Design Considerations for Accelerated Construction with the MEPDG

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Summary

- The give and take of accelerated construction
- What is the MEPDG?
- How can it help us?
- Sensitivity analysis based on section thickness
- Conclusion

Accelerated Construction

- Everyone wants to find ways to build infrastructure faster, safer, cheaper, with improved durability and sustainability
- Construction in urban areas can have a significant impact on the traveling public
- Because of this sometimes we need to build things fast!
- It is difficult to understand how a change of one variable will impact another

Common Questions

- If I use a high early strength concrete mixture how will that impact the service life or durability of the road?
- Can I reduce the thickness or quality of my base layers and still meet the required design life?
- What is the change in design life if I change my joint spacing for a JPCP?
- How does my asphalt design compare to concrete?

Needs…

- Owners, designers, and contractors need tools to help make these decisions
- The FHWA noticed these needs and started to develop a tool in 1996
- These efforts lead to the creation of the Mechanistic and Empirical Pavement Design Guide (MEPDG)


SUPERMAN™
VS.
LEX LUTHOR™

MEPDG

Unknown

Concrete

Asphalt

Concrete

Asphalt

MEPDG

Background of the MEPDG

- Mathematical models based on failure mechanisms are used to predict performance
- These models have been “tuned” by comparing the predicted and actual performance of pavements
- This model allows 150+ inputs to be changed to see how they impact the performance of the pavement
- Unfortunately the mathematical model is slow
- To make the concrete model of the MEPDG perform faster a neural network is used

What is a Neural Network?

- A numerical tool that is designed to mimic the processing methods of the human brain
- The tool uses a large number of inputs and outputs to “learn” the importance of different variables and how they impact the results

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- The MEPDG neural network was “trained” by taking inputs and outputs from the MEPDG algorithms and establishing patterns of behavior
- When one runs an analysis in the concrete model of the MEPDG the neural network uses the given inputs and its training to provide an answer

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Benefits of MEPDG

- There are over 150+ variables that can be changed!
- Model now includes specific failure mechanisms
- Allows better use of available materials
- Characterize materials changes with time
- Characterize seasonal effects

Challenges with the MEPDG

- There are over 150+ variables that can be changed!
- The analysis does not give the user a required thickness for the inputs
- Instead it determines if the design inputs meet the established failure criteria
- Source code is not available for the neural network or the MEPDG concrete solver

MEPDG Sensitivity Analysis

- Sensitivity analysis has been done by others (Zaghloul et. al 2006, Kannekanti 2006, Harvey 2006, Mallela et. al 2005)
- Little information is given about the metrics used
- There is a lack of detail of the ranges of the variables investigated
- No constant metric was used

Research at OSU

- A methodology was established to determine the impact of a variable on the thickness design in the MEPDG
- A MEPDG sensitivity analysis was done based on the impact of thickness design for controllable variables
- All work was done with version 1.0 and 1.1 of the MEPDG
- All input and output files are available for download

Impact on Thickness Design

- A common Oklahoma pavement section was entered into the MEPDG
- The AADTT was increased until the section was found to just fail
- This is the critical AADTT!
- A variable (other than the thickness) was changed in the pavement design while the critical AADTT was held constant
- The thickness was either increased or decreased until the pavement was found to be satisfactory

Common Pavement Inputs

Design life	20 years*
Cement	600 lbs of type I
Concrete flexural strength	690 psi / 750 psi
Curing	curing compound
Shoulder	tied
JCP dowel diameter	1.5"
CRCP reinf. Ratio	0.70%
Location	Stillwater
Pavement opening	Fall
Base Layers	4" asphalt 8" chemically stabilized base
Subgrade	8000 psi resilient modulus*

*default inputs for the MEPDG

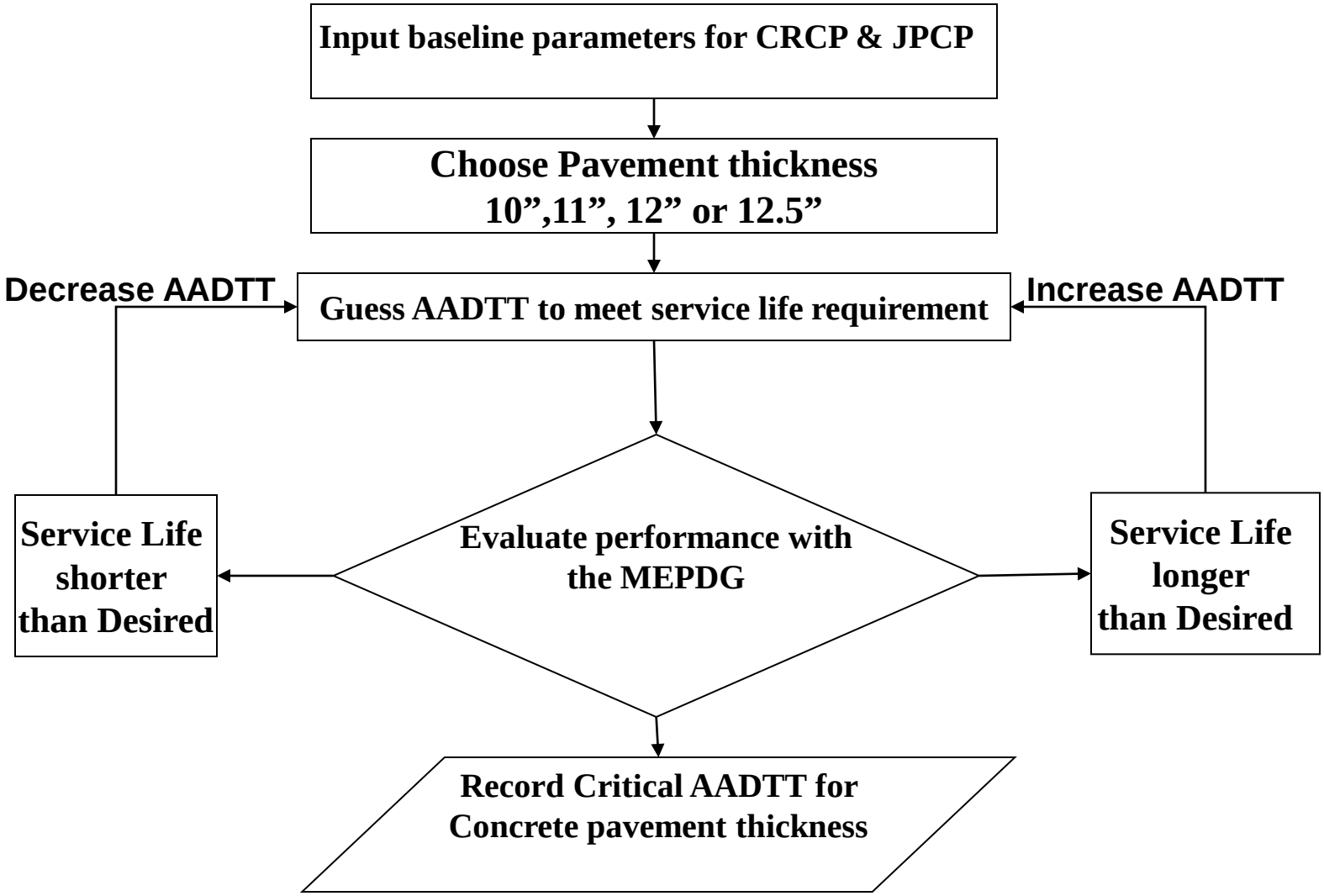
Failure Criteria

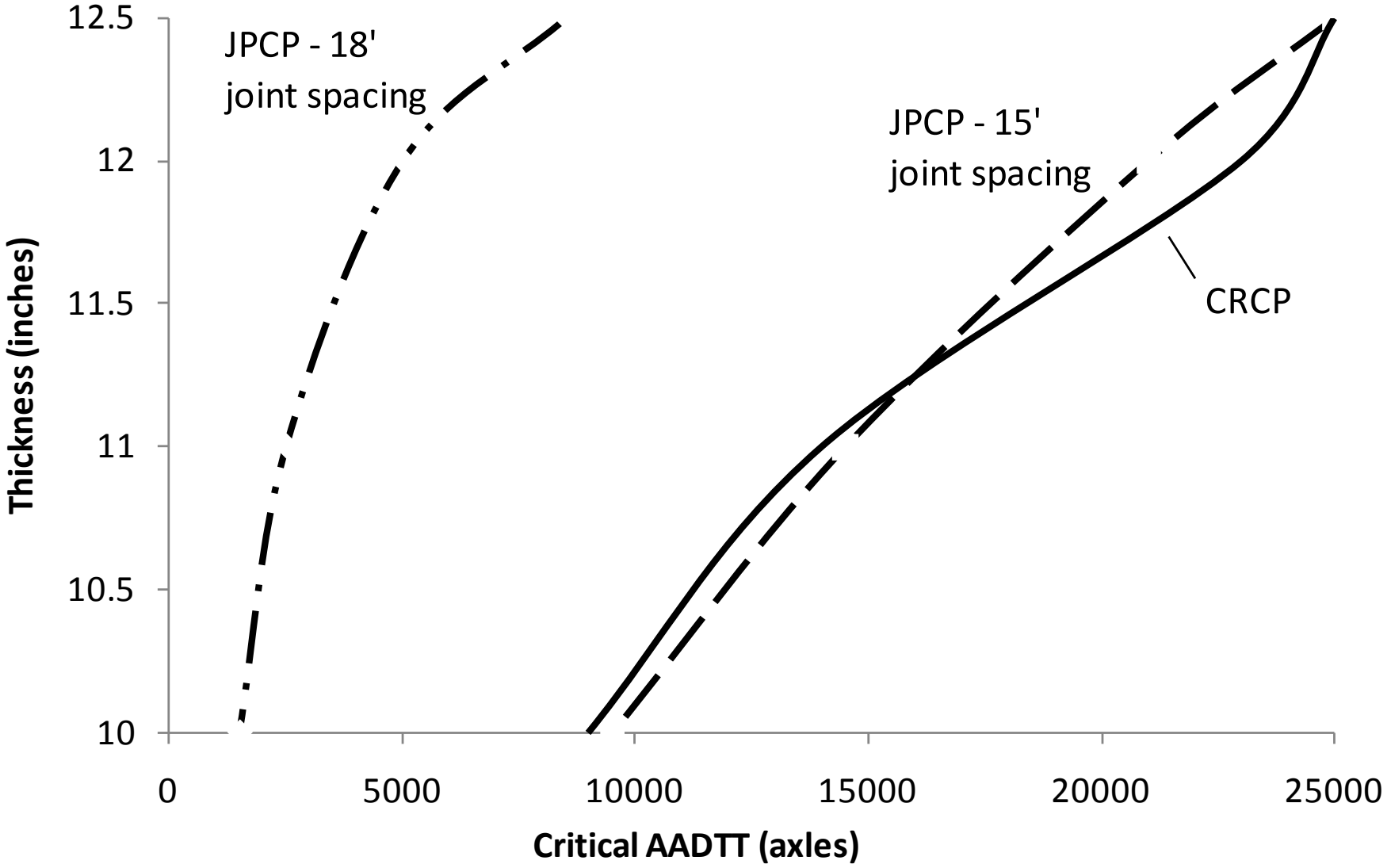
CRCP failure criteria	limit	reliability
terminal IRI (in/mi)	**172**	**90**
CRCP Punchouts (per mi)	**10**	**90**
maximum CRCP crack width (in)	**0.02**	
minimum crack load transfer efficiency (LTE %)	**75**	

JPCP failure criteria		
terminal IRI (in/mi)	**172**	**90**
transverse cracking (% slabs cracked)	**15**	**90**
mean joint faulting (in)	**0.12**	**90**

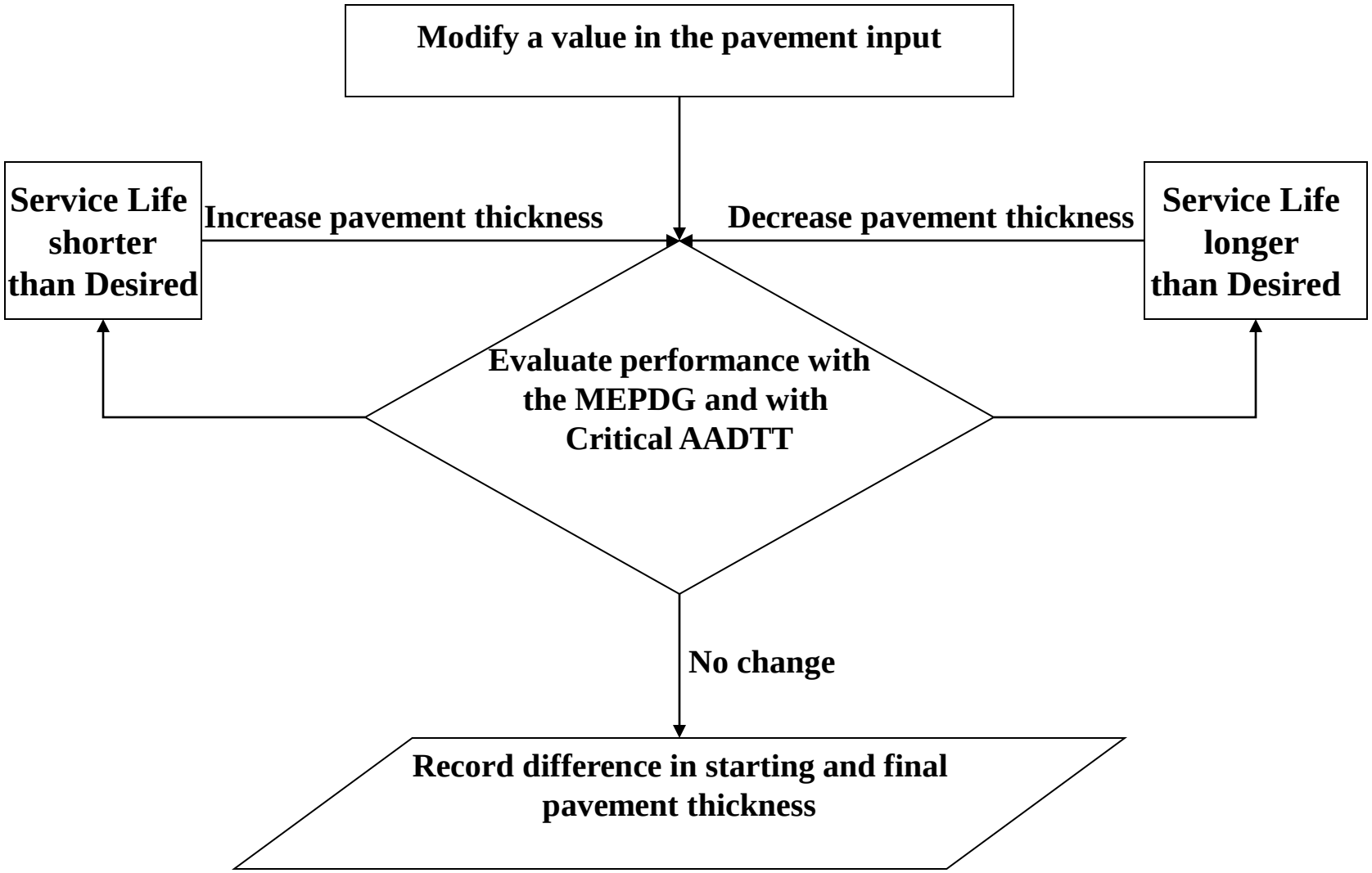
*All values are defaults for the MEPDG

Flowchart showing steps to find out Critical AADTT



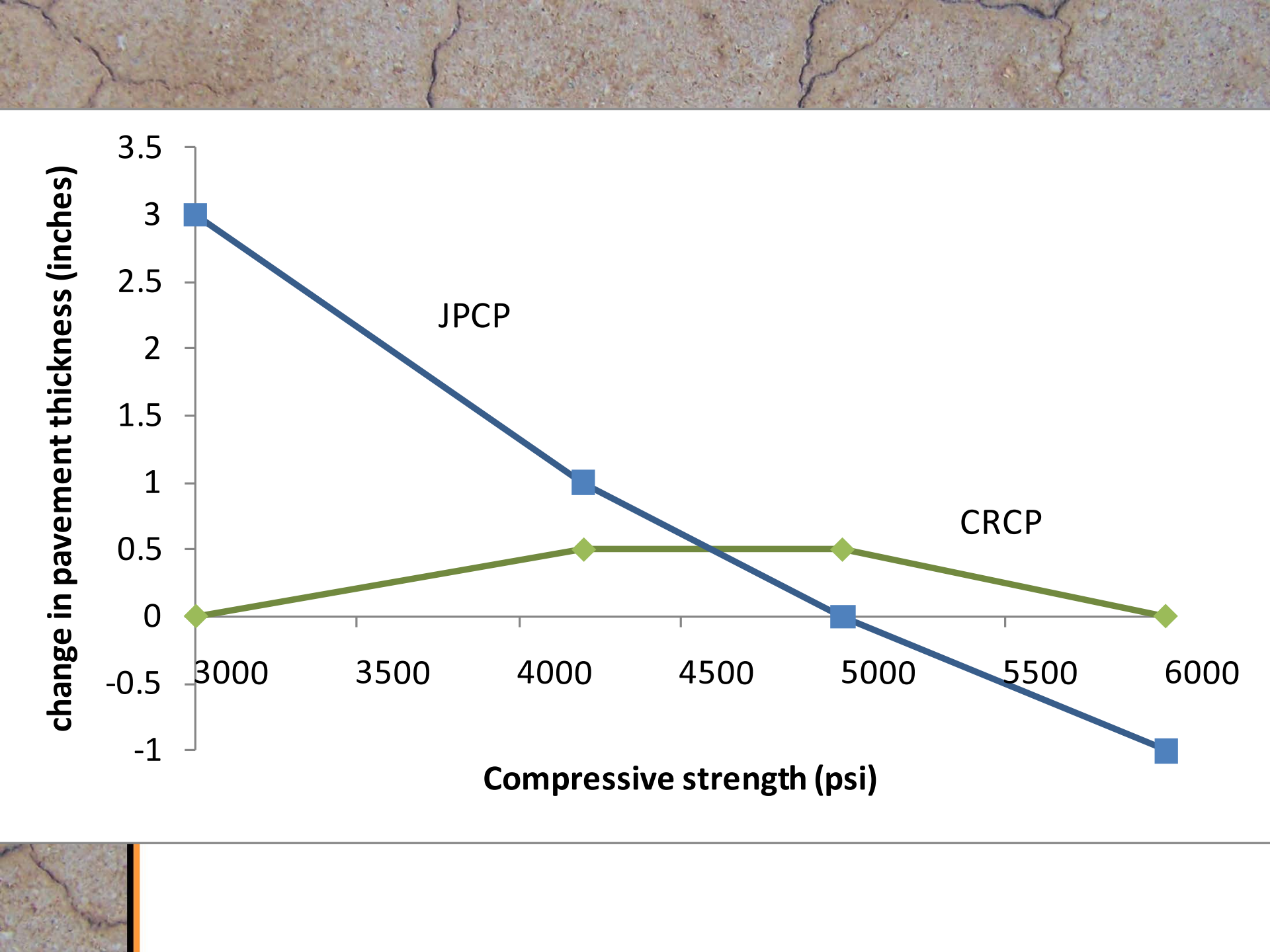

12.5
12
11.5
11
10.5
10
Thickness (inches)
JPCP - 18'
joint spacing
JPCP - 15'
joint spacing
CRCP
0
5000
10000
15000
20000
25000
Critical AADTT (axles)

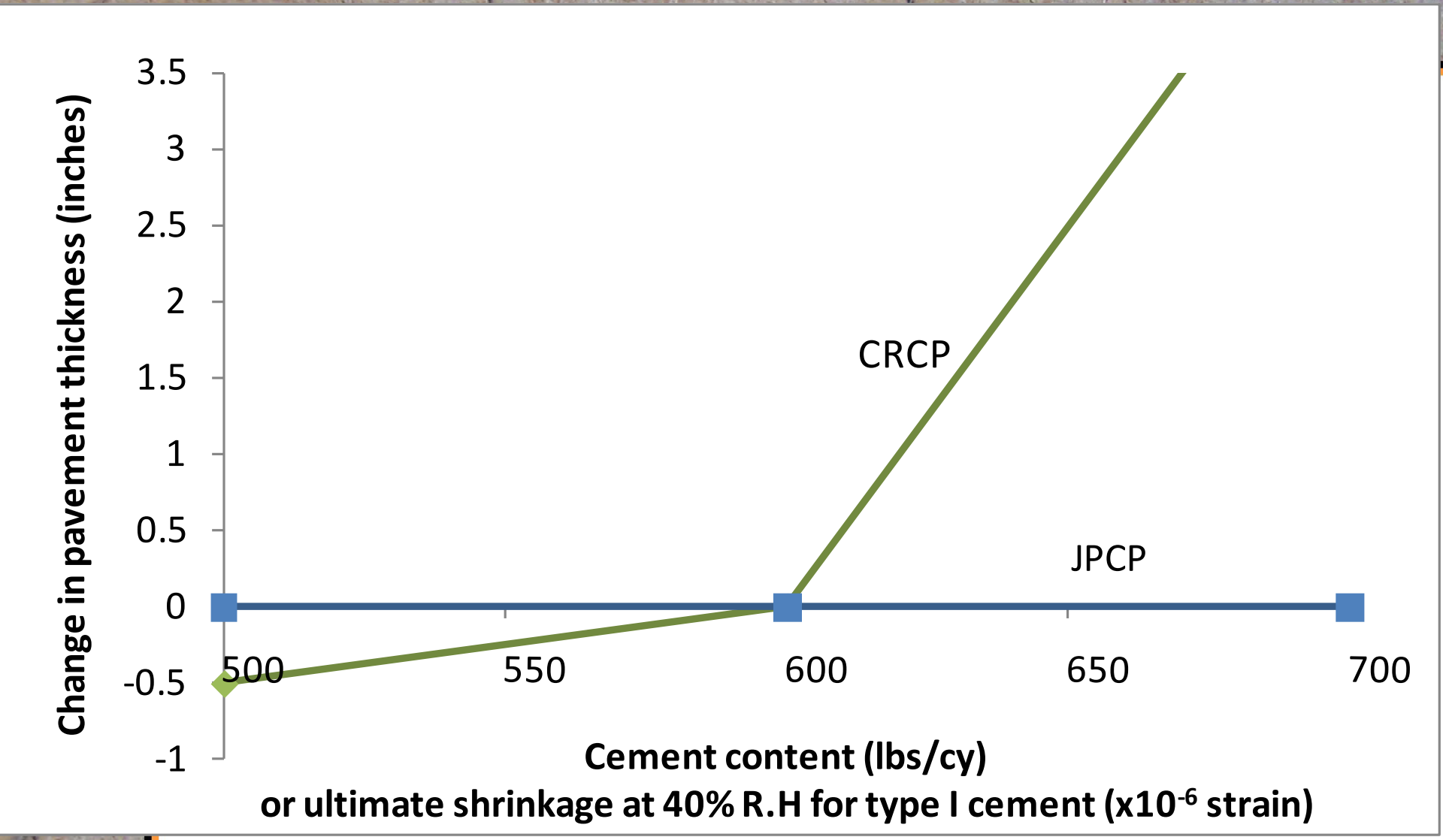
Flowchart showing steps to find out the Thickness change

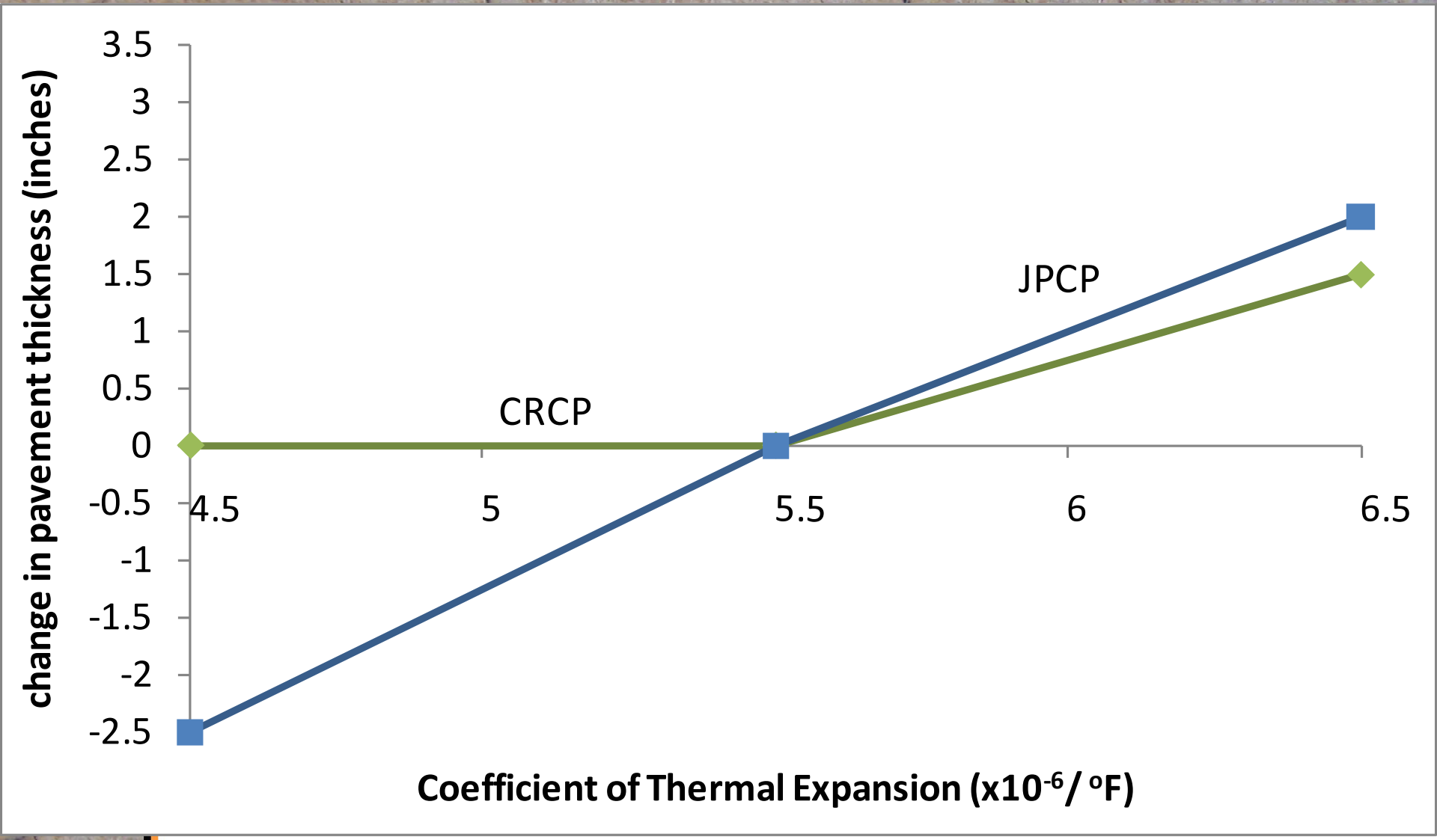


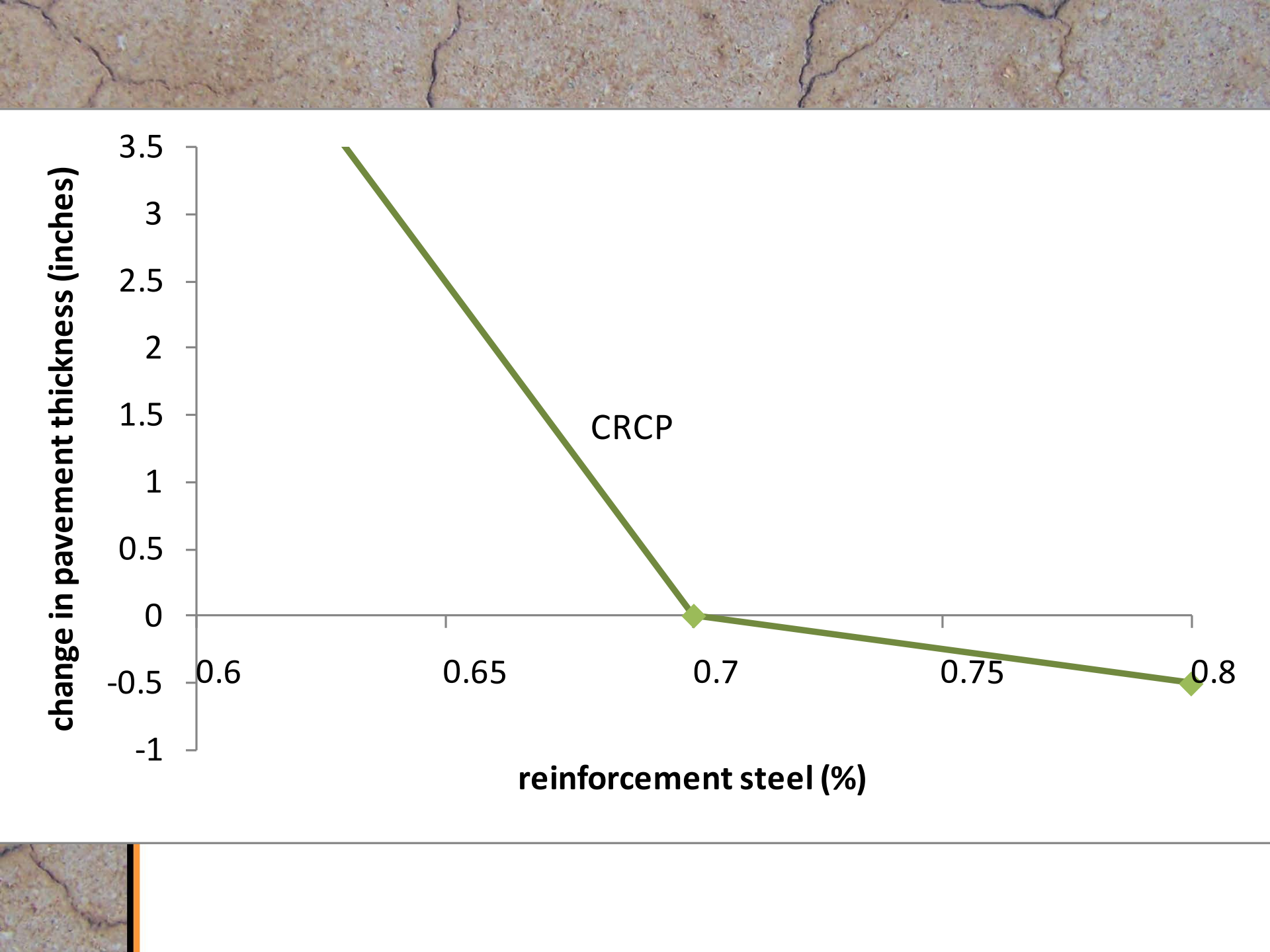
Sensitivity Analysis

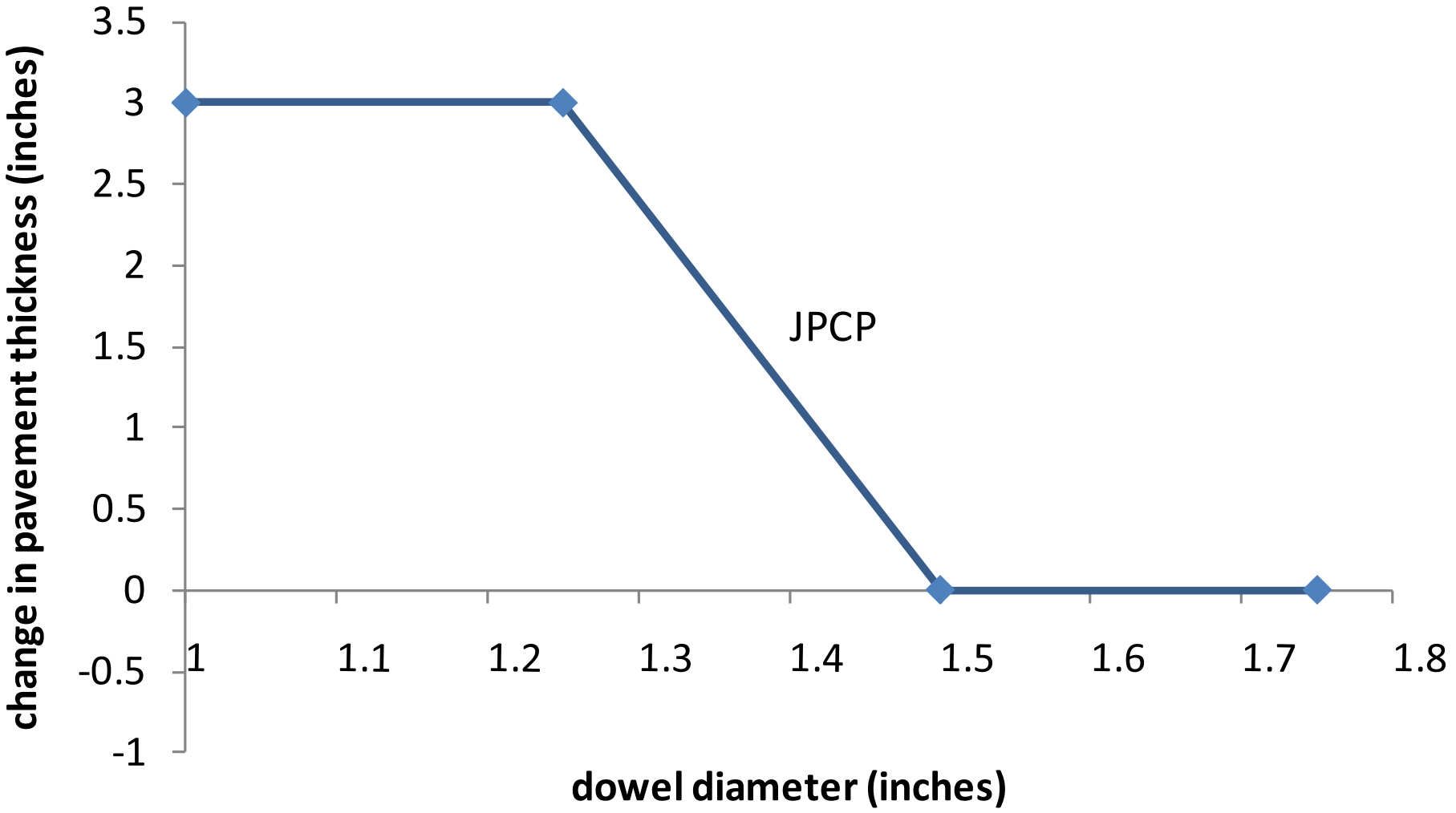
- The following sections were investigated for thicknesses from 10” to 12.5”:
  - JPCP w/ 18’ and 15’ joint spacing
  - CRCP
- A large number of variables were investigated
- The results are presented for:
  - 11” thick JPCP with 18’ joint spacing
  - 11” thick CRCP

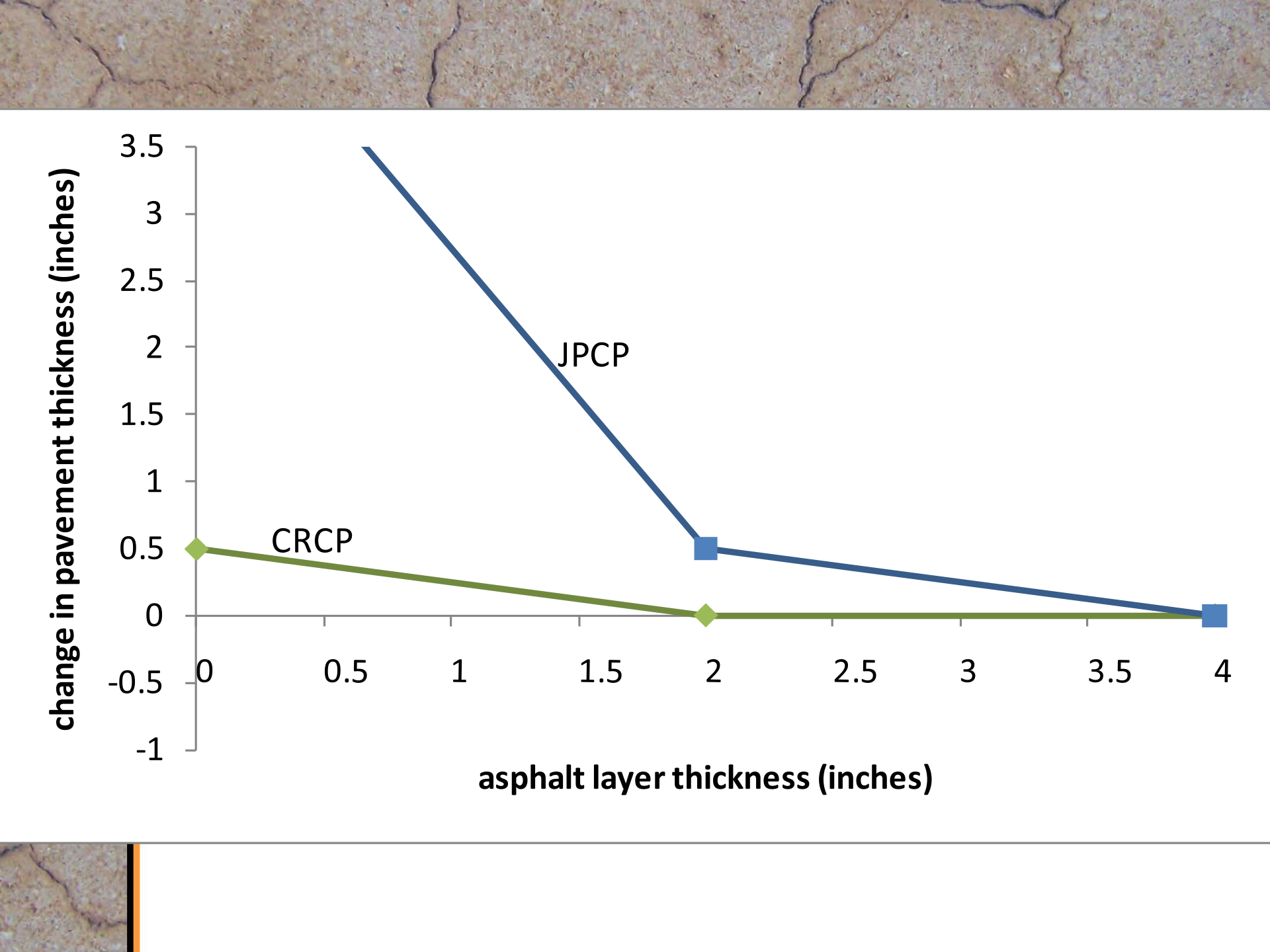

change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
JPCP
CRCP
3000
3500
4000
4500
5000
5500
6000
Compressive strength (psi)

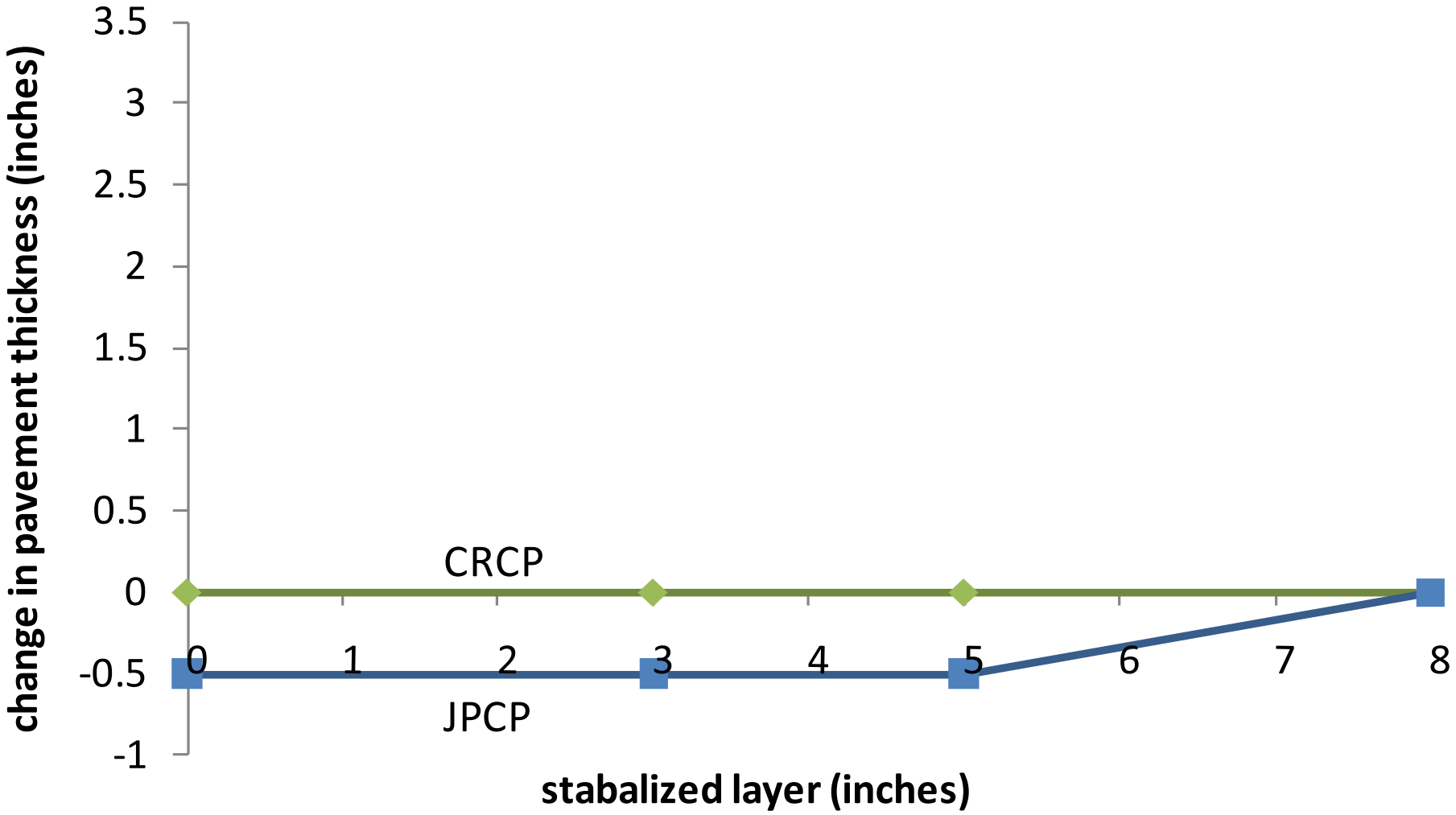

Change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
CRCP
JPCP
500
550
600
650
700
Cement content (lbs/cy)
or ultimate shrinkage at 40% R.H for type I cement (x10-6 strain)

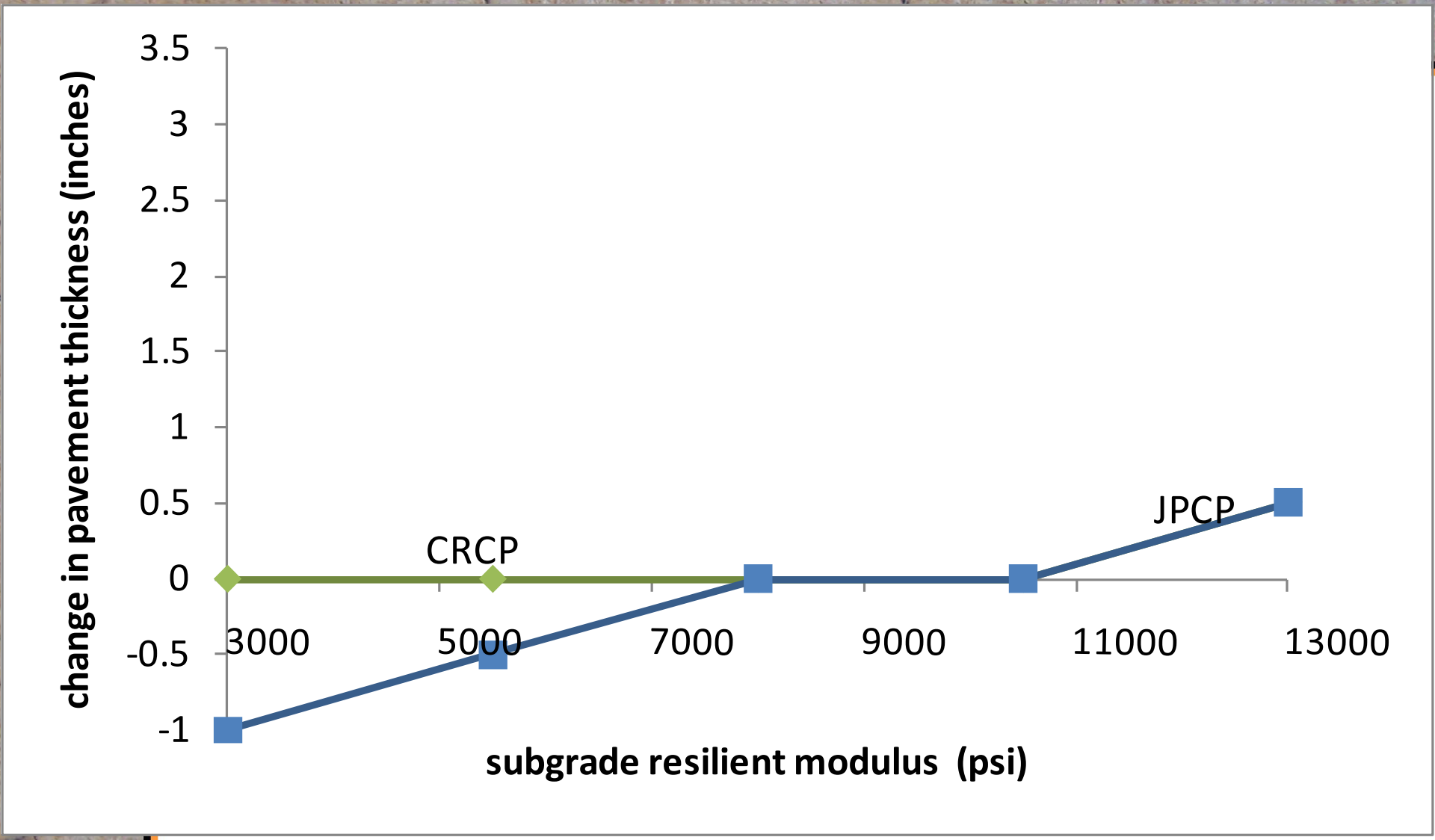

change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
JPCP
CRCP
4.5
5
5.5
6
6.5
Coefficient of Thermal Expansion (x10-6/ oF)

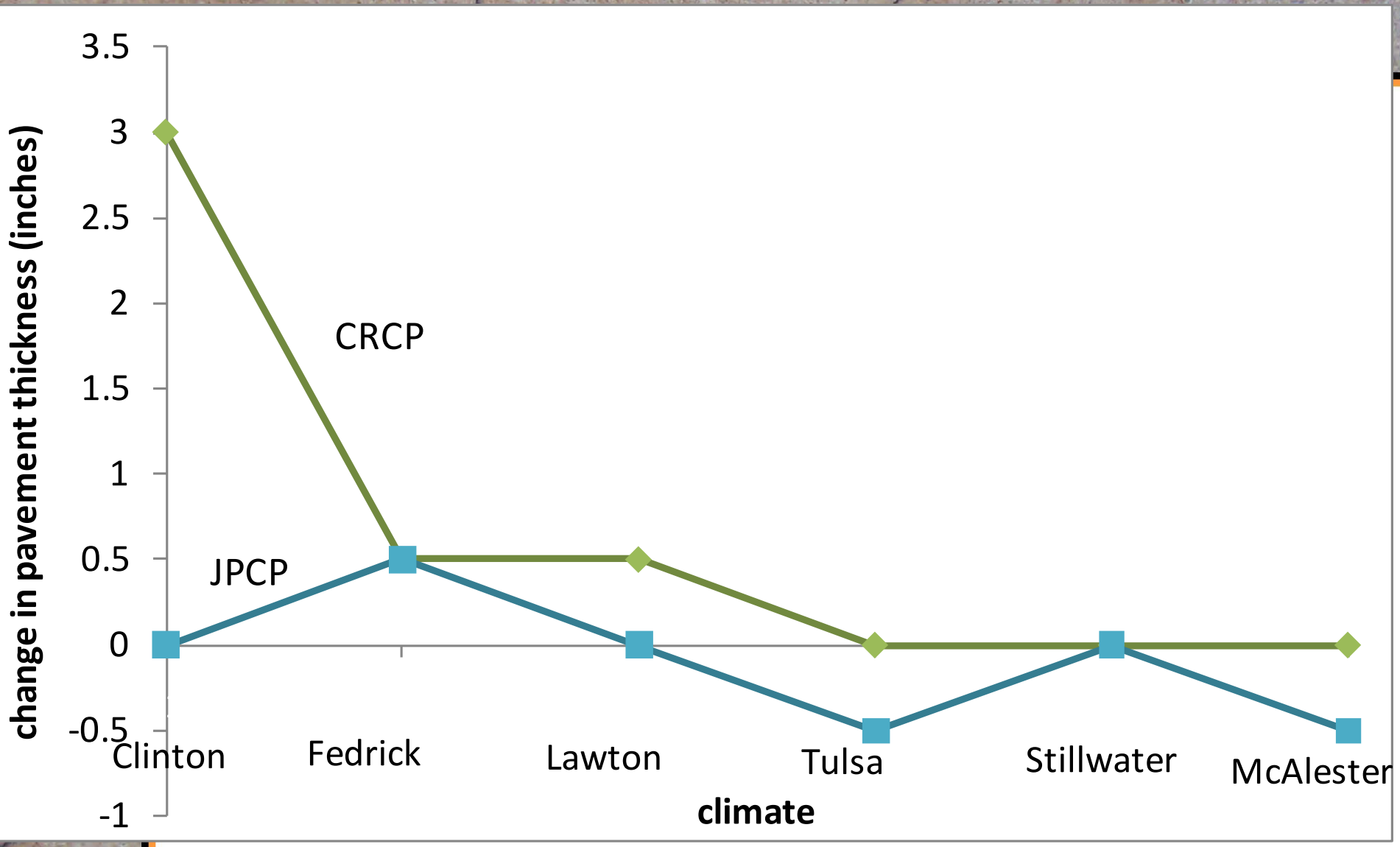

change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
CRCP
0.6
0.65
0.7
0.75
0.8
reinforcement steel (%)


change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
JPCP
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
dowel diameter (inches)


change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
JPCP
CRCP
0
0.5
1
1.5
2
2.5
3
3.5
4
asphalt layer thickness (inches)


change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
CRCP
JPCP
0
1
2
3
4
5
6
7
8
stabalized layer (inches)


change in pavement thickness (inches)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
3000
5000
7000
9000
11000
13000
CRCP
JPCP
subgrade resilient modulus (psi)


3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
change in pavement thickness (inches)
CRCP
JPCP
Clinton
Fedrick
Lawton
Tulsa
Stillwater
McAlester
climate

Climatic parameters	Clinton	Frederick	Lawton	McAlester	Tulsa	Stillwater
Mean annual air temperature (ºF)	60.9	62.8	62.1	62.1	60.6	59.9
Mean annual rainfall (in)	20.3	20.3	26.3	31.0	38.9	29.3
Freezing index (ºF-days)	137	103	139	118	204	211
Average Annual Number of Freeze/Thaw Cycles	46	41	58	43	61	57

Summary for 11” pavements

	CRCP	JPCP w/ 18' joint spacing
concrete strength	N	!
cement content	!	N
CTE	!	!
% steel	!	-
dowel diameter	-	!
asphalt layer thickness	N	!
stabilized layer thickness	N	N
resilient modulus	N	Y
climate	!	N

N – less than 1” thickness change
Y – more than 1” thickness change
! – more than 2” thickness change

Observations

- A number of variables were investigated over reasonable levels
- CRCP and JPCP w/ 15’ joint spacing had a similar performance for the section investigated
- Every variable investigated for 11” thick CRCP and JPCP w/ 18’ joint spacing impacted the design thickness by more than 2” except for the resilient modulus and the thickness of the stabilized layer

Observations

- Several of the variables investigated required thickness changes that were greater than expected
- Since the source code of the MEPDG is not available it is difficult to determine why this is happening

Why has this not been reported before?

- None of the previous sensitivity analysis used a constant metric of comparison
- No previous sensitivity analysis used thickness design as a comparison metric
- The MEPDG is still being adopted

What is Causing This Behavior?

- It is difficult to say…
- None of the source code of the MEPDG is available
- The user manual does not provide enough details to examine the logic
- Even if we knew what the logic is a neural network is used to determine a solution

Discussion of Neural Networks

- One challenge with a neural network is that if it is improperly trained then the results can be erratic (Sarle, 1994; Hagen et al. 2002)

- Because of the 150+ variables used in the MEPDG it would be challenging to effectively educate the neural network

Discussion of Neural Networks

- Erratic answers may be expected if obscure inputs were used that are outside of the training of the system
- However the range of the variables investigated were reasonable and represented very practical combinations

What Should Be Done?

- Details of the MEPDG should be re-examined including the effectiveness of the neural network
- Future sensitivity analysis should be done with practical comparison metrics such as thickness
- The methodologies and source code should be transparent and available for others to investigate
- All users should use common sense when interpreting the data

More Information

- A journal paper has been authored and submitted to the *International Journal of Pavement Engineering* presenting these results
- All of the input and output files used are available at my FTP site
- Contact me for more information:

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Conclusion

- A methodology was presented that allows users to compare the impact of different variables on the thickness design with the MEPDG
- This methodology was used to compare the impact of a number of variables of reasonable ranges on the design of concrete pavements
- Erratic results were sometimes found
- The MEPDG methodology (especially the neural network) needs to be investigated in more detail

Questions???