12-9-2021

Creating Transparent and Accessible Methods For Approximating the Composite Strength of Concrete Sandwich Wall Panels

Ruth Taylor
Utah State University, ruth.eloisa.456@gmail.com

Best of 2019

Concrete: the most destructive material on Earth

Limestone quarries and cement factories are often sources of air pollution. Photograph: Zoonar GmbH/Alamy

https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth

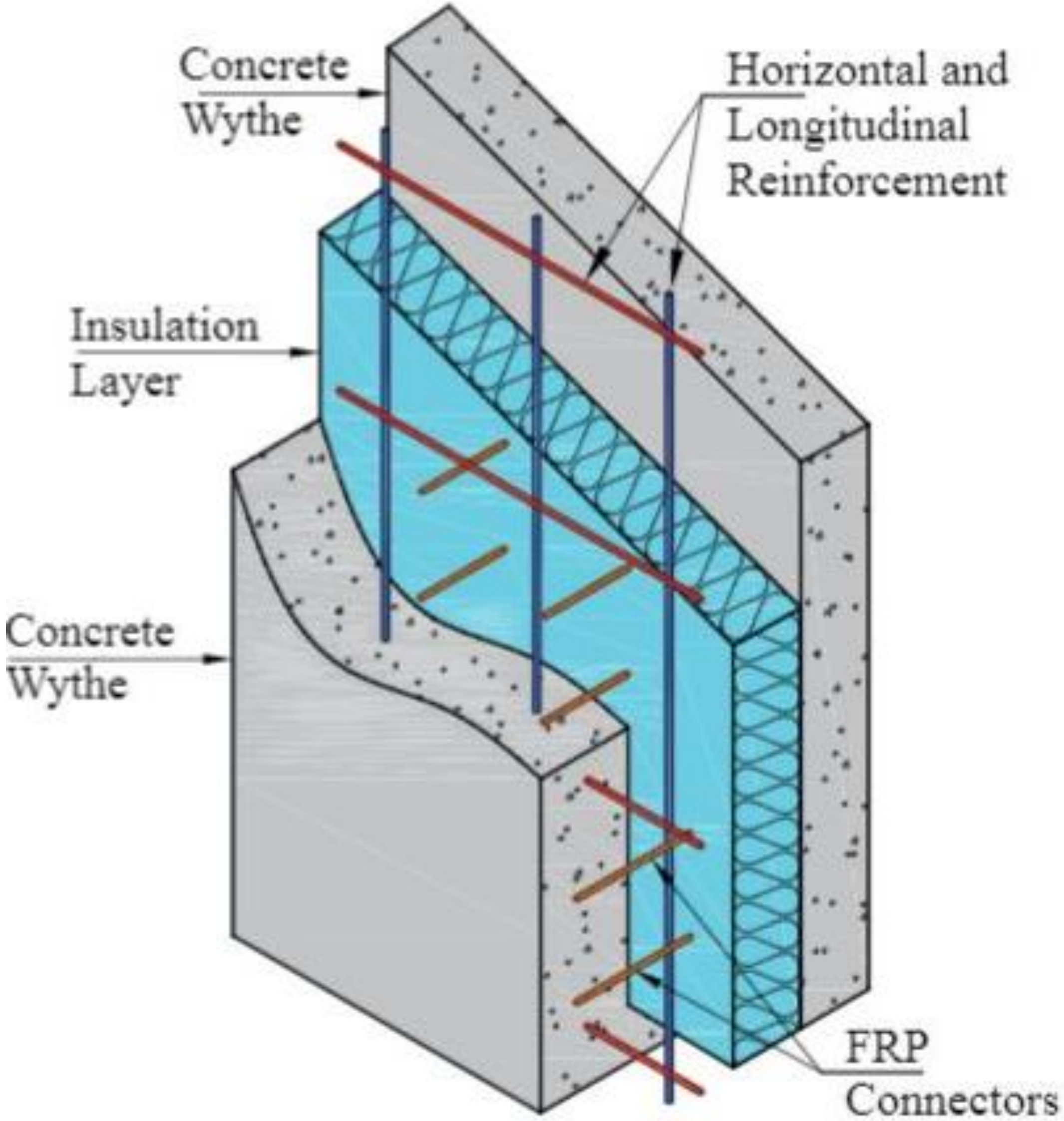
Climate change: The massive CO2 emitter you may not know about

By Lucy Rodgers
BBC News

https://www.bbc.com/news/science-environment-46455844

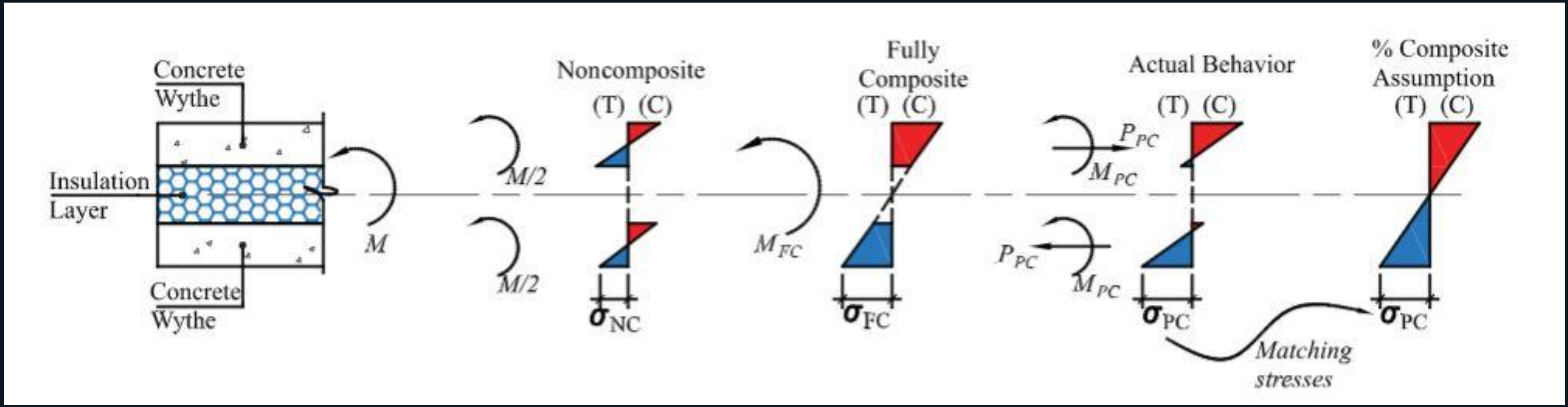
"If the cement industry were a country, it would be the third largest carbon dioxide emitter in the world" [3]

Partially Composite Sandwich Wall Panels (SWPs)



"General configuration of an ICWP […]" [5]

- Original design of *non-composite* insulated concrete wall panels (ICWPs) dated back to 1906
- *Partially composite* ICWPs/SWPs rapidly overtaking design trends
- Stronger and more environmentally efficient
- **Construction has outpaced regulation and guidelines on structure**



"Stress distributions through panel depth for noncomposite, fully composite, and partially composite panels" [5]

Percent Composite Action

- main method used to design partially composite SWPs
- Relative measure of the strength of the wall on the scale from non-composite (0%) to fully composite (100%)

The need for *approximations* for practicing engineers

- Theoretical formulas for calculating percent composite
- Proprietary software
- Rely on values from manufacturers

Creating Transparent and Accessible Methods for Approximating the Composite Strength of Concrete Sandwich Wall Panels

Variable Candidates

Two ranges of variables

- FULL range
- “COMMON” range

Wall dimension variables

- Span/height (L)
- Wythe 1 thickness (WT1)
- Wythe 2 thickness (WT2)
- Insulation layer thickness (Ins)
- Overall wall width (Width)

Wall characteristic variables

- Elasticity (Ec)
- Tensile strength (fr)
- Connector stiffness (K)

Variable	“Common” Range	Possible Range	Increment
L	240-540 (in)	120-1020 (in)	0.25 in
WT1	3-4 (in)	1-5 (in)	0.25 in
WT2	3-4 (in)	1-5 (in)	0.25 in
Ins	3-4 (in)	1-5 (in)	0.25 in
Width	96-144 (in)	24-192 (in)	1 in
Ec	4,000-5,100 (ksi, ksi=1000*psi)	3,000-10,000 (ksi, ksi=1000*psi)	Any real #
fr	0.53-0.70 (ksi, ksi=1000*psi)	0.30-2.0 (ksi, ksi=1000*psi)	Any real #
K	0-200 (kip/in)	0-3600 (kip/in)	Any real #

Translating code and data simulation

MATLAB code applying ISBT* method on data set

Functions in R for any single wall configuration or data set:

Examples:
connector_locations()
ISBT()

Data simulation functions:

Example:
randomdata()

ISBT applied to data

Example:
ISBT_randomdata()

Multiple data sets per range ~1,000,000 observations each

*Iterative Sandwich Beam Theory Method

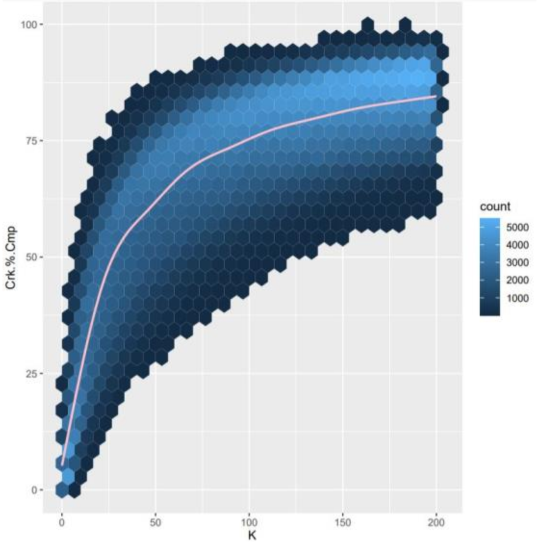
Data exploration and variable selection

- Penalized regression
- Random forest variable importance plots
- Regression trees
- Variable selection process in GAM package

- Two universally important variables: K (average sheer stiffness) and L (span)

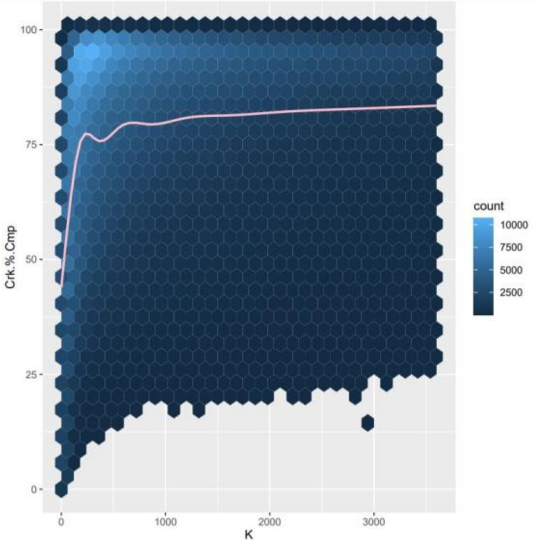
Percent Cracking Composite (CrkCmp)

LIMITED RANGE



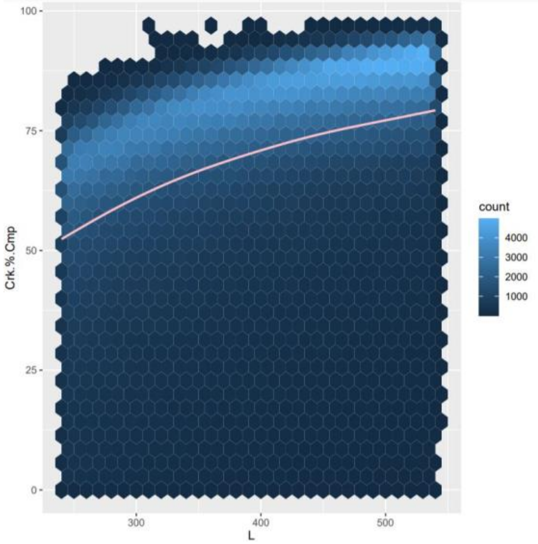
CrkCmp vs K

FULL RANGE



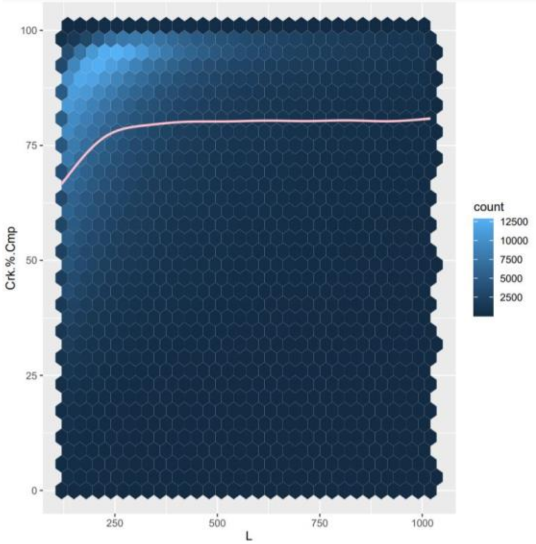
CrkCmp vs K

LIMITED RANGE



CrkCmp vs L

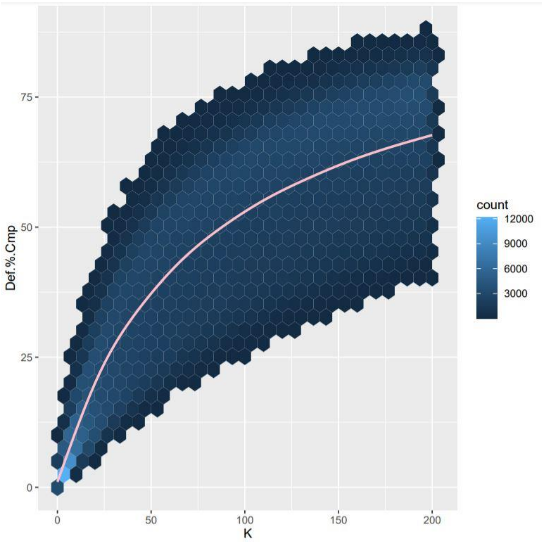
FULL RANGE



CrkCmp vs L

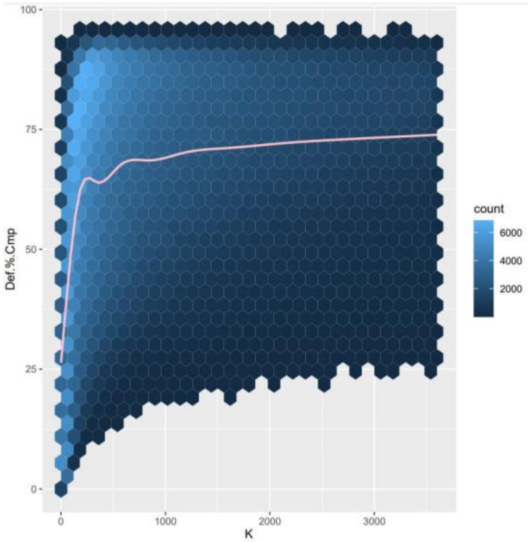
Percent Deflection Composite (DefCmp)

LIMITED RANGE



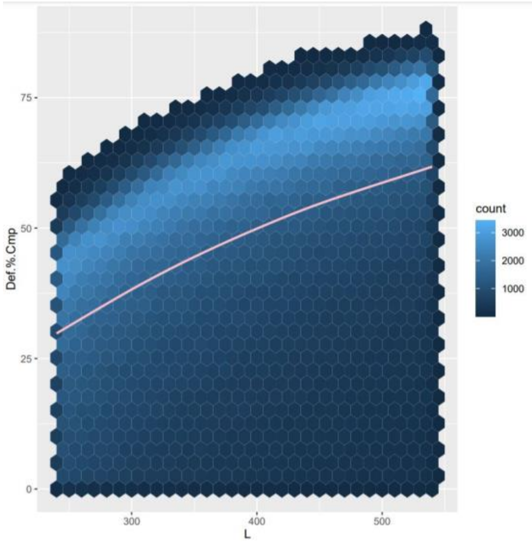
CrkCmp vs K

FULL RANGE



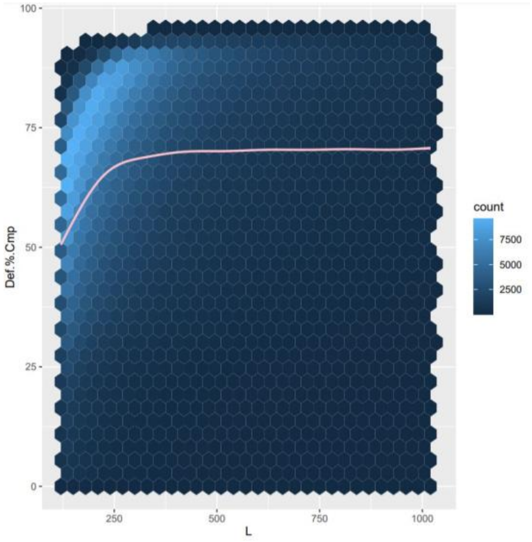
CrkCmp vs K

LIMITED RANGE



CrkCmp vs L

FULL RANGE



CrkCmp vs L

Models for "common" range

- Linear Regression

$$(Def.\%.Cmp)^{1.5} = 2.631294(K) + 1.041109(L - 240)$$

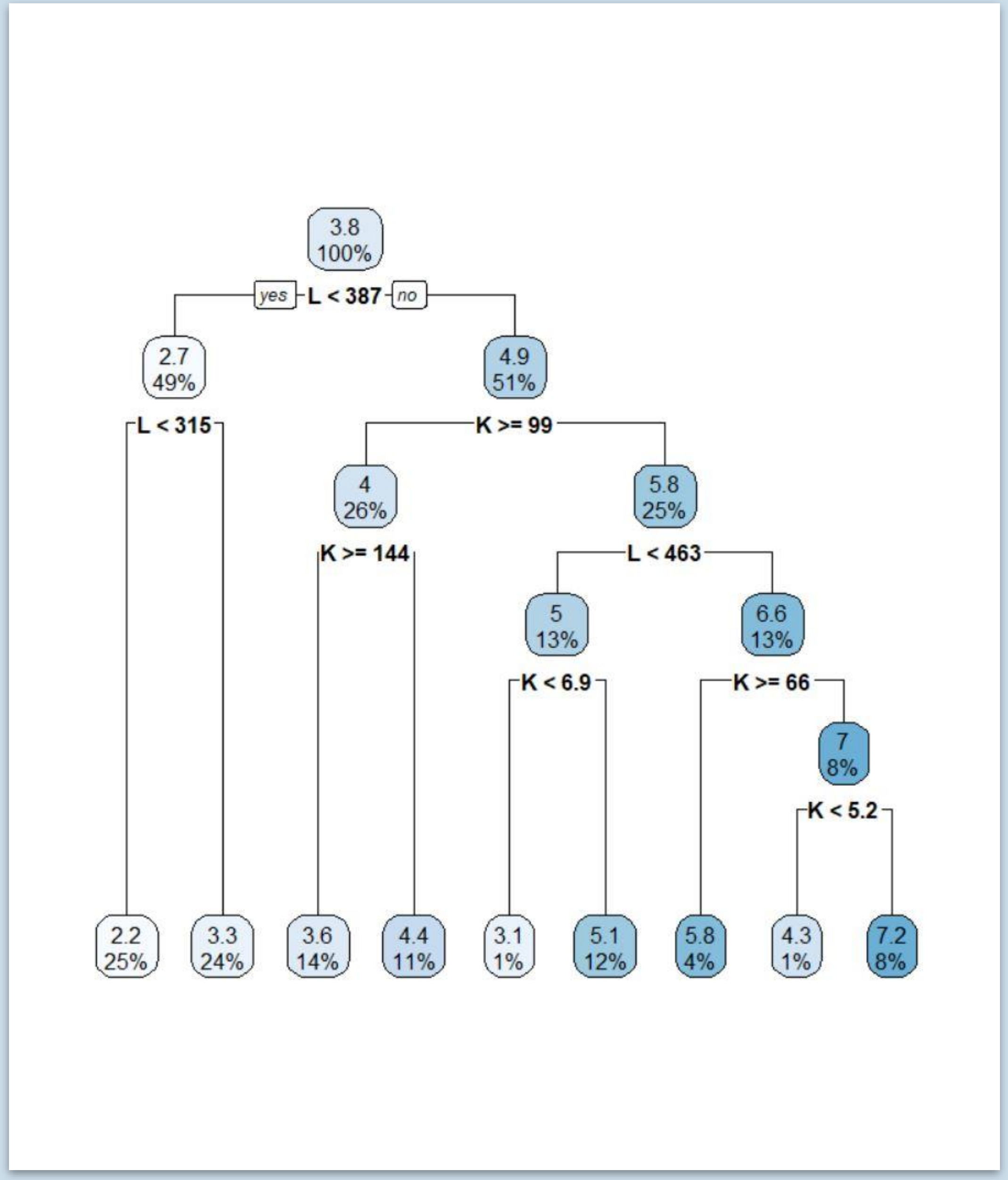
$$(Crk.\%.Cmp)^{2} = 32.430691(K) + 12.136964(L - 240)$$

- Quantile Regression

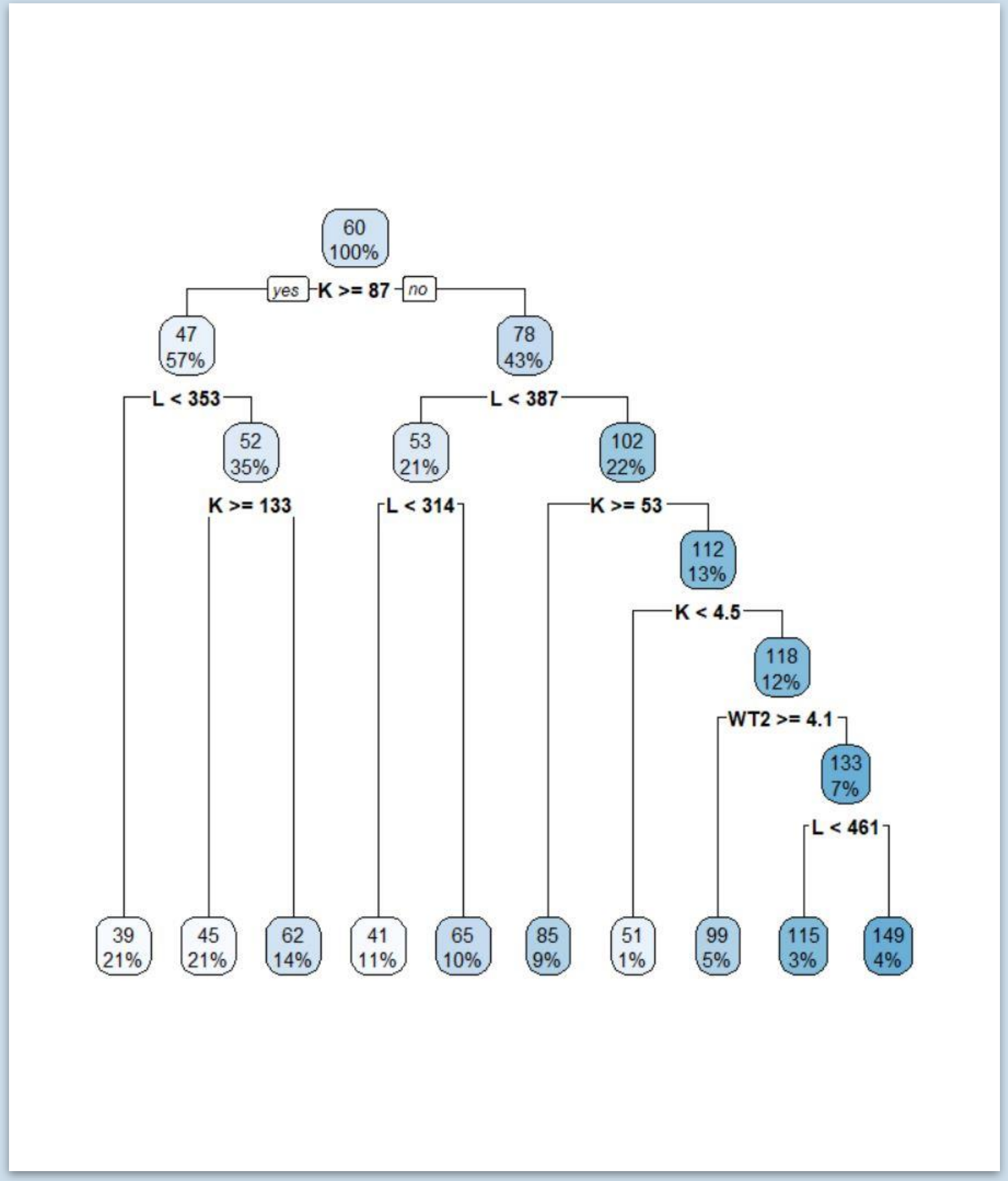
$$(Def.\%.Cmp)^{1.5} = 2.1493264(K) + 0.8137442(L - 240)$$

$$(Crk.\%.Cmp)^{2} = 30.58032(K) + 10.99243(L - 240)$$

Coefficient Tree: Cracking Composite



Coefficient Tree: Deflection Composite

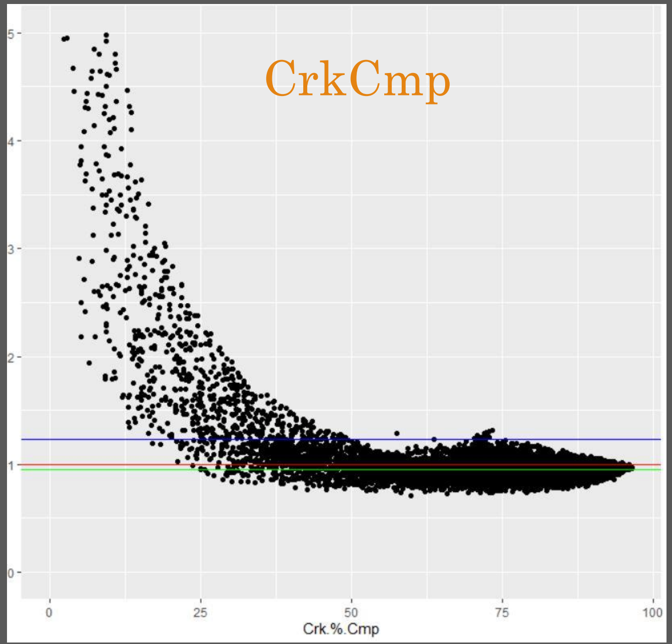


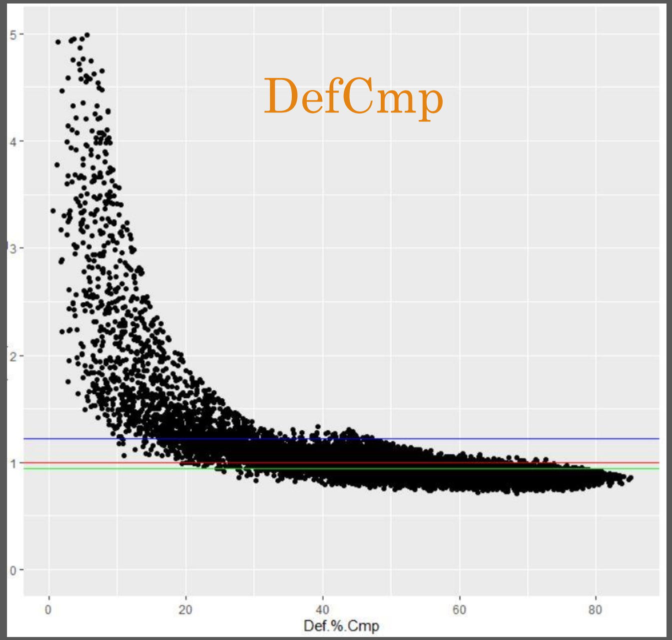
Error Rates

- ***Overprediction***
- Coefficient Tree most accurate

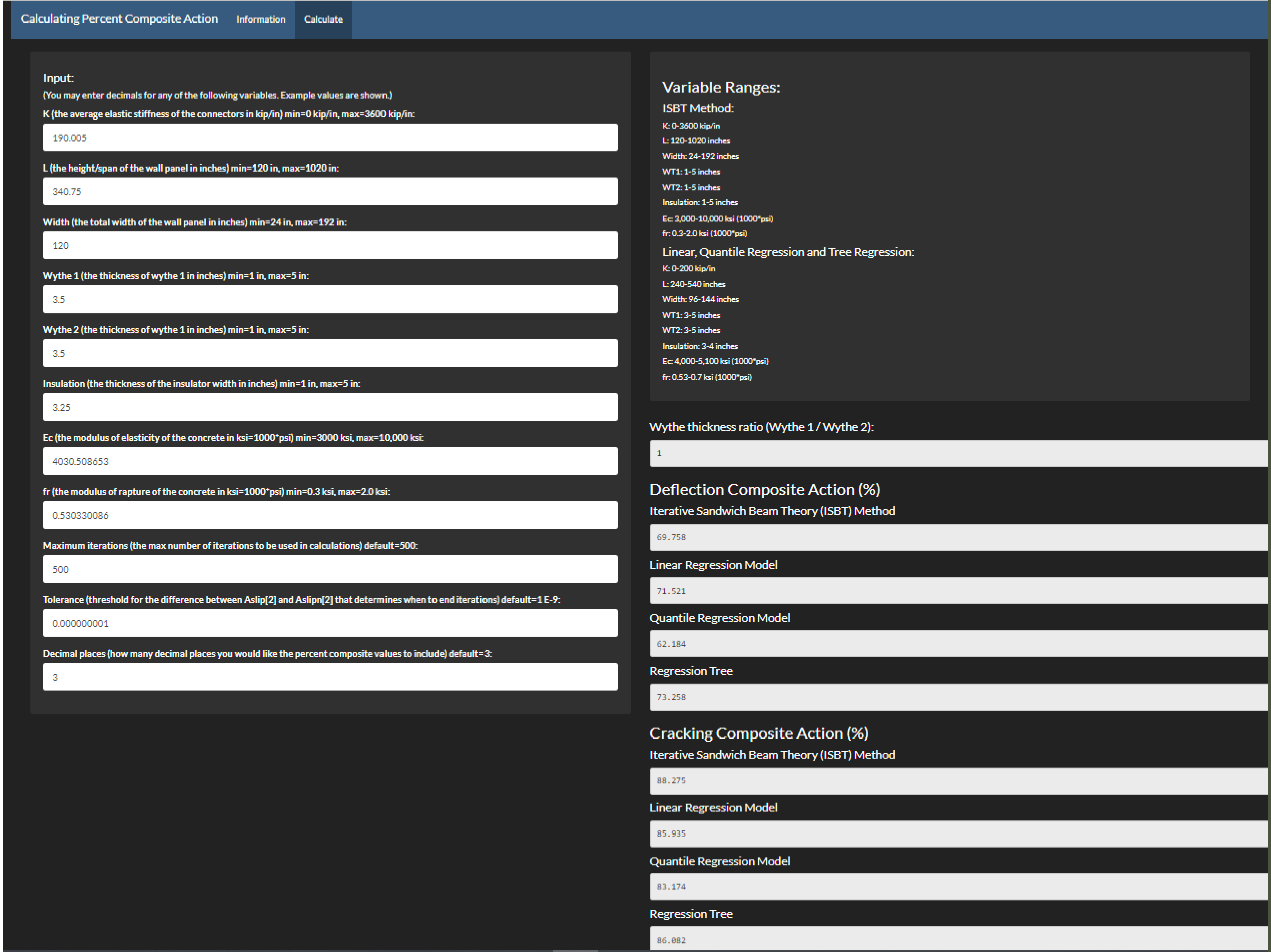
Common Range Data Set				
% Composite	**Regression**	**MSPR**	**MRPR**	**Pred/Obs**
Deflection Composite	OLS	58.89617	Median: 0.0822, Mean: 0.452	Median: 1.0238, Mean: 1.397
	Quantile, τ=0.3	61.81704	Median: 0.0971, Mean: 0.485	Median: 0.970, Mean: 1.331
	Coefficient Tree	**25.90623**	Median: 0.0772, Mean: 0.104	Median: **1.0089**, Mean: **1.0243**
Cracking Composite	OLS	83.34617	Median: 0.0643, Mean: 0.655	Median: 0.988, Mean: 1.578
	Quantile, τ=0.3	86.977	Median: 0.0798, Mean: 0.633	Median: 0.953, Mean: 1.514
	Coefficient Tree	**41.80993**	Median: 0.0663, Mean: 0.171	Median: **1.0058**, Mean: **1.100**

Predicted/Observed Ratio Plots





APP



Calculating Percent Composite Action
Information
Calculate
Input:
(You may enter decimals for any of the following variables. Example values are shown.)
K (the average elastic stiffness of the connectors in kip/in) min=0 kip/in, max=3600 kip/in:
190.005
L (the height/span of the wall panel in inches) min=120 in, max=1020 in:
340.75
Width (the total width of the wall panel in inches) min=24 in, max=192 in:
120
Wythe 1 (the thickness of wythe 1 in inches) min=1 in, max=5 in:
3.5
Wythe 2 (the thickness of wythe 1 in inches) min=1 in, max=5 in:
3.5
Insulation (the thickness of the insulator width in inches) min=1 in, max=5 in:
3.25
Ec (the modulus of elasticity of the concrete in ksi=1000*psi) min=3000 ksi, max=10,000 ksi:
4030.508653
fr (the modulus of rapture of the concrete in ksi=1000*psi) min=0.3 ksi, max=2.0 ksi:
0.530330086
Maximum iterations (the max number of iterations to be used in calculations) default=500:
500
Tolerance (threshold for the difference between Aslip[2] and Aslipn[2] that determines when to end iterations) default=1 E-9:
0.000000001
Decimal places (how many decimal places you would like the percent composite values to include) default=3:
3
Variable Ranges:
ISBT Method:
K: 0-3600 kip/in
L: 120-1020 inches
Width: 24-192 inches
WT1: 1-5 inches
WT2: 1-5 inches
Insulation: 1-5 inches
Ec: 3,000-10,000 ksi (1000*psi)
fr: 0.3-2.0 ksi (1000*psi)
Linear, Quantile Regression and Tree Regression:
K: 0-200 kip/in
L: 240-540 inches
Width: 96-144 inches
WT1: 3-5 inches
WT2: 3-5 inches
Insulation: 3-4 inches
Ec: 4,000-5,100 ksi (1000*psi)
fr: 0.53-0.7 ksi (1000*psi)
Wythe thickness ratio (Wythe 1 / Wythe 2):
1
Deflection Composite Action (%)
Iterative Sandwich Beam Theory (ISBT) Method
69.758
Linear Regression Model
71.521
Quantile Regression Model
62.184
Regression Tree
73.258
Cracking Composite Action (%)
Iterative Sandwich Beam Theory (ISBT) Method
88.275
Linear Regression Model
85.935
Quantile Regression Model
83.174
Regression Tree
86.082

Continuing work

Piecewise regression for multiple variables

Asymptotic regression for multiple variables

Updating and releasing R package and app

Questions?

References

[1] A. M. Omer, “Energy, environment and sustainable development,” Renewable and Sustainable Energy Reviews, vol. 12, no. 9, pp. 2265–2300, 2008.
[2] L. Rodgers, “Climate change: The massive CO2 emitter you may not know about.” https://www.bbc.com/news/science-environment-46455844, December 2018. Accessed: 2-19-2021.
[3] J. Watts, “Concrete: The most destructive material on earth.” https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth, February 2019. Accessed: 2-19-2021.
[4] F. T. Collins, “Precast concrete sandwich panels for tilt-up construction,” in Journal Proceedings, vol. 51, pp. 149–164, 1954.
[5] M. Maguire and F. Pozo-Lora, “Partially composite concrete sandwich wall panels,” Concrete International, October 2020.
[6] M. J. Gombeda, P. Trasborg, C. J. Naito, and S. E. Quiel, “Simplified model for partially-composite precast concrete insulated wall panels subjected to lateral loading,” Engineering Structures, vol. 138, pp. 367–380, 2017.
[7] S. Al-Rubaye, T. Sorensen, J. Olsen, and M. Maguire, “Evaluating elastic behavior for partially composite precast concrete sandwich wall panels.,” PCI Journal, 2018

References

[8] Eriksson Software. https://www.erikssonsoftware.com/, 2021. Accessed: 5-1-2021.
[9] Losch Software. http://www.loscheng.com/lecwall.html, 2021. Accessed: 5-1-2021.
[10] R. O'Hegarty and O. Kinnane, "Review of precast concrete sandwich panels and their innovations," Construction and Building Materials, vol. 233, p. 117145, 2020.
[11] R. O'Hegarty, A. Reilly, R. West, and O. Kinnane, "Thermal investigation of thin precast concrete sandwich panels," Journal of Building Engineering, vol. 27, p. 100937, 2020.
[12] S. Al-Rubaye, "Experimental and simplified analytical investigation of full-scale sandwich
panel walls," Master's thesis, Utah State University, 2017. Accessed: 5-1-2021.
[13] S. Al-Rubaye, T. Sorensen, R. J. Thomas, and M. Maguire, "Generalized beam–spring model for predicting elastic behavior of partially composite concrete sandwich wall panels," Engineering Structures, vol. 198, p. 109533, 2019.
[14] A. Holmberg and E. Plem, Behaviour of load-bearing sandwich-type structures. Byggforskningen, 1965.
[15] A. S. Nowak and K. R. Collins, Reliability of structures. CRC Press, 2012.
[16] S. Al-Rubaye, T. Sorensen, and M. Maguire, "Iterative and simplified sandwich beam theory for partially-composite concrete sandwich wall panels," Journal of Structural Engineering, 2021. Forthcoming.

References

[17] N. Simon, J. Friedman, T. Hastie, and R. Tibshirani, “Regularization paths for cox’s proportional hazards model via coordinate descent,” Journal of Statistical Software,
vol. 39, no. 5, pp. 1–13, 2011.

[18] R. N. Rodriguez and Y. Yao, “Five things you should know about quantile regression,”
in Proceedings of the SAS global forum 2017 conference, Orlando, pp. 2–5, 2017.

[19] R. Koenker, “quantreg: Quantile regression.” https://CRAN.R-project.org/package=quantreg, 2021. R package version 5.85.

[20] L. Breiman, J. Friedman, C. J. Stone, and R. A. Olshen, Classification and regression
trees. CRC press, 1984.

[21] T. Therneau and B. Atkinson, “rpart: Recursive partitioning and regression trees.” https://CRAN.R-project.org/package=rpart, 2019. R package version 4.1-15.