Development of a Geotechnical Asset Management Tool for Retaining Walls

Robert L. Parsons[1], Stacey Kulesza[2] Jie Han[3]

[1]Professor, University of Kansas

[2]Associate Professor, Texas State University

[3]Professor, University of Kansas

Acknowledgements

- Luke Augustine, USACE
- William Radnor, HDR
- Luke Metheny, KDOT
- Bryan Pope, KDOT
- Hao Liu, KU

Why Geotechnical Asset Management?

- A Geotechnical Asset Management (GAM) system provides a systematic means for
  - Evaluation
  - Valuation
  - Prioritization
  - Rehabilitation

We want a numerical score

Why Start with a GAM for Retaining Walls?

- Evaluating backfill conditions since 2013
- Developed MSE electrical resistivity method
- 2019 NCHRP *Geotechnical Asset Management for Transportation Agencies*
- KDOT needed to develop a GAM

Geotechnical Asset Management for Transportation Agencies

Implementing GAM

1. Define asset
2. **Asset inventory**
3. Performance Assessment
4. Life-cycle planning and risk management
5. Financial planning and investment

Asset Categories

- Walls
- Slopes
- Embankments
- Subgrades

Study Goal

- Develop an asset ratings system for retaining walls
- Use that system on an existing set of walls
- Provide examples to future inspectors so wall conditions can be consistently evaluated

Project Scope

- Develop a preliminary inspection sheet for retaining walls
- Inspect 18 walls with a combined team of university and KDOT personnel to rate the various wall conditions
- Consult with a substantial number of subject experts to develop a weighting system for the inspection categories
- Produce a final retaining wall inspection sheet, with weights for the various categories, and ratings for the 18 walls

Retaining Wall Rating System (Kansas)

- 5 main categories + Other
  - Movement
  - Drainage
  - Backfill
  - Facing
  - Exterior
  - Other
- 14 subcategories within the 5 main categories
- Each item is rated on a scale from 1 – 4, with 4 being the best
- Categories were weighted using the AHP procedure

MSE Wall Inspection Checklist

KDOT MSE Wall Inspection Form									
Height (ft)		**GPS Coordinate**				**Survey Date:**		**County**	
Length (ft)									
Width (ft)		% of Wall Condition				W%	Score	**Wall ID**	
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting					12%			
	Backfill Settlement					8%			
Drainage	Scour/Soil Erosion					11%			
	External Drainage					6%			
	Internal Drainage					11%			
Backfill	Panel Bowing / Bulging					11%			
	Resistivity					8%		Temp: Resistivity:	
	Backfill Material Loss					10%			
Facing	Joint Spacing					8%			
	Panel Staining					2%			
	Panel Cracking					4%			
	Panel Spalling					4%			
Exterior	Coping Damage					2%			
	Vegetation					3%			
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes or No							
Score	**Rating Score**							Modifiers	
	Height of Wall (ft)							**M_H**	
	AADT (veh/day)							**M_T**	
	Year Constructed							**M_A**	
	Risk Adjusted Rating Score								

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MSE Wall Inspection Checklist

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	Vegetation					3%		
Other								

MSE Wall Inspection Checklist

Engineer Inspection	*If category was rated 50% > Poor	Yes or No			
Score	**Rating Score**			Modifiers	
	Height of Wall (ft)			**M_H**	
	AADT (veh/day)			**M_T**	
	Year Constructed			**M_A**	
	Risk Adjusted Rating Score				

The Analytical Hierarchy Process (AHP)

- Used to develop category weights
- Based on expert opinions regarding the relative importance of various subcategories
- 30 experts were interviewed for this study from around the country
- Experts are given pairs of items (A & B) and asked to rate the relative importance of the two items on a scale from 1 to 9

The Analytical Hierarchy Process (AHP)

The expert is asked to rank A vs B

Rating	Description
9	Extremely more important
7	Strongly more important
5	Moderately more important
3	Somewhat more important
1	Equal

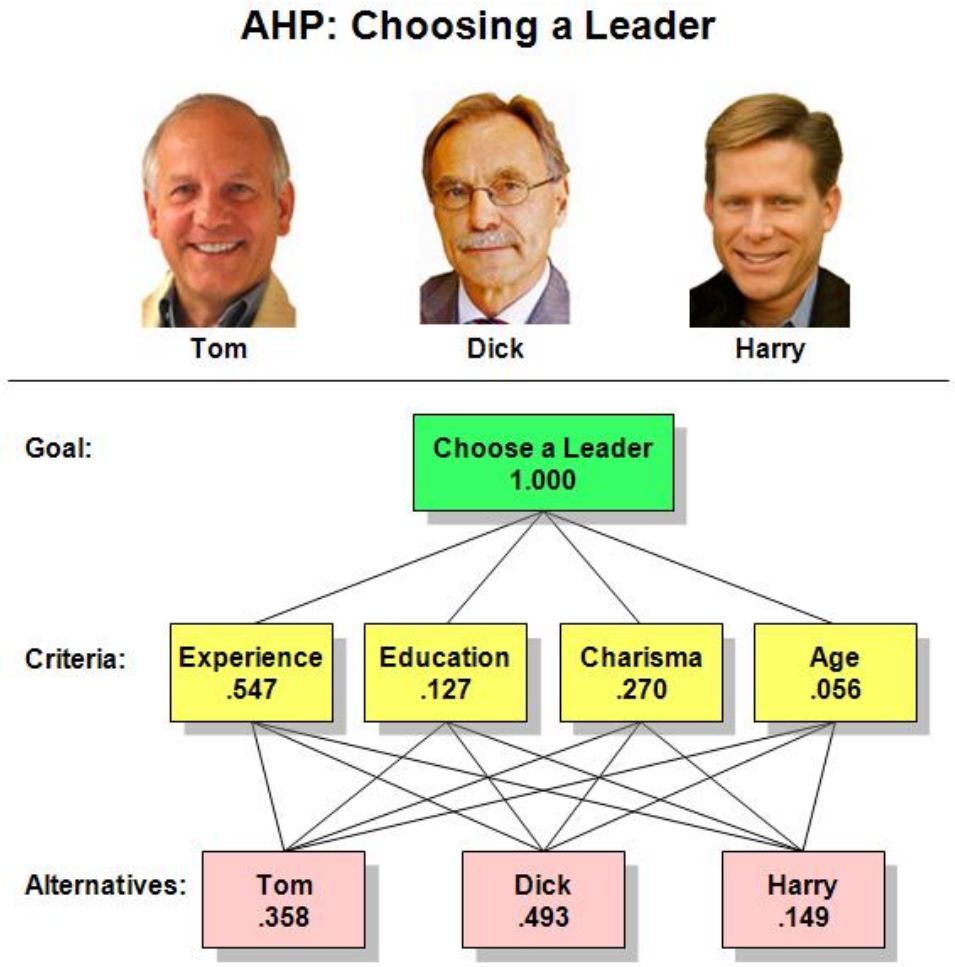
If the expert thinks B > A, the rankings go from 1 to 1/9

Example AHP Matrix

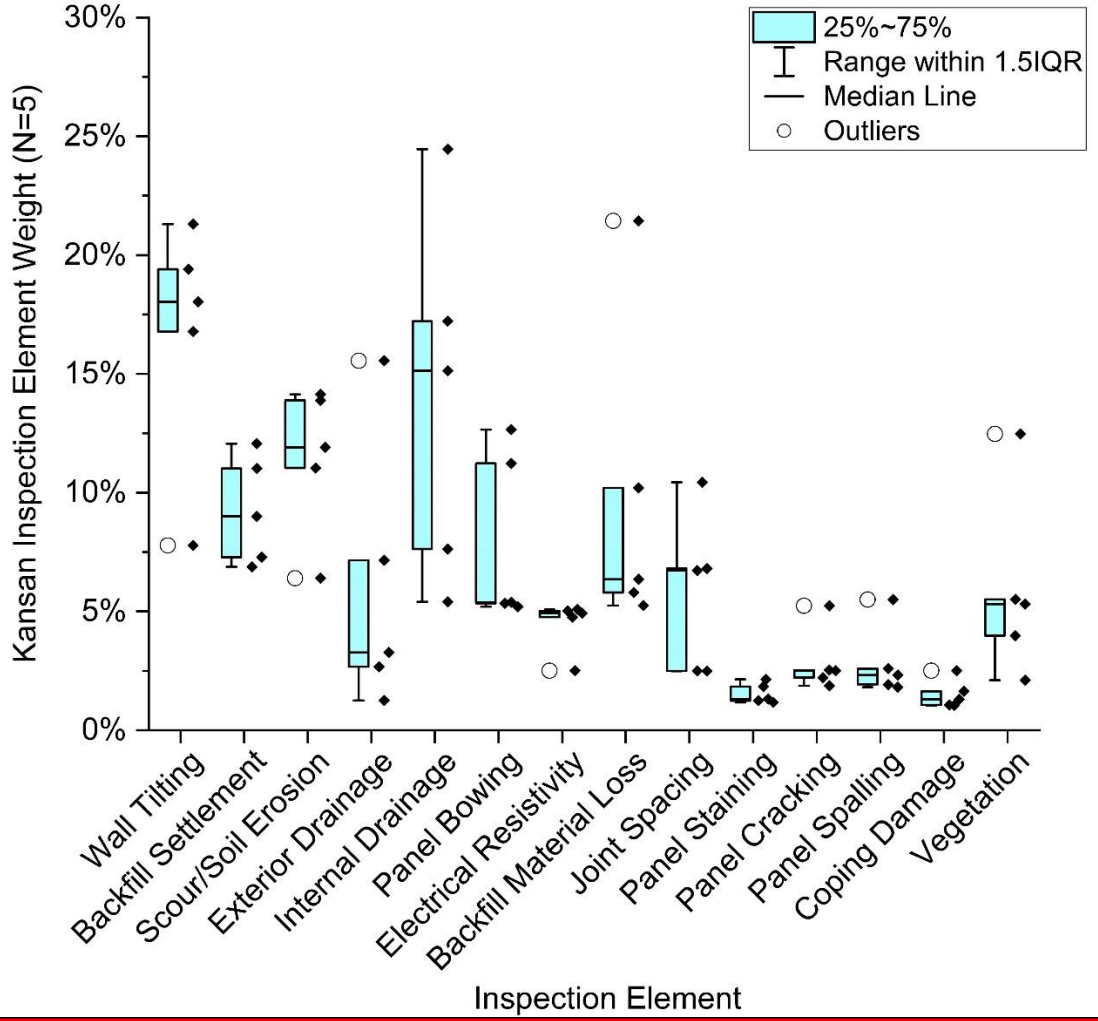
	Wall tilting	Panel Bowing / Bulging	Internal Drainage	Backfill Settlement	Scour/Soil Erosion	Exterior Drainage	Backfill Material	Joints	Cracking	Spalling	Coping	Vegetation	Resistivity
Wall Tilting	1.00	1.00	1.00	3.00	5.00	5.00	5.00	5.00	9.00	9.00	9.00	9.00	7.00
Panel Bowing / Bulging	1.00	1.00	1.00	3.00	3.00	5.00	5.00	5.00	9.00	9.00	9.00	9.00	5.00
Internal Drainage	1.00	1.00	1.00	3.00	3.00	3.00	5.00	3.00	7.00	7.00	7.00	7.00	5.00
Backfill Settlement	0.33	0.33	0.33	1.00	3.00	1.00	3.00	5.00	7.00	7.00	7.00	7.00	3.00
Scour/Soil Erosion	0.20	0.33	0.33	0.33	1.00	1.00	3.00	5.00	5.00	5.00	5.00	5.00	3.00
Exterior Drainage	0.20	0.20	0.33	1.00	1.00	1.00	3.00	3.00	5.00	5.00	5.00	5.00	1.00
Backfill Material	0.20	0.20	0.20	0.33	0.33	0.33	1.00	3.00	5.00	5.00	5.00	5.00	1.00
Joints	0.20	0.20	0.33	0.20	0.20	0.33	0.33	1.00	3.00	3.00	3.00	3.00	0.20
Staining	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Cracking	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Spalling	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Coping	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Vegetation	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.33
Resistivity	0.14	0.20	0.20	0.33	0.33	1.00	1.00	5.00	5.00	5.00	5.00	3.00	1.00

AHP Calculation

- **Piece-wise matrix comparison**
  - Normalization of piece-wise comparison
  - $\overline{a_{ij}} = {a_{ij}}/{\sum_{i=1}^{m} a_{ij}}$
  - Priority vector
  - $w_i = \sum_{i=1}^{m} \overline{a_{ij}} / m$
- m = number of inspection items



Kansas-Only AHP

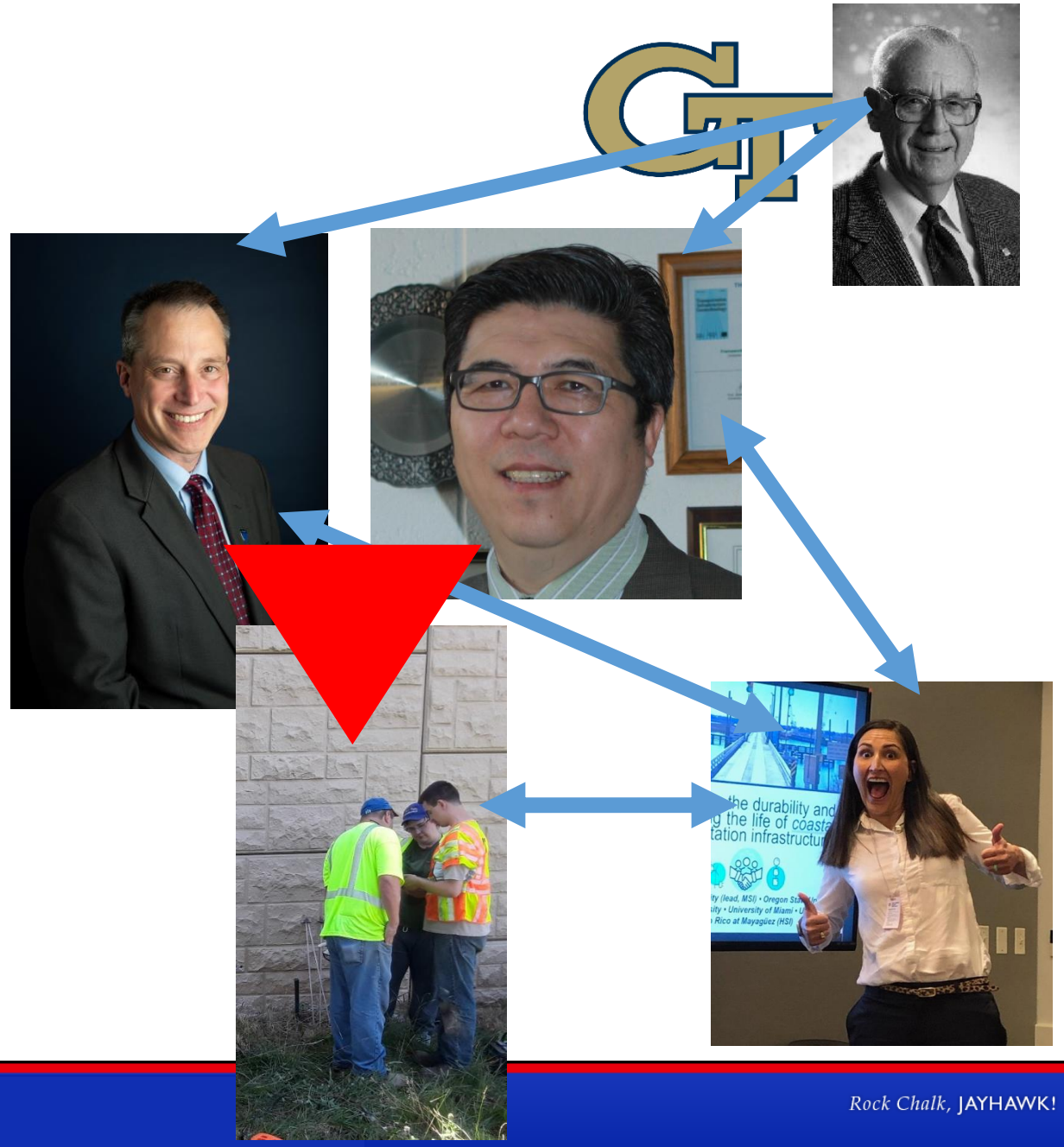


Group	Inspection Item	Kansas Weight (%) (N=5)
Movement	Wall Tilting	17.3
	Backfill Settlement	9.9
Drainage	Scour/Soil Erosion	13.2
	Exterior Drainage	4.5
	Internal Drainage	13.6
Backfill	Panel Bowing	8.0
	Electrical Resistivity	4.6
	Backfill Material Loss	9.1
Facing	Joint Spacing	5.4
	Panel Staining	1.6
	Panel Cracking	2.9
	Panel Spalling	2.8
Exterior	Coping Damage	1.5
	Vegetation	5.3

AHP – Bias is a Concern

- 2 experts from the same school with the same professors
- 5 experts worked together on multiple projects

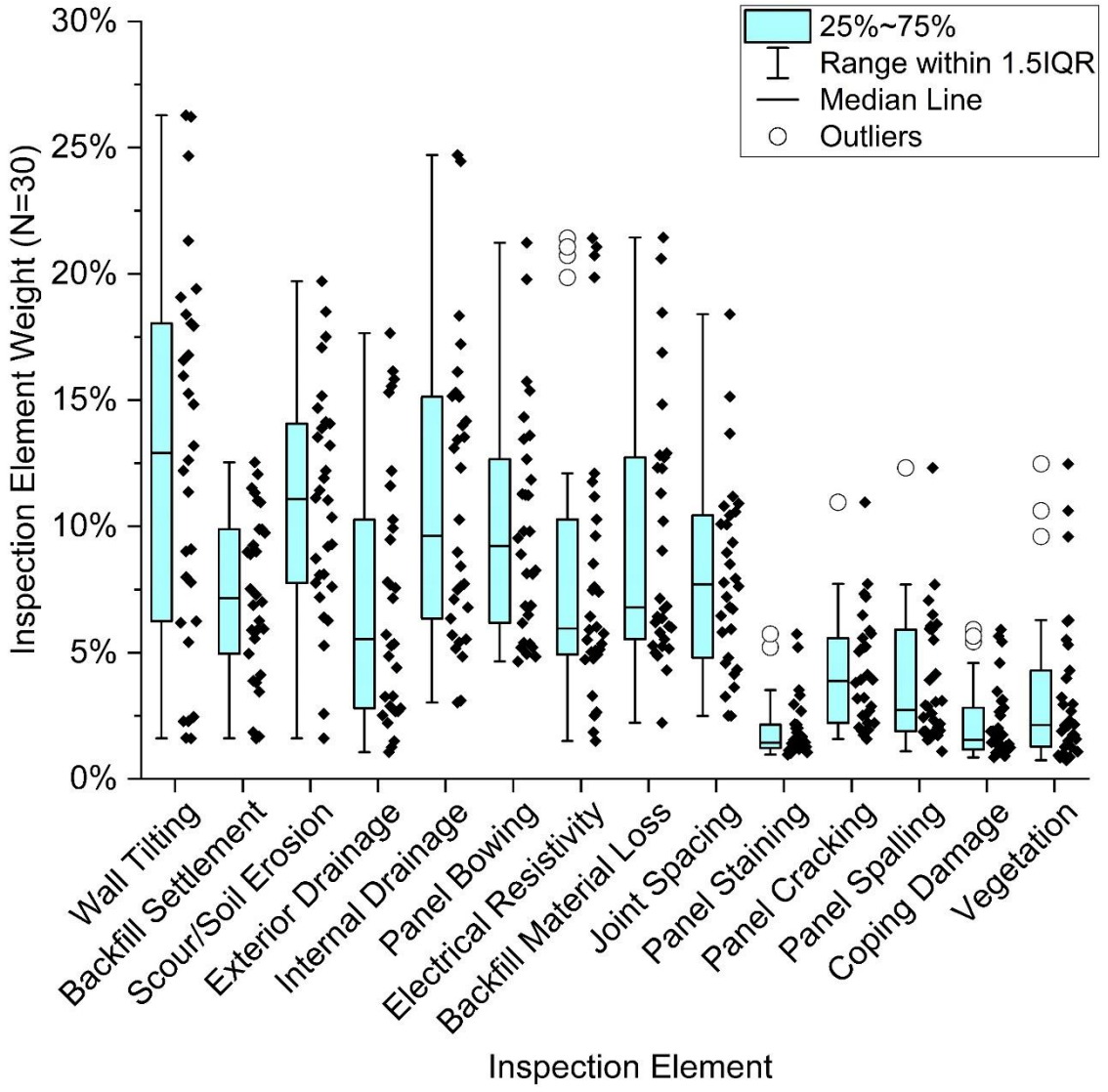
- Group Think is a Thing!



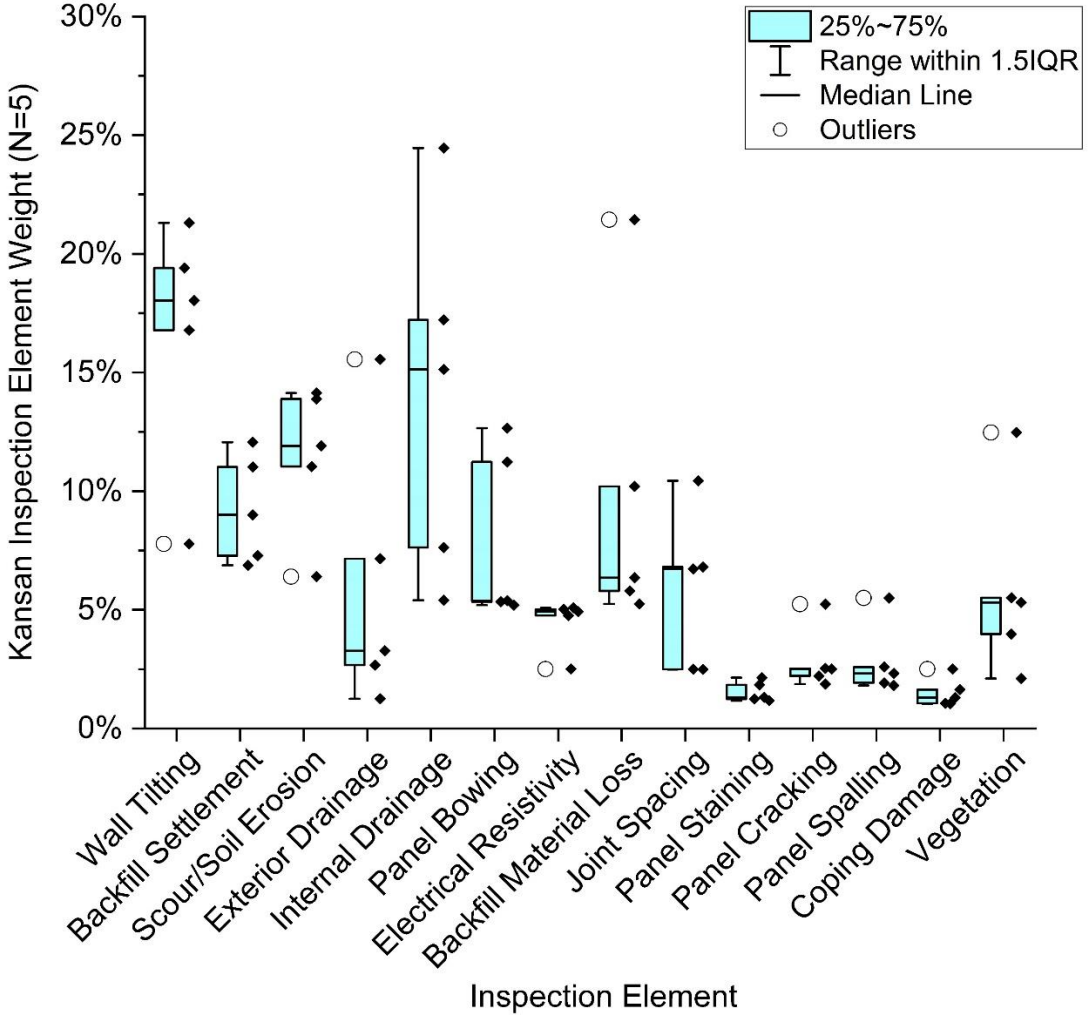
Add More Experts…N=30

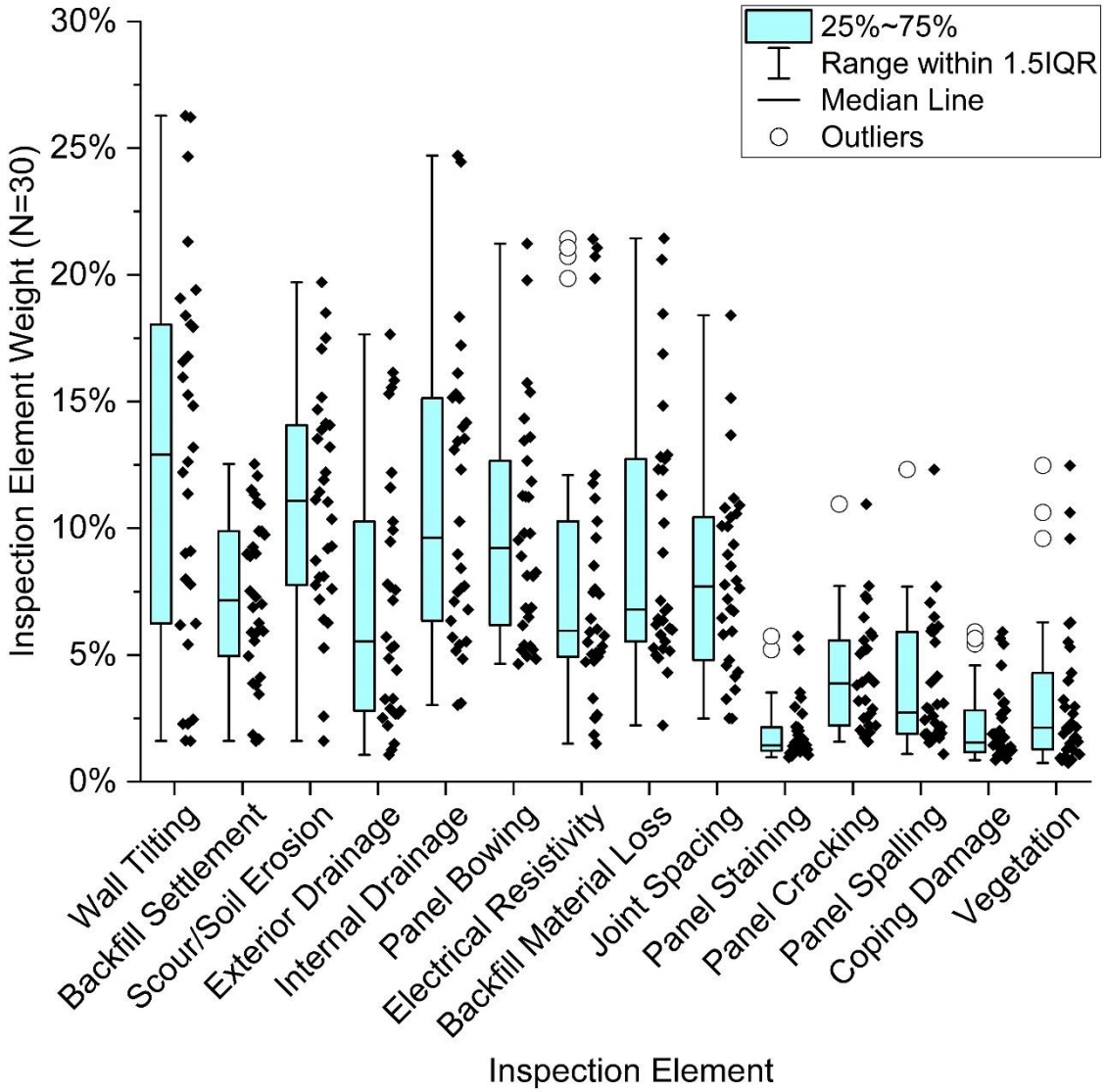
	NE	S	MW	NW
Academia	1*	3	6	1
DOT	2	3	4	1
Industry	3	4	2	0
Total	6	10	12	2

***Northeast Canada**

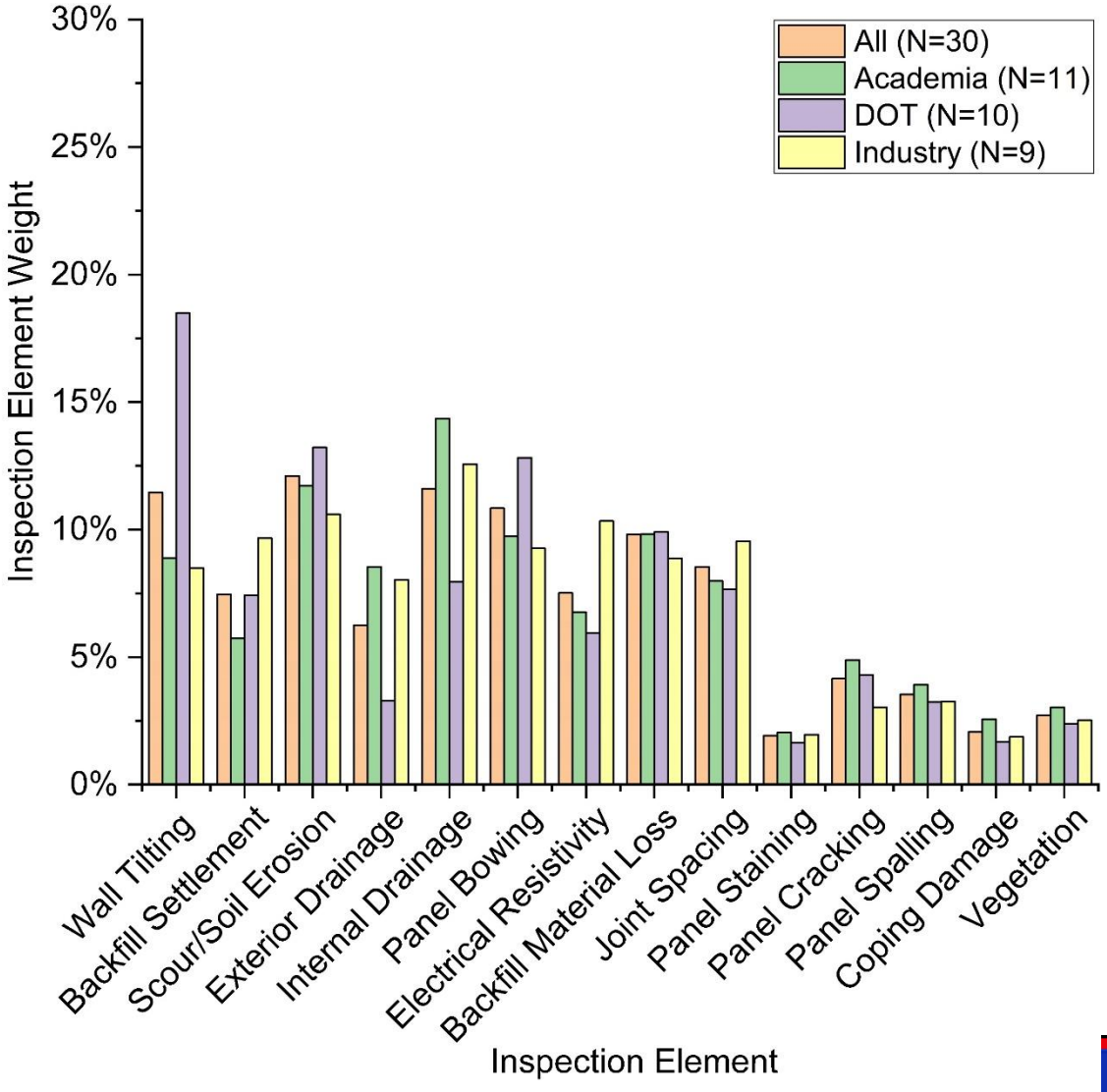


Kansas vs the World



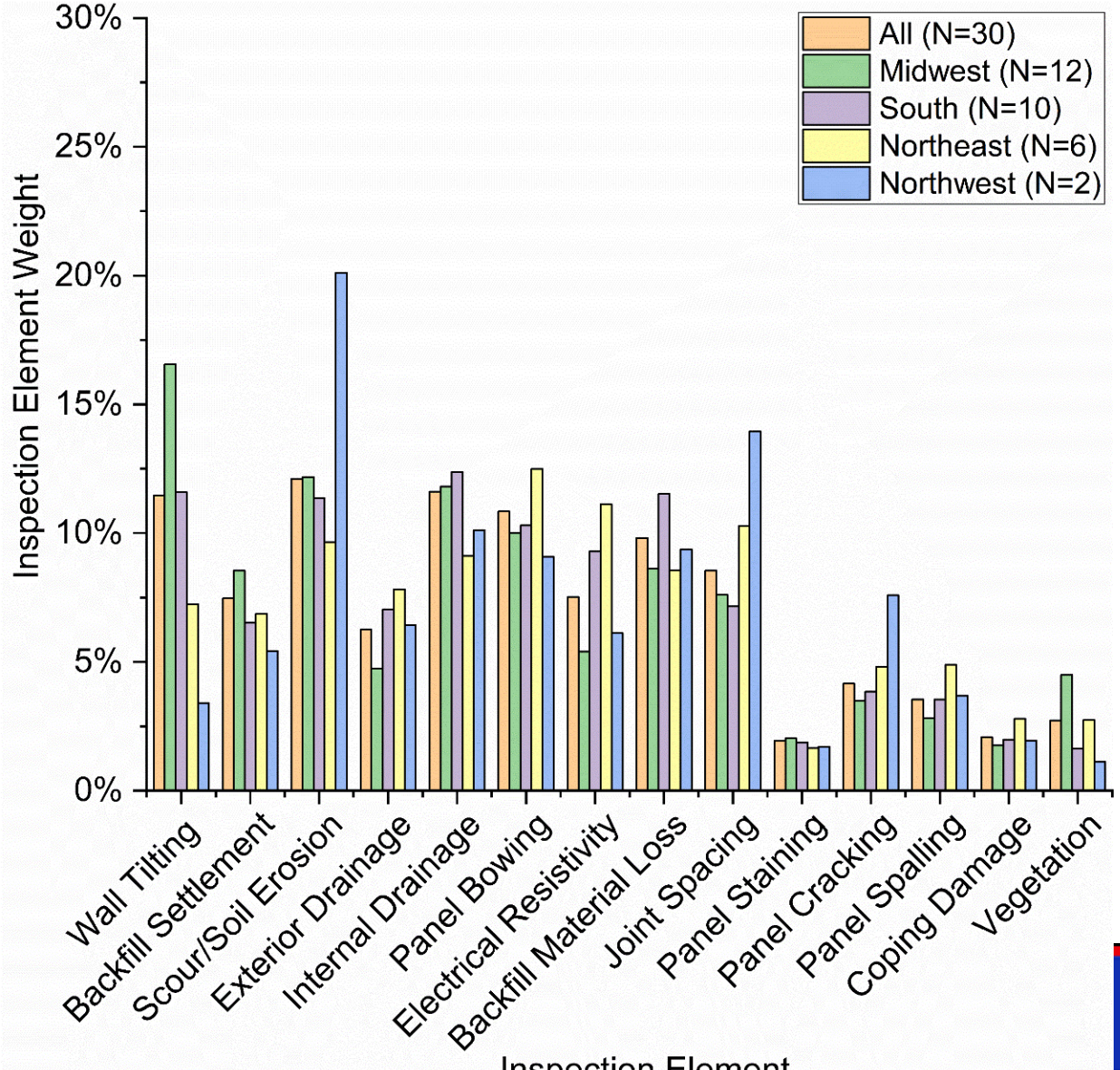


Does career matter?



- **Academia**: Internal drainage (14.3%), Scour (11.7%), Backfill material loss (9.8%)
- **DOT**: Wall tilting (18.5%), Scour (13.2%), Panel bowing (12.8%)
- **Industry**: Internal drainage (12.6%), Scour (10.6%),
  Electrical resistivity (10.3%)

Effects of local practice?



Midwest, wall tilting (16.6%)

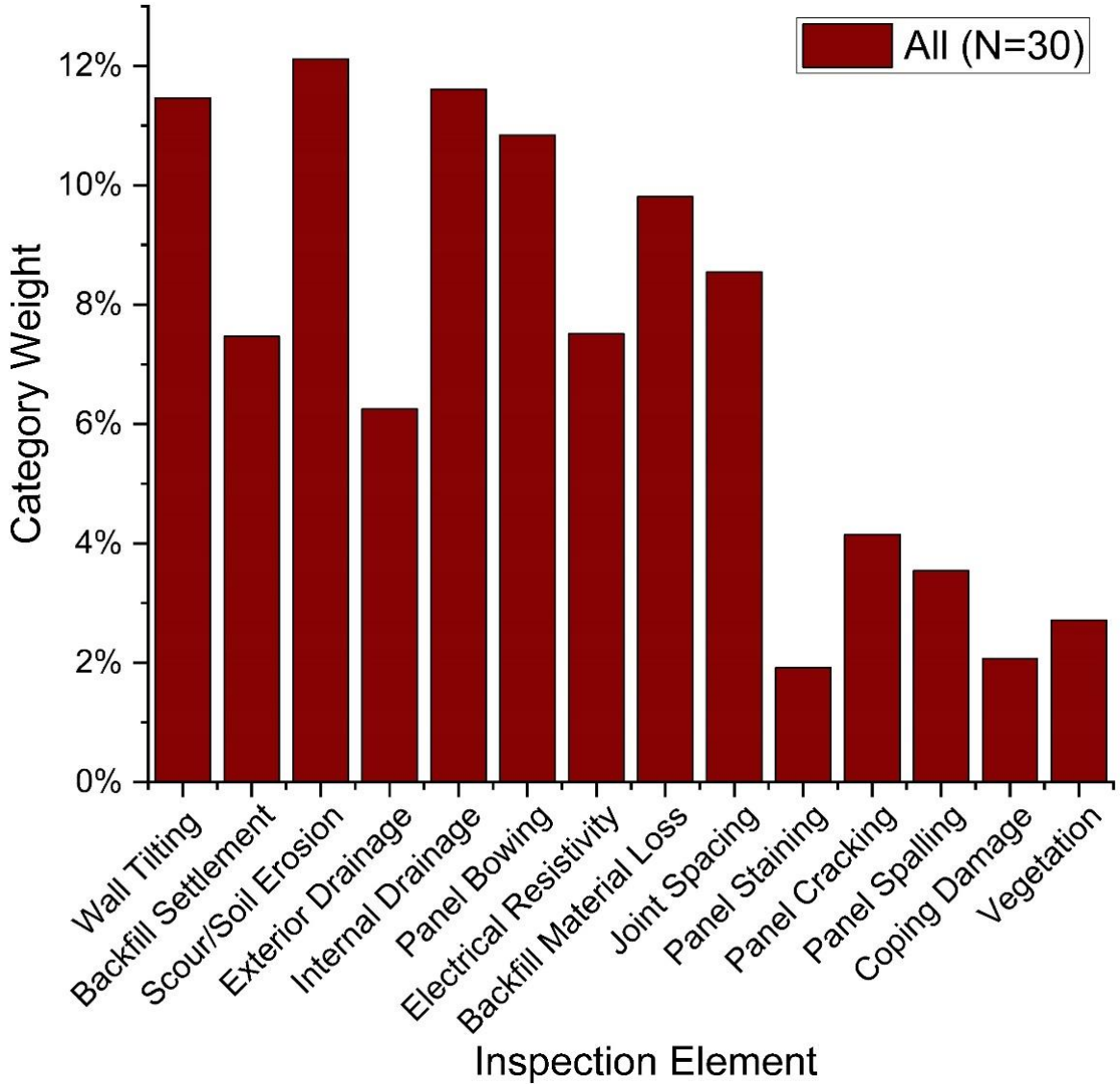
South, internal drainage (12.4%)

Northeast, panel bowing (12.5%)

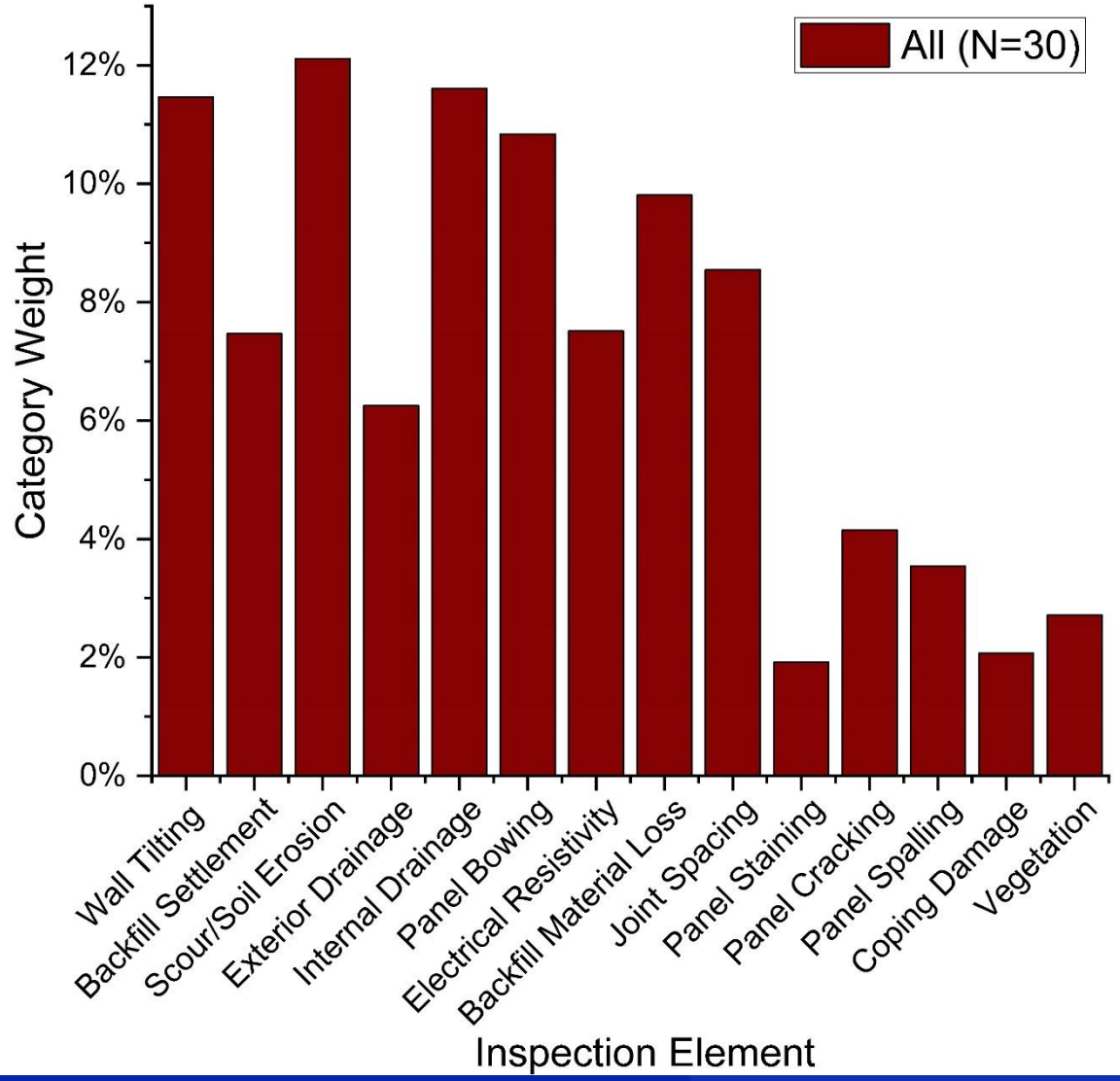
Final Weights – What Came Out on Top?

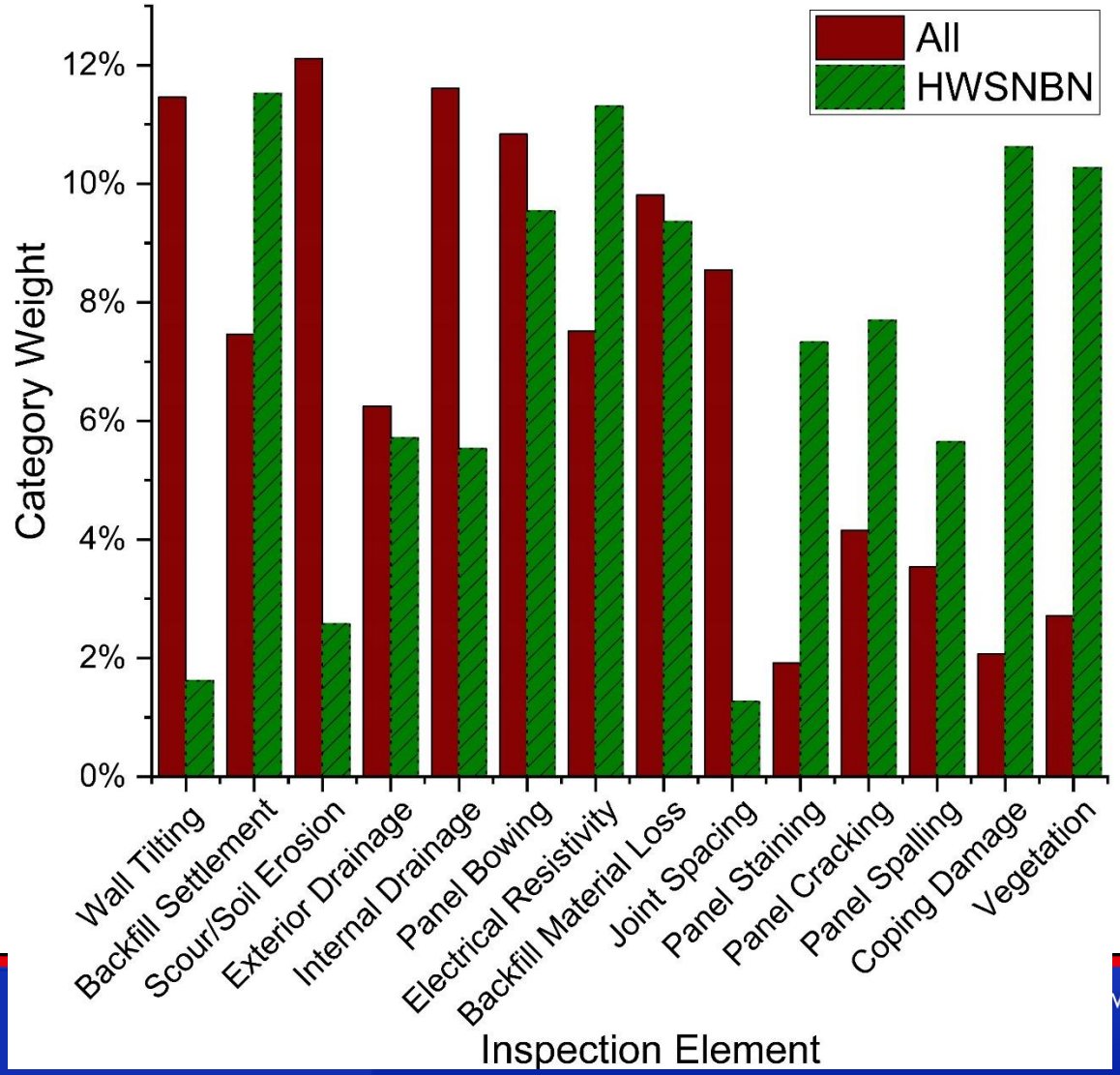
Top Three:

- Scour/Soil Erosion
- Internal Drainage
- Wall Tilting



Who is right?


All (N=30)
Category Weight
12%
10%
8%
6%
4%
2%
0%
Wall Tilting
Backfill Settlement
Scour/Soil Erosion
Exterior Drainage
Internal Drainage
Panel Bowing
Electrical Resistivity
Backfill Material Loss
Joint Spacing
Panel Staining
Panel Cracking
Panel Spalling
Coping Damage
Vegetation
Inspection Element


All
HWSNBN
Category Weight
12%
10%
8%
6%
4%
2%
0%
Wall Tilting
Backfill Settlement
Scour/Soil Erosion
Exterior Drainage
Internal Drainage
Panel Bowing
Electrical Resistivity
Backfill Material Loss
Joint Spacing
Panel Staining
Panel Cracking
Panel Spalling
Coping Damage
Vegetation
Inspection Element

Example

Wall Tilting

$$(\text{rating})(\%) * (\text{weight}) = \text{score}$$

$$(4)(1.00) * (0.115) = 0.46$$

Exterior Drainage

$$[(3)(0.75) + (2)(0.25)] * (0.063)$$

$$= 0.17$$

If not weighted, the overall score would be 2.96

Category	Inspection Element	4 Good	3 Fair	2 Poor	1 Severe	Weight	Score
Movement	Wall Tilting	100%				11.5	0.46
	Backfill Settlement	100%				7.5	0.3
Drainage	Scour/Soil Erosion	100%				12.1	0.48
	Exterior Drainage		75%	25%		6.3	0.17
	Internal Drainage	50%	50%			11.6	0.41
Backfill	Panel Bowing / Bulging		100%			10.8	0.32
	Resistivity		100			7.5	0.23
	Backfill Material	100%				9.8	0.39
Facing	Joints	100%				8.5	0.34
	Staining			25%	75%	1.9	0.02
	Cracking		50%	50%		4.2	0.11
	Spalling		100%			3.5	0.11
Exterior	Coping			25%	75%	2.1	0.03
	Vegetation			25%	75%	2.7	0.03
	Overall Score						**3.4**

Additional Modifiers - Tarawneh, Al Bodour, and Masada (2018)

MSE Wall Age (years)	Age Modifier (M_a)	AADT (veh/day)	Traffic Modifier (M_T)	MSE Wall Height (ft)	Height Modifier (M_H)
<10	1.00	<4,000	1.00	<16	1.00
10-15	0.98	4,000-18,500	0.98	16 - 33	0.98
15-20	0.96	18,500-35,000	0.96	33 - 49	0.96
>20	0.94	>35,000	0.94	> 49	0.94

$$M_A = 1.17 - 0.17\log(A)$$

$$MGRS = GRS * M_T * M_H * M_A$$

MSE Wall Inspection Ratings Guide

Category	Rating	4	3	2	1
		Good	Fair	Poor	Severe
Movement	Wall tilting	None	Minor uniform titling of the wall section. Minor misalignment	Moderate uniform tilting of the wall section. Moderate misalignment	Extreme uniform tilting of the wall section. Extreme misalignment
	Settlement	None	Some settlement but no effect on the roadway	Moderate settlement roadway moderately affected	Extreme settlement roadway affected, and traffic completely impeded

MSE Wall Inspection Ratings Guide

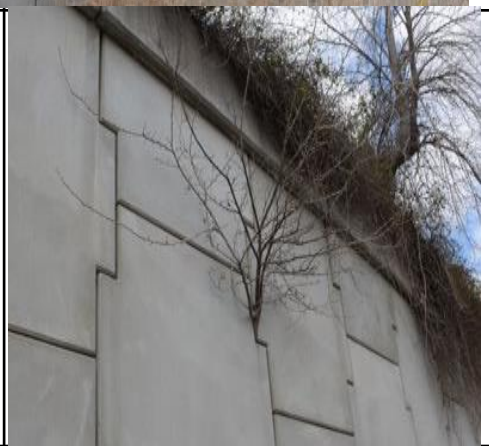
Category	Rating	4	3	2	1
		Good	Fair	Poor	Severe
Drainage	Scour/Soil Erosion	None, Riprap in place or if on rock use 4	Some riprap missing	Moderate amount of riprap missing with moderate soil erosion	Riprap is gone with extreme soil erosion exposing wall toe
	Exterior Drainage	Free draining	Water is not ponded with slow drainage	Water is ponded with little drainage from the roadway above the wall	Water is ponded with no drainage from the roadway
	Internal Drainage	Free draining	Some debris in the drain, drainage from the wall still occurring	Drains contain debris with some drainage occurring	Drain completely full of debris no drainage occurring
Backfill	Panel Bowing / Bulging	None	Panel joints have bowed without geotextile fabric exposure	Panel joints have bowed with some geotextile fabric and soil exposure	Panel joints have bowed with complete geotextile fabric and soil exposure
	Electrical Resistivity (lab drained or in situ)	Greater than 8,000 Ohm-cm	5,000 – 8,000 Ohm-cm	3,000 -5,000 Ohm-cm	Less than 3,000 Ohm-cm
	Backfill Material	None	Minor backfill erosion visible	Moderate backfill erosion visible	Extreme backfill erosion visible structural integrity is compromised

Examples of Ratings

Category	Fair	Poor	Severe
Cracking			
Joints			

Examples of Ratings

Category	Fair	Poor	Severe
Panel Bowing or Bulging			
Backfill Erosion			

Category	Fair	Poor	Severe
Internal Drainage			
Coping			
Vegetation			

Example Wall

KDOT MSE Wall Inspection Form				Survey Date:				March 15, 2022	
Height (ft)	24	GPS Coordinates		38° 56' 27'' N 94° 47' 49'' W				County	Sedgwick
Length (ft)	1000								
Width (ft)	60	% of Wall Condition				W%	Score	Wall ID #	I-435 over Lackman
Category	Rating	4 Good	3 Fair	2 Poor	1 Severe			Notes	
Movement	Wall Tilting	100%				12%	0.48		
	Backfill Settlement	100%				8%	0.32		
Drainage	Scour/Soil Erosion	23%	50%	25%		11%	0.32		
	Exterior Drainage	25%	75%			6%	0.20	Southwest column (corner)	
	Internal Drainage		100%			11%	0.33		
Backfill	Panel Bowing / Bulging	100%				11%	0.44		
	Resistivity			100%		8%	0.16	T: 9C R:4500ohm-cm	
	Backfill Material	100%				10%	0.40		
Facing	Joints		100%			8%	0.24	Southwest column and 2 panels on west side	
	Staining	100%				2%	0.08		
	Cracking	100%				4%	0.16		
	Spalling	50%	50%			4%	0.14	Two sections on west side	
Exterior	Coping	100%				2%	0.08		
	Vegetation			100%		3%	0.06	Multiple large trees adjacent to structure	
Other									
Engineer Inspection	*If category was rated 50% > Poor	YES							
Score	Rating Score					3.41			
	Height of Wall					24	ft	M_H	0.98
	AADT					23000	veh/day	M_A	0.96
	Constructed					2014		M_A	1.00
	Risk Adjusted Rating Score					**3.20**			

Example Wall

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	Backfill Material	100%				10%	0.40				

Example Wall

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Exterior	Coping	100%				2%	0.08		
	Vegetation			100%		3%	0.06	Multiple large trees adjacent to structure	
Other									
Engineer Inspection	*If category was rated 50% > Poor	YES							

Score					
	Rating Score	3.41			
	Height of Wall	24	ft	M_H	0.98
	AADT	23000	veh/day	M_T	0.96
	Constructed	2014		M_A	1.00
	Risk Adjusted Rating Score	**3.20**			

Summary

- Tools and a procedure for assessing the condition of a retaining wall inventory was developed
- Assessed items were rated on a 4-point scale
- Assessed items were weighted based on expert opinions using the AHP ratings method
- Group think is real and should be considered when developing a survey using expert opinions
- Additional risk modifiers were included
- Examples of various ratings were provided

Going Forward

- KU and KDOT are currently engaged in a similar program to assess the slope inventory in Kansas
- If you would like to participate as an expert, let me know!

Final Thoughts

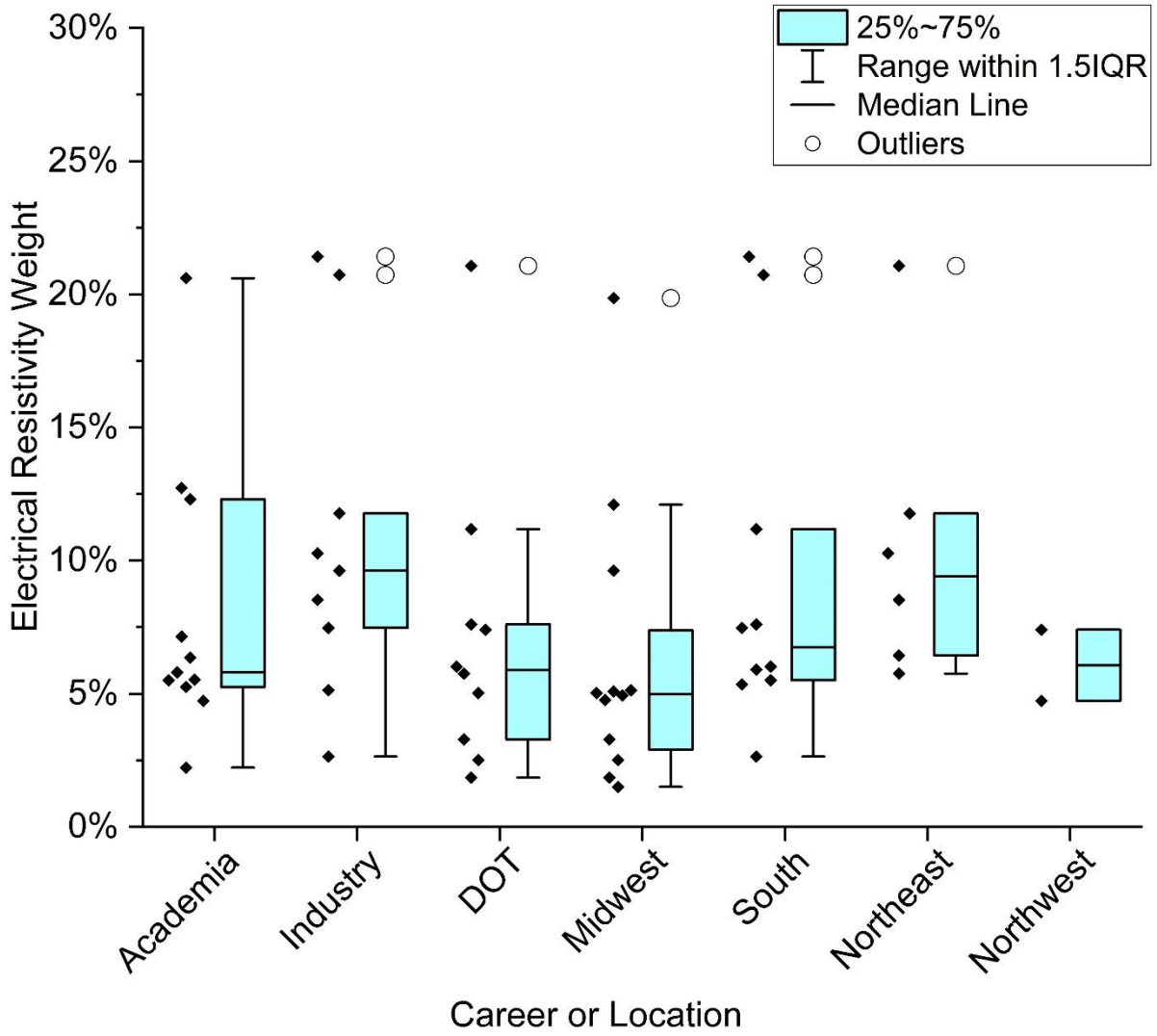
- Highest weights / Potential Failure Mechanism
- Scour (12.2%) - overturning or bearing capacity
- Internal drainage (11.6%) – internal failure
- Wall tilting (11.5%) – overturning, bearing, global stability, or internal failure
  - May be more aesthetic…
- Panel bowing (10.8%) – hydraulic pressure, poor reinforcement connection, overstressing reinforcement, loss of reinforcement, unsupported reinforcement

Thank you!

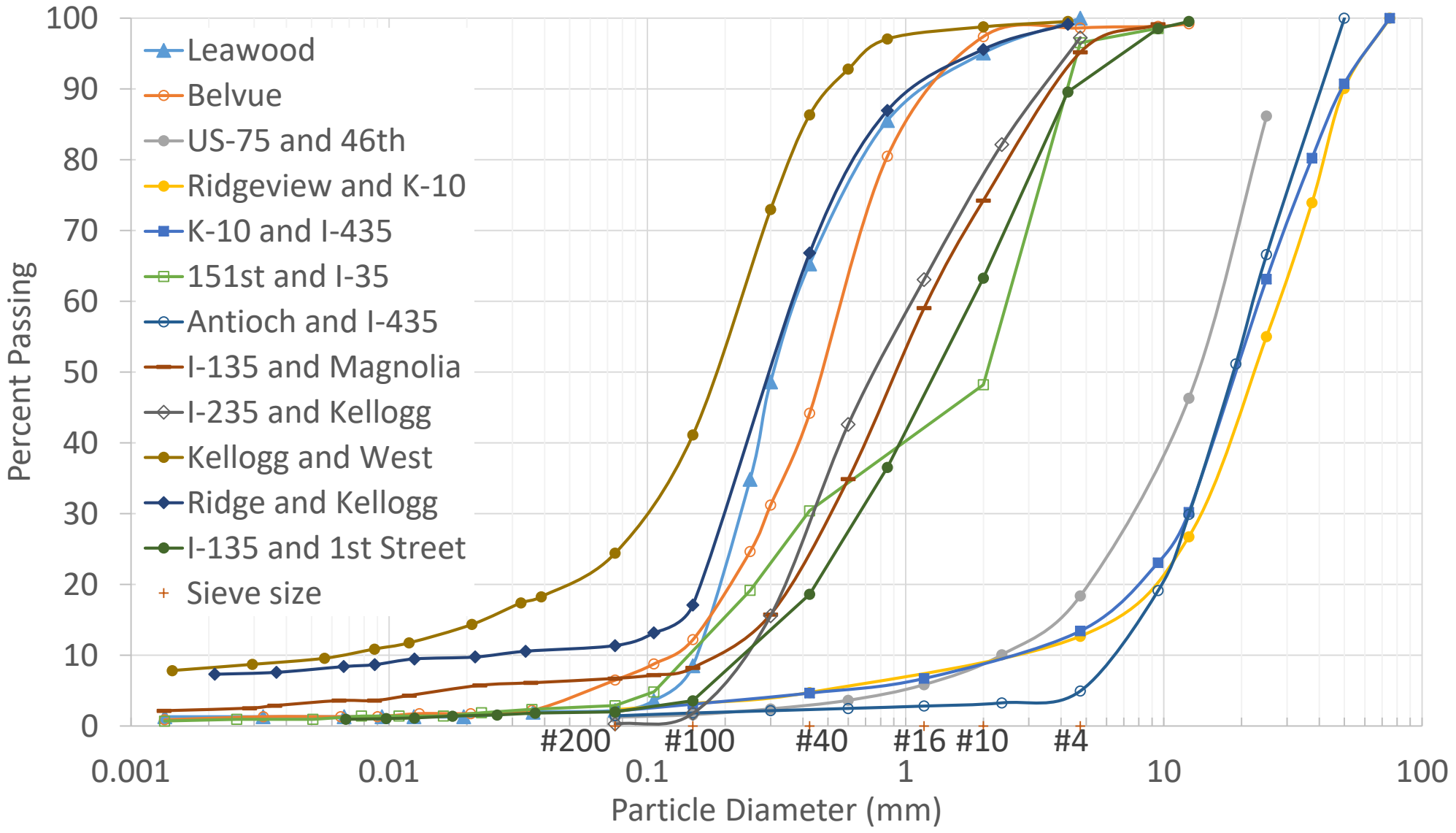
Bonus Slides

Thoughts on electrical resistivitv…

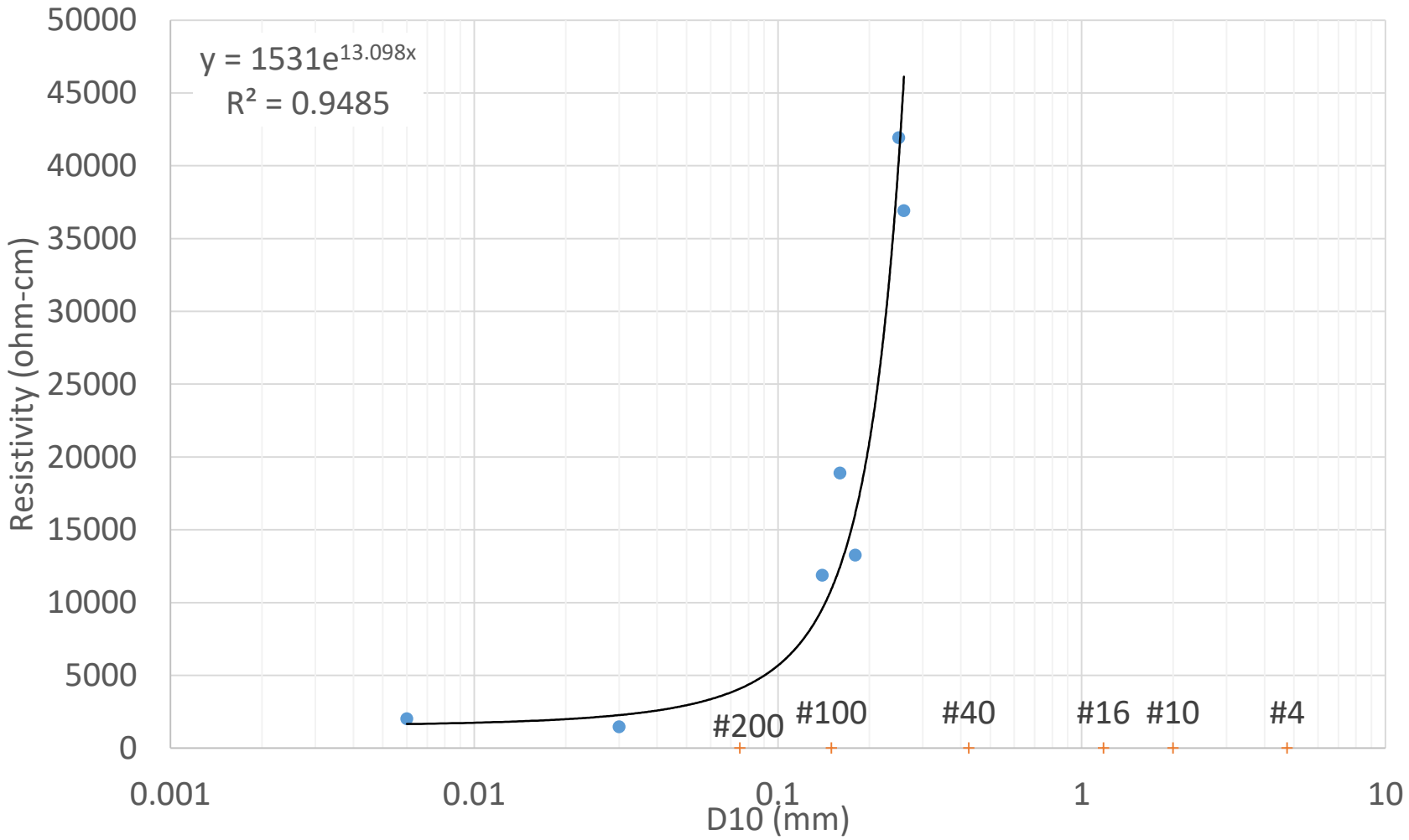
Is electrical resistivity the most appropriate measurement to identify corrosivity?



Sand and Gravel-sized Backfills



Drained Resistivity vs D_{10} for Sand Backfills



Resistivity vs D_{10} Prior to Saturation for Sand Backfills