tests:
  - 1/3 point loading
  - Defects randomly placed
  - 17:1 span to depth ratio
  - Stiffness (MOE)
  - Strength (MOR)
  - Failure Code

Data Collected

- Tension tests
  - Tested for bending stiffness prior to UTS
  - 8′ gauge length between grips
  - Failure Code

Data Adjustments

- MC adjusted for Temperature
- Properties adjusted to 73 °F if needed (<47°)
- Properties adjusted to 15% MC

For MOR > 2415 psi:

$$MOR_2 = MOR_1 + \frac{(MOR_1 - 2415)}{(40 - MC_1)} * (MC_1 - MC_2)$$

Data Adjustments

- To combine data from different sizes, a “size model” is used to convert all data to a Characteristic Size: 2x8 – 12′

$$F_2 = F_1 * \left(\frac{W_1}{W_2}\right)^w * \left(\frac{L_1}{L_2}\right)^l * \left(\frac{T_1}{T_2}\right)^t$$

Exponents for Size Model

Property	Width, w	Length, l	Thickness, t
MOR, UTS	0.29	0.14	0
UCS	0.13	0	0
MOE	0	0	0

MOE not adjusted for size
No properties adjusted for thickness (applies to dimension lumber only)
Compression values not adjusted for length

Converting 2x4 to 2x8

No.2 2x4, MOR = 3265 psi, 59.5" span

$$MOR_{2x8} = 3265 * \left(\frac{3.5}{7.25}\right)^{0.29} * \left(\frac{59.5}{144}\right)^{0.14}$$

$$MOR_{2x8} = 2336\,psi$$

GQI

- Grade Quality Index – determined from failure code at point of failure.
- Uses ASTM D245 equations to calculate the “strength ratio”
- Based on strength reducing characteristics:
  - Knots
  - Slope of Grain

GQI Check

- D1990 requires a GQI check to ensure that tested material appropriately represents the defects permitted in the grade.
  - SS grade - SR = 0.65
  - #2 grade - SR = 0.45
- *Of pieces for which SR can be calculated*, the 5th percentile must be within +/- 7 points

Nonparametric Statistics

- We do not assume a “normal” (or any other) statistical distribution.
- Use “order statistics” to estimate values of interest.
- Permits analysis without actually breaking every piece.

5TH PERCENTILE

- Rank order all data from lowest to highest.
- (5% * sample size) is approximately the order statistic of the 5th percentile "point estimate".
- Example: 100 pieces broken in bending. Use the 5th weakest piece to estimate the 5th percentile.

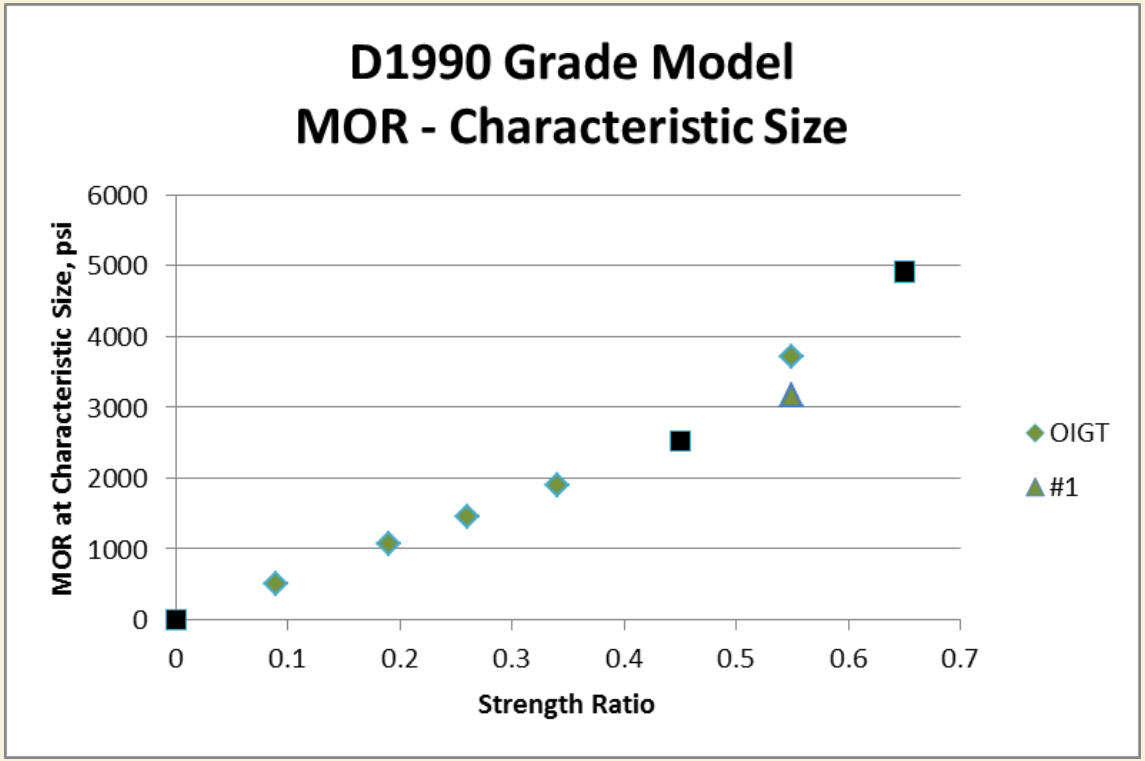
Tolerance Limits

- ASTM D1990 uses the 75% confidence tolerance limit on the 5th percentile.
- Uses data from a piece weaker than actual 5th percentile “point estimate”.
- Provides increased confidence that true 5th percentile is equal to or greater than our estimate.

Grade Model

- Using strength ratios, values for untested grades may be estimated.
- Tested grades:
  - SS with strength ratio of 0.65
  - #2 with strength ratio of 0.45
- Untested Grades:
  - #1 (SR = 0.55), #3 (SR = 0.26), etc.

Grade Model for Original IGT



2013 - #1 2X6

- Not tested in original matrix
- Design values determined from grade and size models
  - #1 uses a 15% reduction for modelling uncertainties

#1 2X6 Results

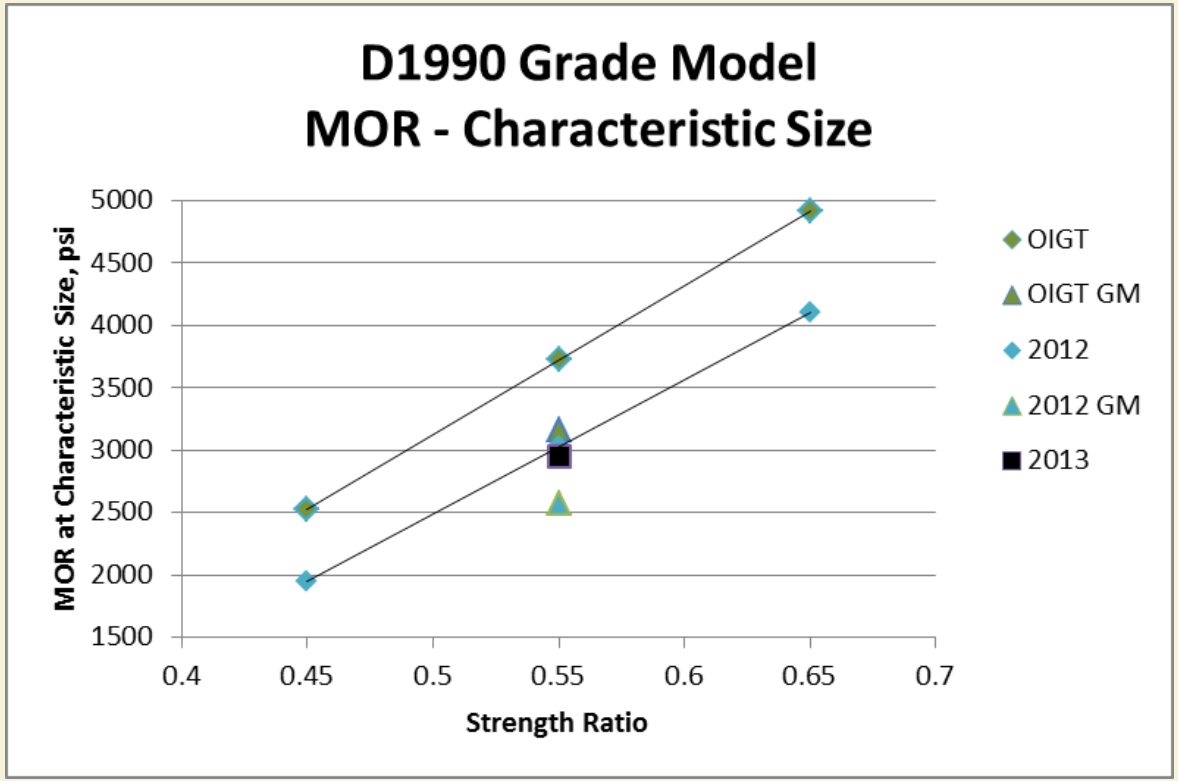
2012 Published Values:

F_b= 1350 psi, E = 1.6 million psi

Year	n	Avg. MC	Avg E (21:1)	MOR TL	Corresp. DV	Avg SG
2013	361	14.0	1.61	3400	1432	0.54

"Corresponding Design Value" is based on cell data, converted to published length (12') and includes 2.1 factor of safety.

Grade Models for MOR



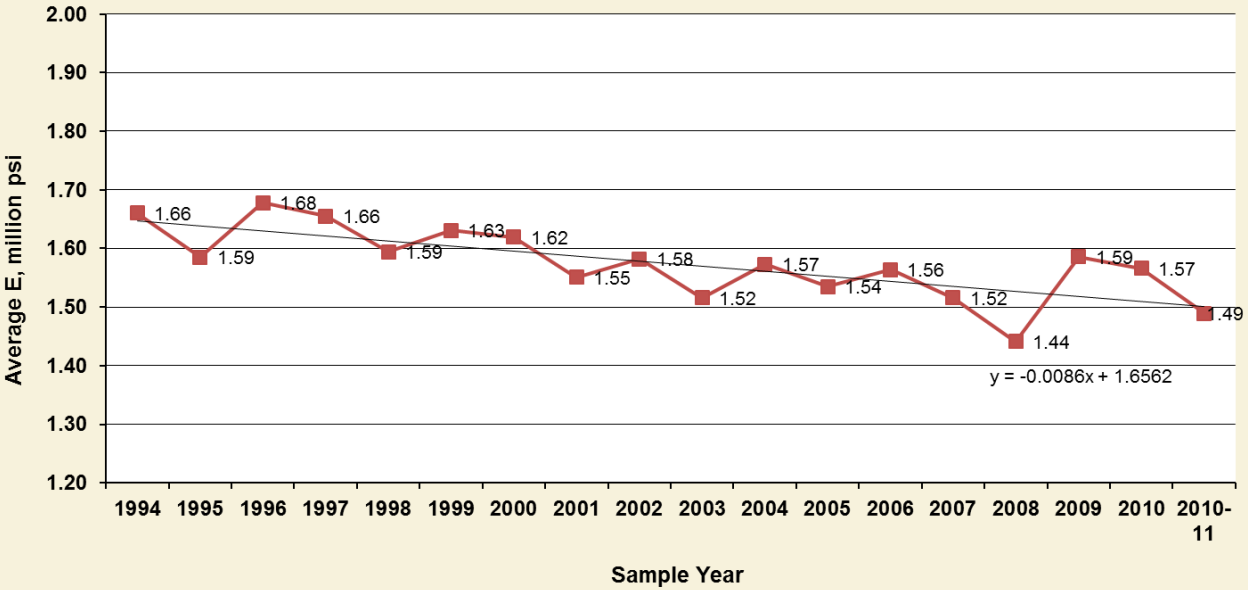
Conclusions

- The #1 2x6 test data supports the D1990 grade and size models used to assign #1 2x6 bending design values.
- The #1 2x6 test results are in line with the design value reductions taken in 2012.

2014

2X4 #2

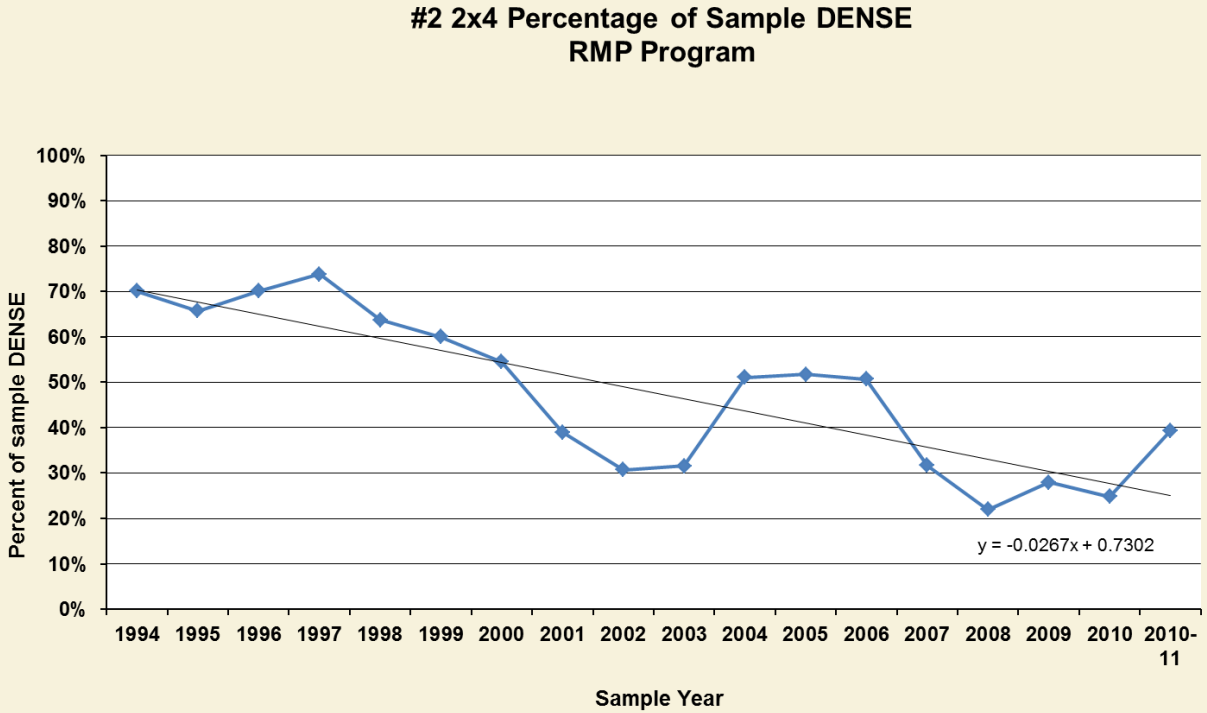
Monitoring Results



Definition of Dense

- SPIB Grading Rules 103.1
- On one end or the other:
  - 6 rpi and 33% sw OR
  - 4 rpi and 50% sw
- Historical IGT and RMP data only had growth info on GM end

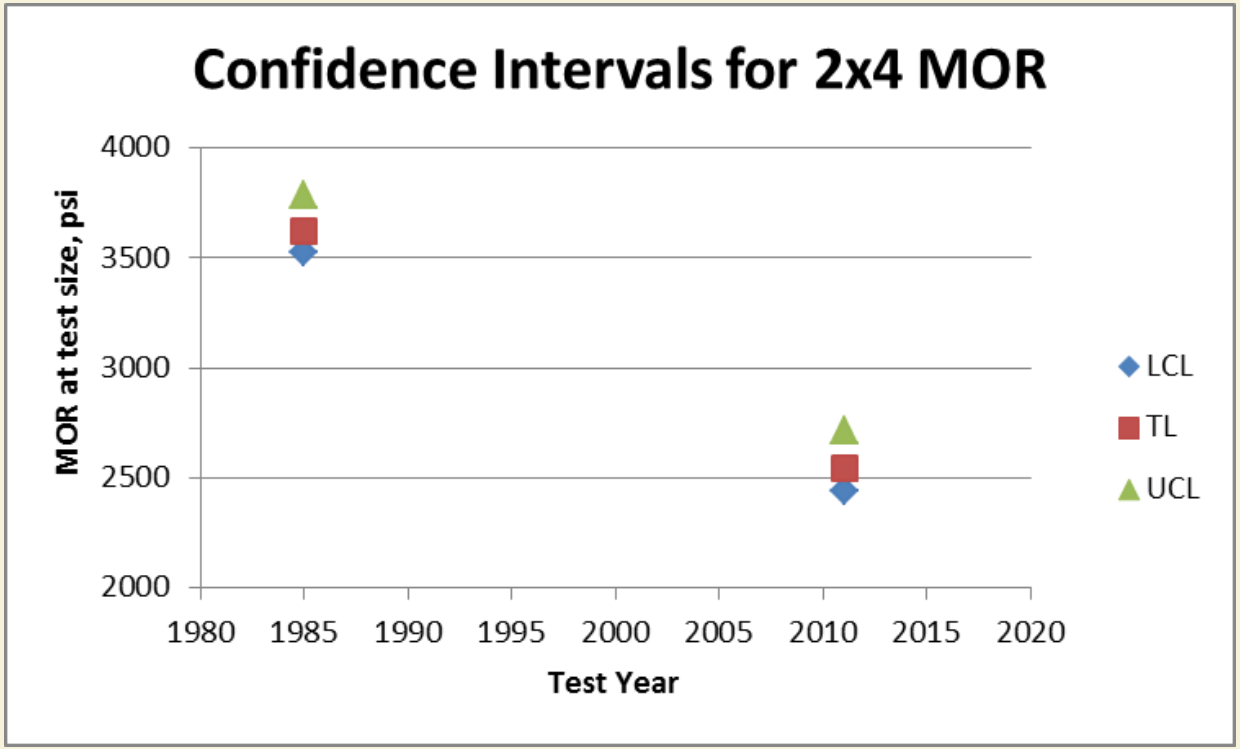
Monitoring Results



#2 2X4

Sample	n	Avg MC	Avg E (21:1)	MOR TL (psi)	Corresp. DV	SPG
Original IGT	413	14.2	1.56	3621	1524	
2011	409	11.2	1.33	2547	1071	0.51

Compare Confidence Limits



D1990 Wilcoxon Test

- 2014 revisions to D1990 include a statistical test to compare samples
- Compares the entire distribution – not tails
- Wilcoxon test uses sum of ranks
- Data is combined from two sets and ranked
- Sum of ranks from each set is compared

Wilcoxon Test

Use the sum of the ranks to calculate a Z-value:

$$Z = \frac{\left(SumRank + \frac{1}{2}\right) - \left(m * \left(\frac{N+1}{2}\right)\right)}{\sqrt{\frac{m * n * (N+1)}{12}}}$$

Where m = sample size corresponding to SumRank

n = sample size from other sample

N = total sample size (m + n)

Wilcoxon Results

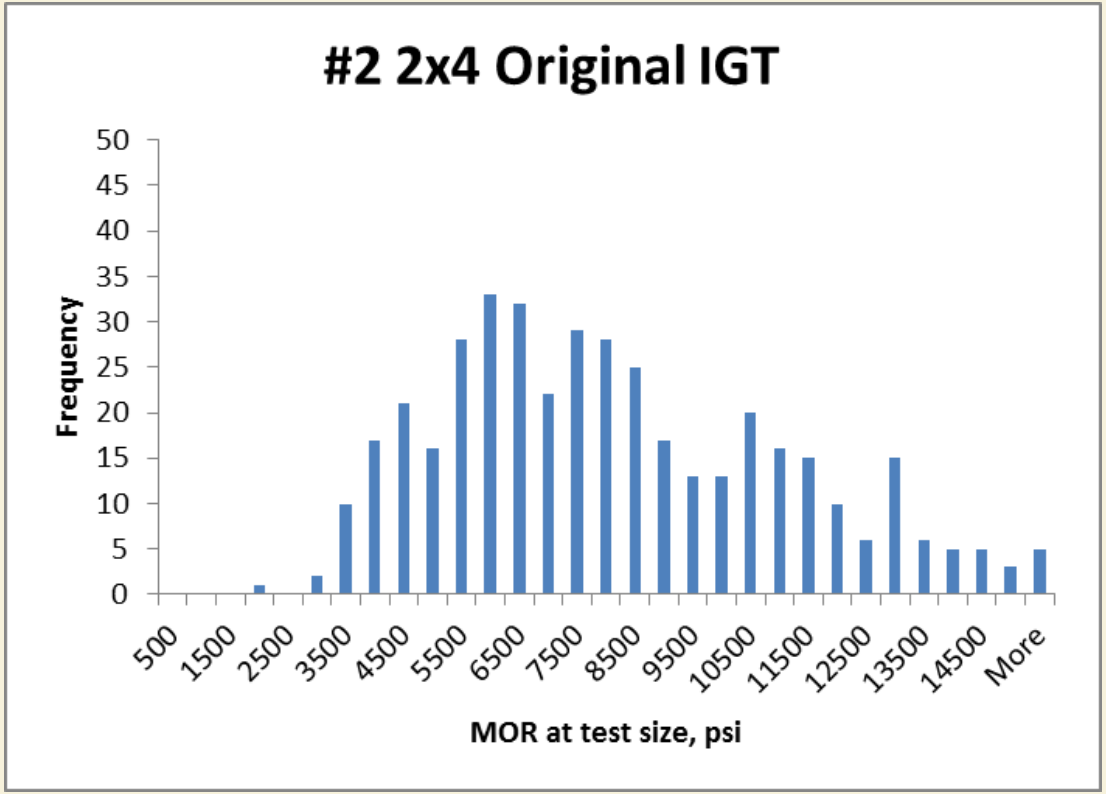
MOR	OIGT	2011
n	413	408
Rank Sum	203,186	134,245
Avg Rank	492	329
Z = -9.84, p = 0.00		

MOE	OIGT	2011
n	413	403
Rank Sum	194,096	139,240
Avg Rank	470	346
Z = -7.54, p = 0.00		

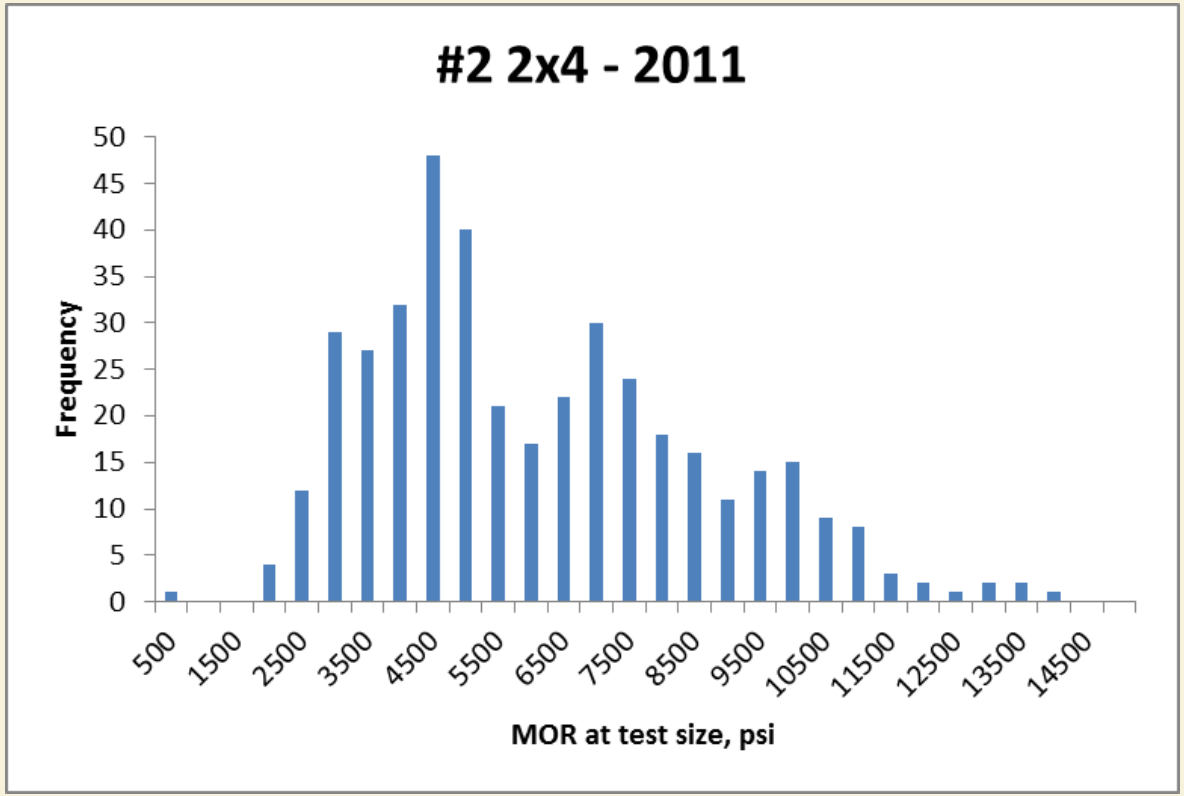
2014 Results

Sample	n	Avg MC	Avg E (21:1)	MOR TL (psi)	Corresp. DV	SPG
Original IGT	413	14.2	1.56	3621	1524	
2011	409	11.2	1.33	2547	1071	0.51
2014	362	14.8	1.50	3265	1374	0.53

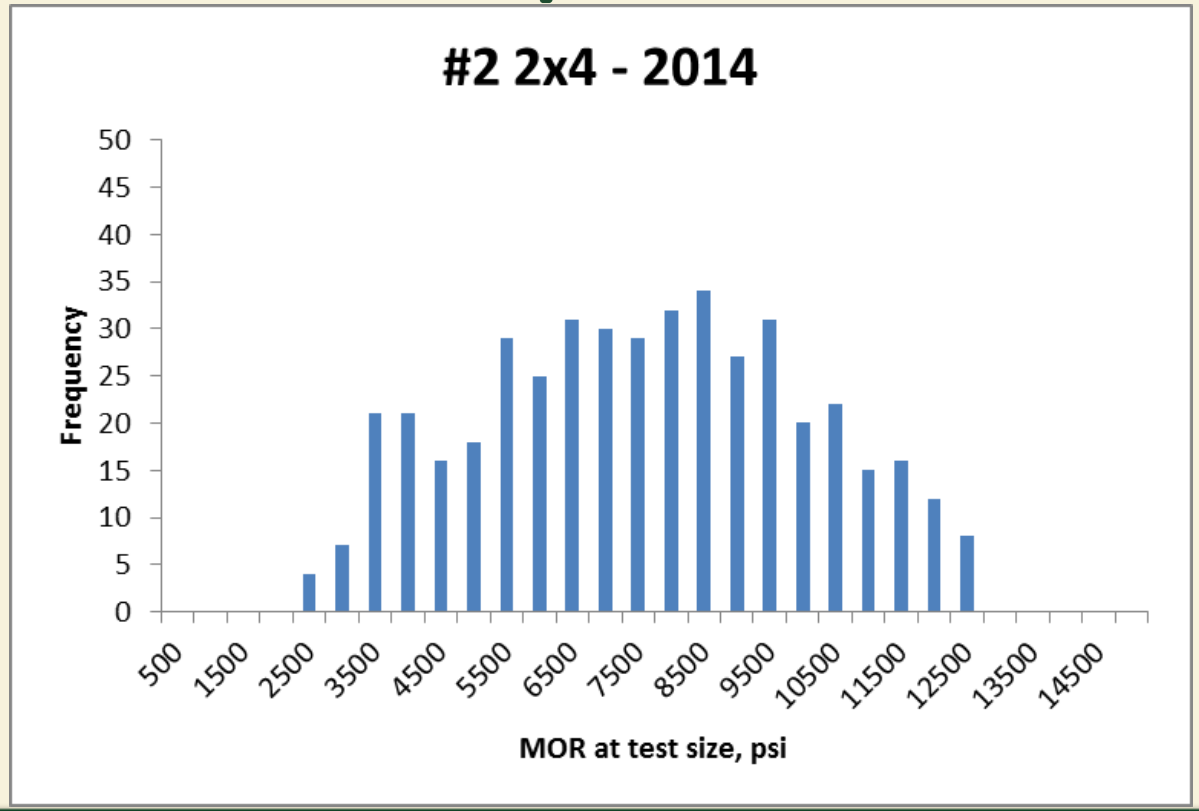
Original IGT - MOR



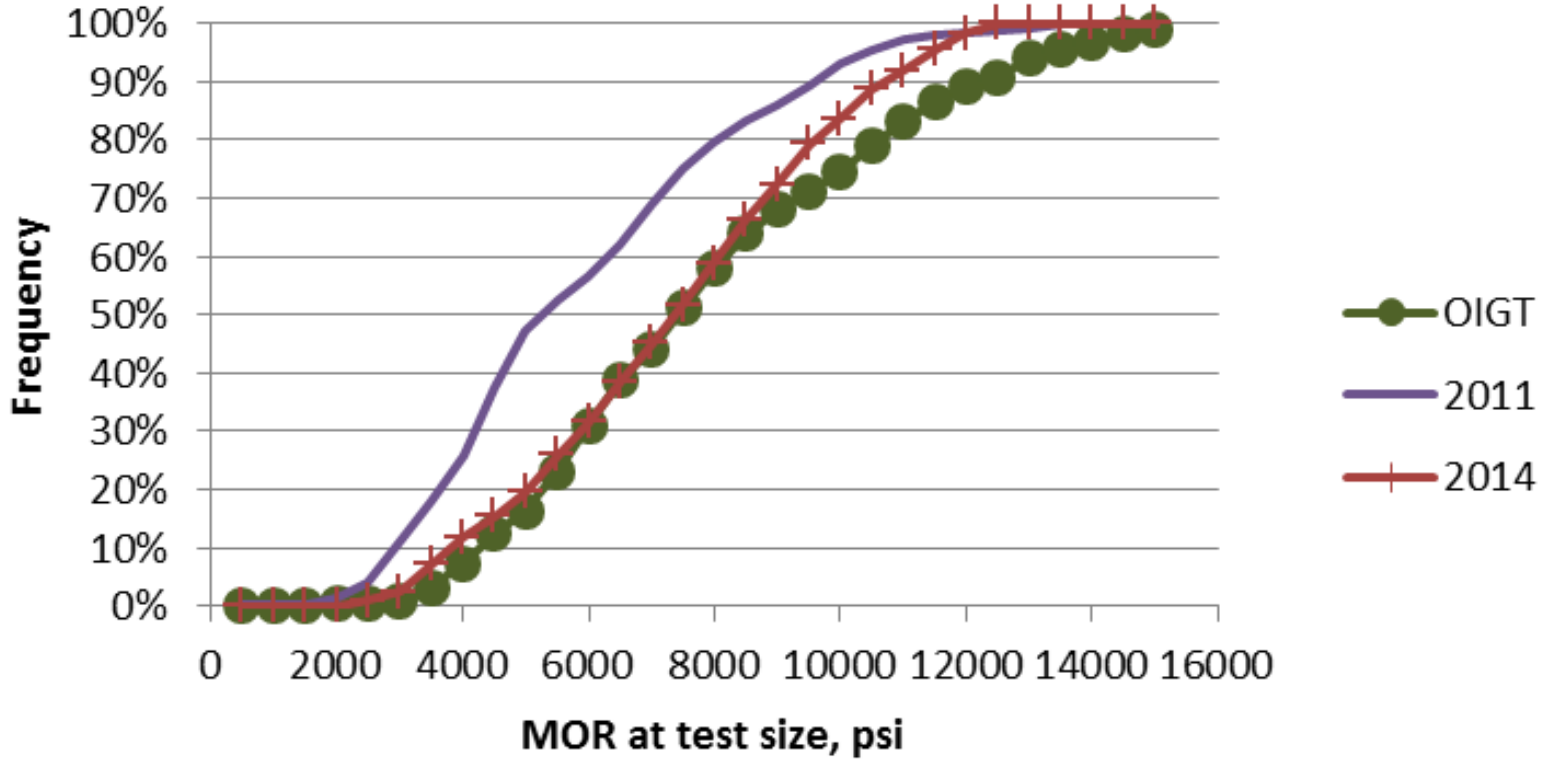
2011 - MOR

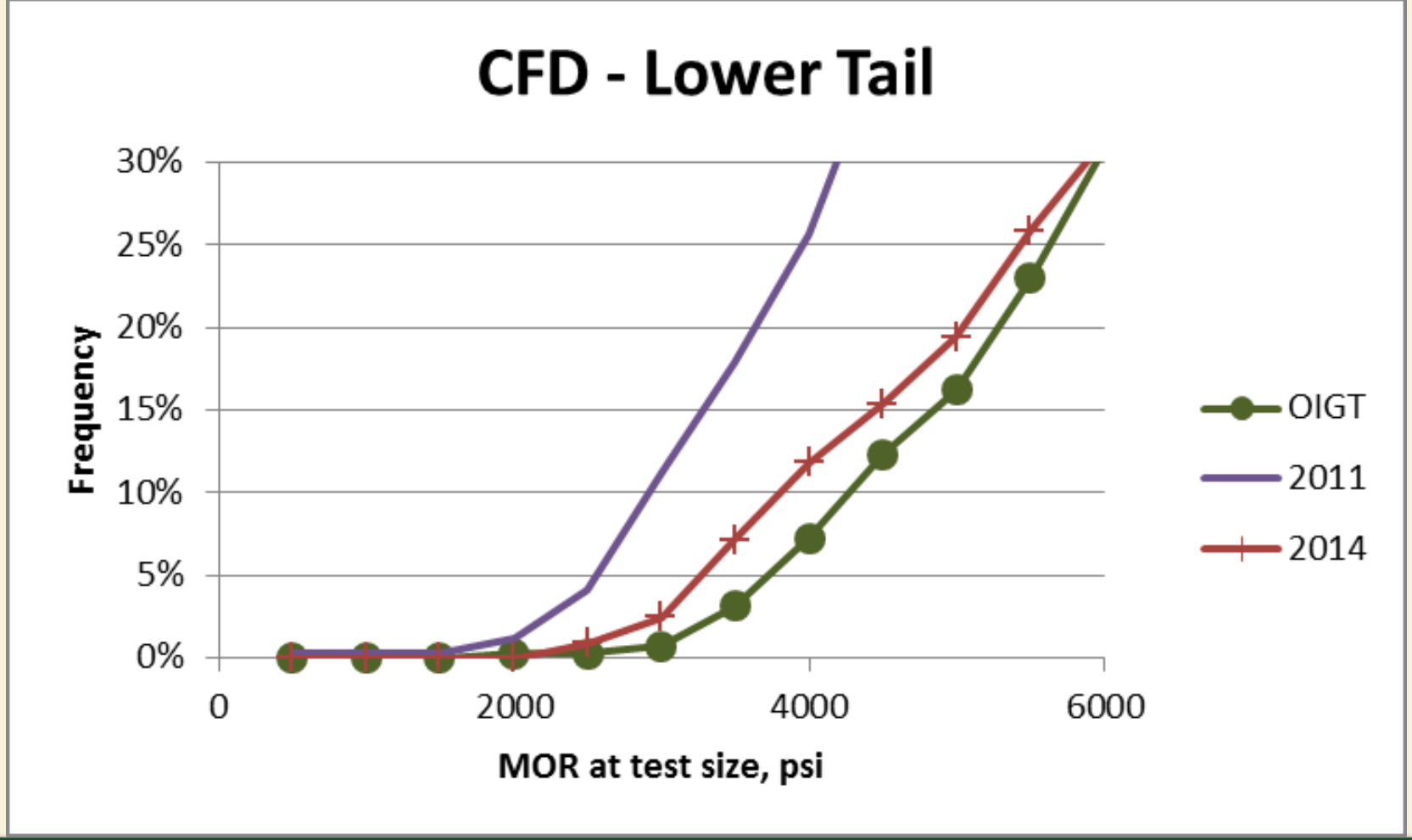

#2 2x4 - 2011
Frequency
50
45
40
35
30
25
20
15
10
5
0
500
1500
2500
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
MOR at test size, psi

2014 - MOR

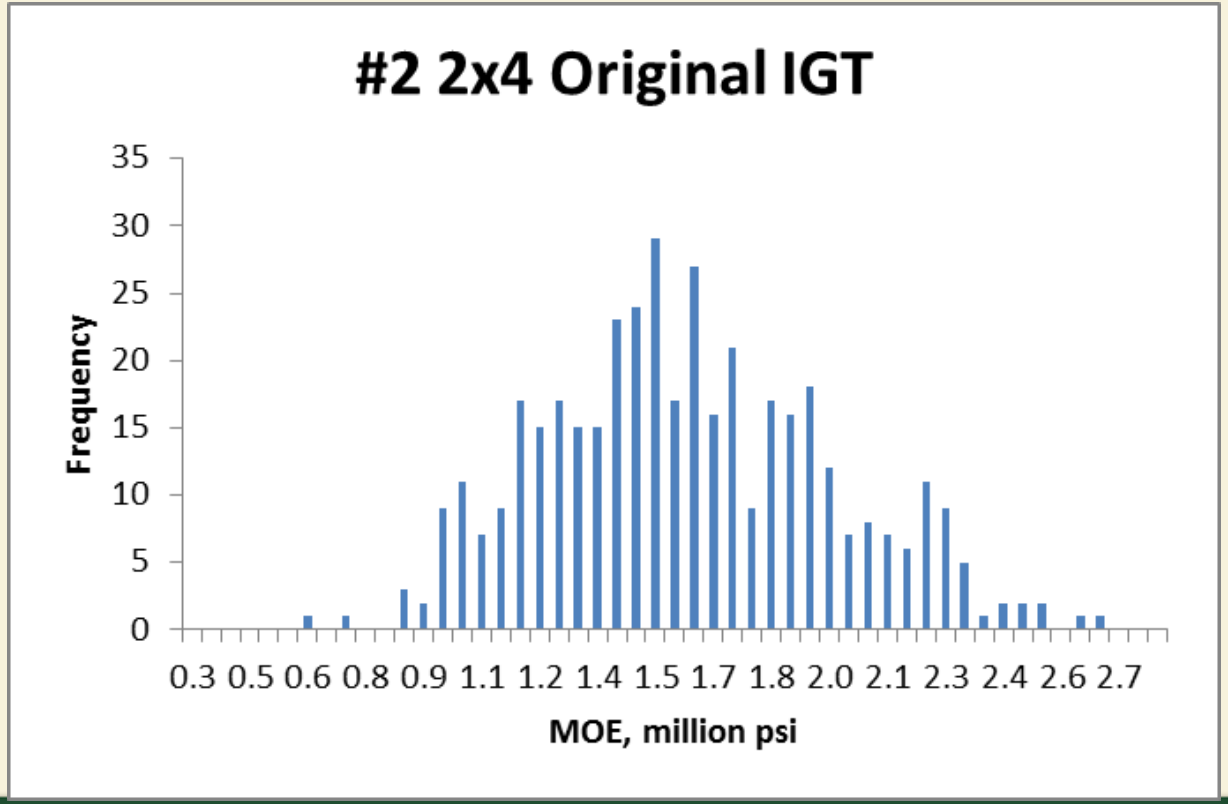

#2 2x4 - 2014
Frequency
50
45
40
35
30
25
20
15
10
5
0
500
1500
2500
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
MOR at test size, psi

Cumulative Frequency Distribution

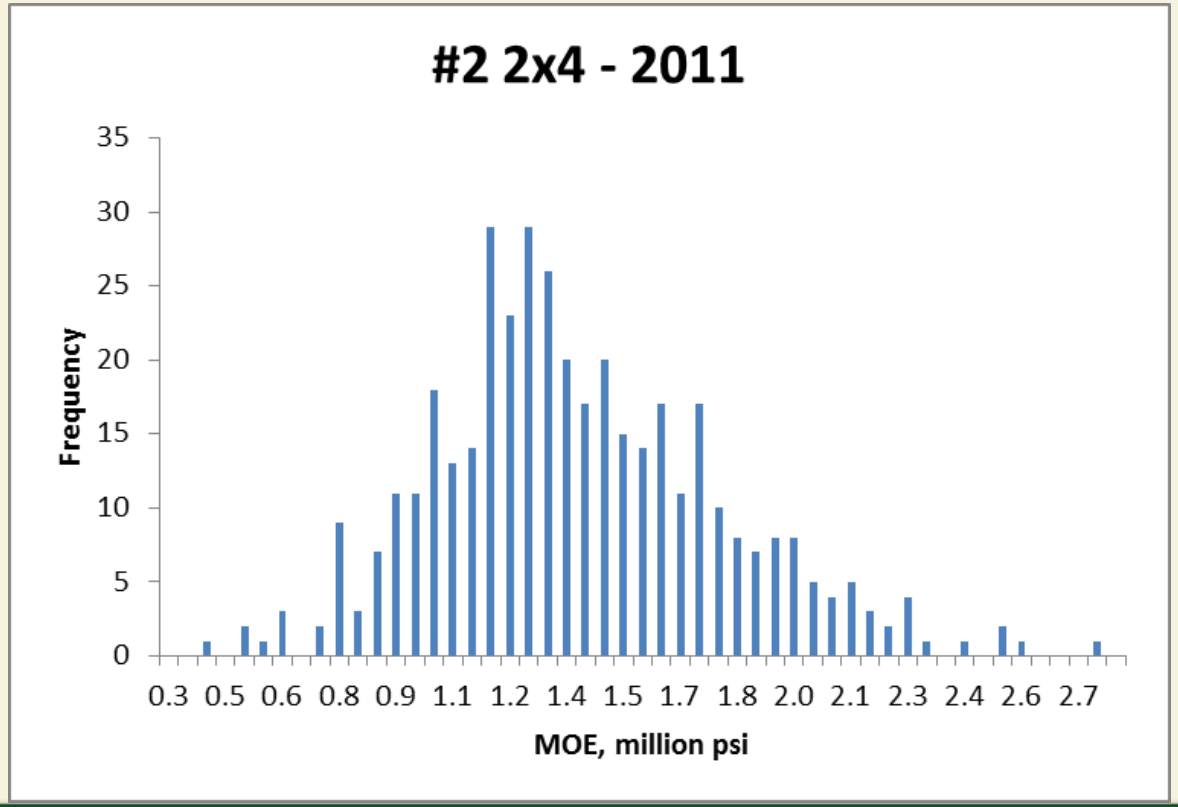



CFD - Lower Tail
30%
25%
20%
15%
10%
5%
0%
Frequency
0
2000
4000
6000
MOR at test size, psi
OIGT
2011
2014

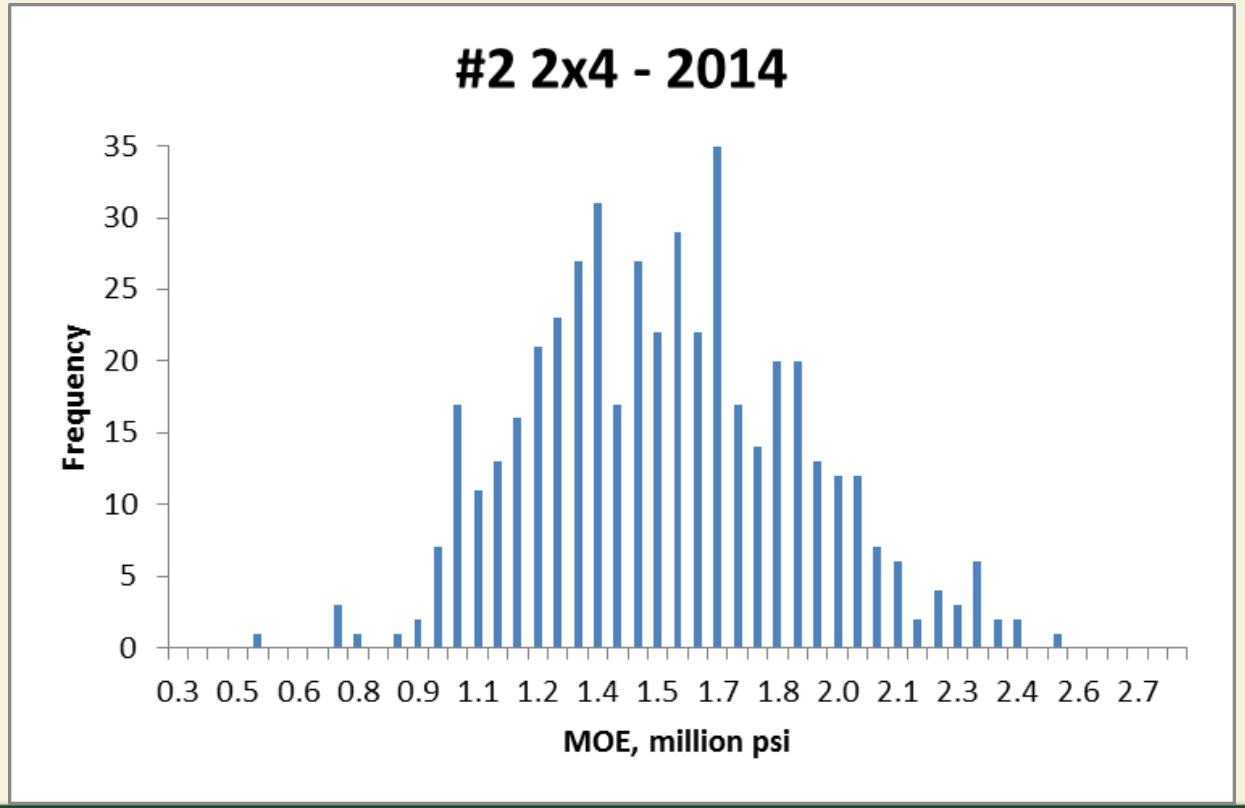
Original IGT - MOE



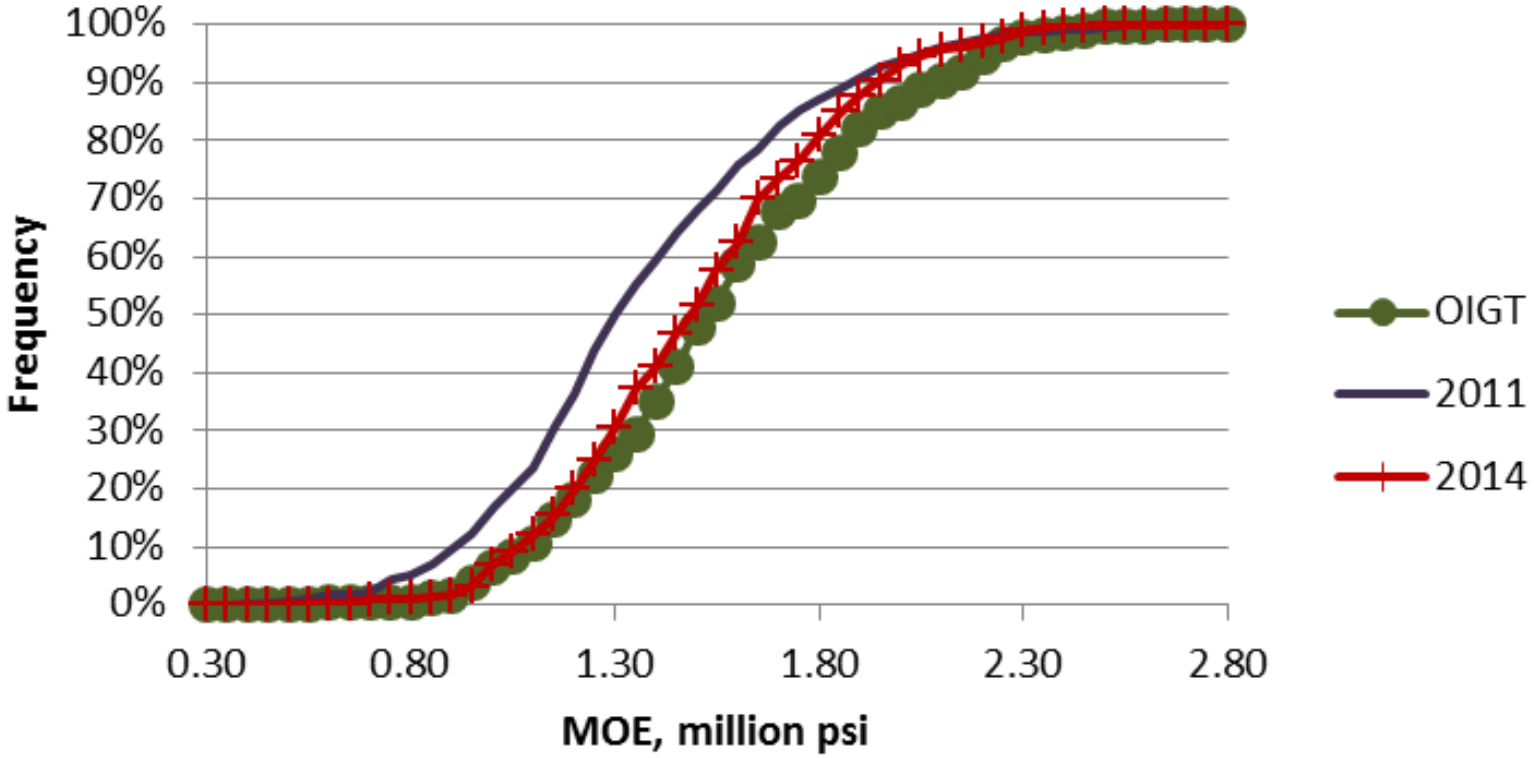
2011 - MOE

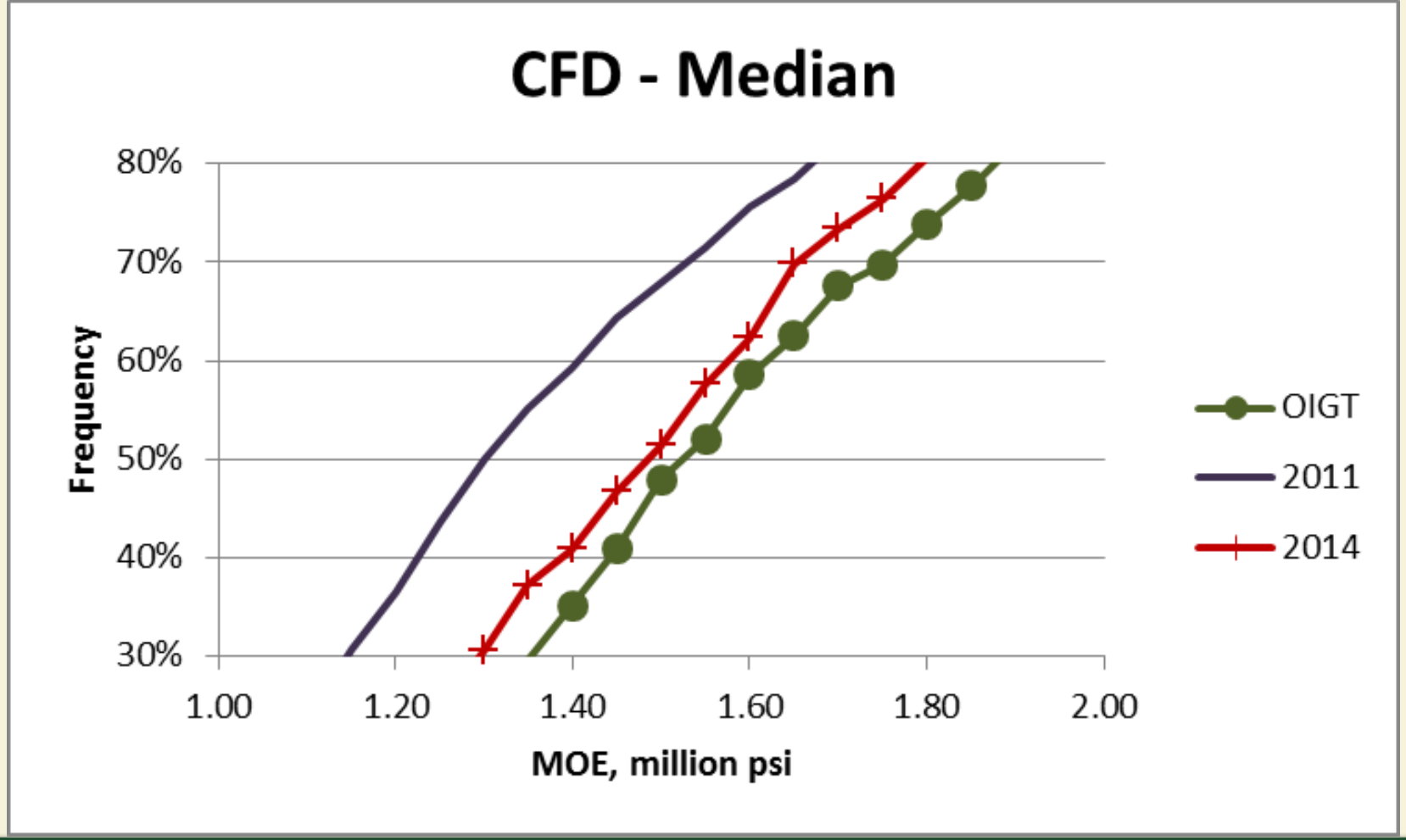

#2 2x4 - 2011
Frequency
35
30
25
20
15
10
5
0
0.3 0.5 0.6 0.8 0.9 1.1 1.2 1.4 1.5 1.7 1.8 2.0 2.1 2.3 2.4 2.6 2.7
MOE, million psi

2014 - MOE


#2 2x4 - 2014
Frequency
35
30
25
20
15
10
5
0
0.3 0.5 0.6 0.8 0.9 1.1 1.2 1.4 1.5 1.7 1.8 2.0 2.1 2.3 2.4 2.6 2.7
MOE, million psi

Cumulative Frequency Distribution




CFD - Median
80%
70%
60%
50%
40%
30%
Frequency
1.00
1.20
1.40
1.60
1.80
2.00
MOE, million psi
OIGT
2011
2014

Wilcoxon Results - MOR

	OIGT	2011
n	413	408
Rank Sum	203,186	134,245
Avg Rank	492	329
Z = -9.84, p = 0.00		

	2011	2014
n	408	362
Rank Sum	129,899	166,936
Avg Rank	318	461
Z = -8.89, p = 0.00		

	OIGT	2014
n	413	362
Rank Sum	162,482	138,218
Avg Rank	393	382
Z = -0.72, p = 0.24		

Wilcoxon Conclusions - MOR

- The 2011 sample is significantly different than the original IGT and the 2014 sample.
- When considering the entire distribution, the 2014 sample is not significantly different from the original IGT sample.
- At 5^{th} percentile, 2014 sample is lower than the original IGT sample (≈ 150 psi in F_b).
- Therefore, may need to consider alternate statistical tests to compare samples.

Wilcoxon Results - MOE

	OIGT	2011
n	413	403
Rank Sum	194,096	139,240
Avg Rank	346	470
Z =-7.54, p = 0.00		

	2011	2014
n	403	362
Rank Sum	136467	156528
Avg Rank	339	432
Z =-5.86, p = 0.00		

	OIGT	2014
n	413	362
Rank Sum	166,275	134,425
Avg Rank	403	371
Z = -1.94, p = 0.03		

Wilcoxon Conclusions - MOE

- At the $\alpha = 0.05$ level, all three samples are significantly different from each other.
- A test looking at the entire distribution may be more appropriate for MOE (average value published) than for MOR (5^{th} percentile basis for design values)

Observations

- Average MOE and 5th percentile MOR from all samples are different
- Moisture content of samples varied
  - Data adjusted for MC
  - 2011 sample much drier
- Presence of combination knots at failure varied
- Percentage of Dense varied

Comparing Samples

	OIGT	2011	2014
MOR TL, psi	3621	2547	3265
# combination knots	0	90	19
Avg MC	14.2	11.8	14.8
% Dense	55%	39%	59%

* rpi and %sw at grademarked end

Observations

- While the 2014 #2 2x4 MOR and MOE values increased somewhat from 2011, they are still lower than the original IGT values
- Other grades and sizes tested in 2012 confirmed decreases from OIGT

Observations

- More variability between samples than expected.
- Appears that present design values represent lower end of what could be included in the grade.

Questions?

Future Testing

- Monitoring procedures added to ASTM D1990
- Test most commonly produced size/grade every 5 years
- SPIB plans to test #2 2x4 every 3 years
- Test additional grades/sizes in other years

Testing options

- #2 2x4 in tension?
- #1 2x6 in tension?
- #1 2x4 in bending and/or tension?
- Compression tests not a priority
- 2x12 really too large for present equipment

Year	Size	Grade	Property
2011	2x4	#2	E, MOR, UTS
2012	2x4, 2x8, 2x10	SS, #2	E, MOR, UTS, UCS
2013	2x6	#1	E, MOR
2014	2x4	#2	E, MOR
2015	2x4	#2	E, UTS
2016	2x4	#2	E, MOR
2017	2x4, 2x8	#2	E, MOR (UTS for 2x4)
2018	2x4	#2	E, MOR
2019	2x4	#2	E, UTS
2020	2x4, 2x8	#2	E, MOR (UTS for 2x4)

Thank You