University of Massachusetts
UMASS Lowell

Structural Engineering Research Group (SERG)
Summer Seminar Series #16
Lowell, Massachusetts
August 25, 2014

Theoretical and Experimental Analysis of Phase Velocity Changes in Concrete with Different Water to Cement Ratio (W/C) over Time

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SERG

Outline

- Introduction
- Objectives
- Literature Review
- Experimental Approach
- Results
- Summary
- References
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Introduction

- Ultrasonic Testing (UT) is one of the most popular non-destructive testing used in the assessment of concrete properties.
- In UT, measurable parameters include:
  - Phase Velocity
  - Path Length
  - Surface Velocity
  - Crack Depth
  - Compressive Strength
  - Estimating Elastic Modulus

Objectives

- To analyze the change of phase velocity in concrete with different W/C over time from experimental & theoretical data and model by using UT.

- To provide the relationship between Young's Modulus of concrete and Phase Velocity by using UT, Mechanical Testing and Sensing (MTS), and Digital Image Correlation (DIC) methods.

Literature Review

- Concrete with highest aggregate content has the highest strength. [Trtnik et. al. (2008)]
- Concrete with highest aggregate content has the highest phase velocity.
- After oven dried, concrete with highest phase velocity have the highest strength.

Literature Review

- Young's Modulus Equations

  - From Stiffness,

    $E=(kH)/A$ [Connor and Faraji (2013)]

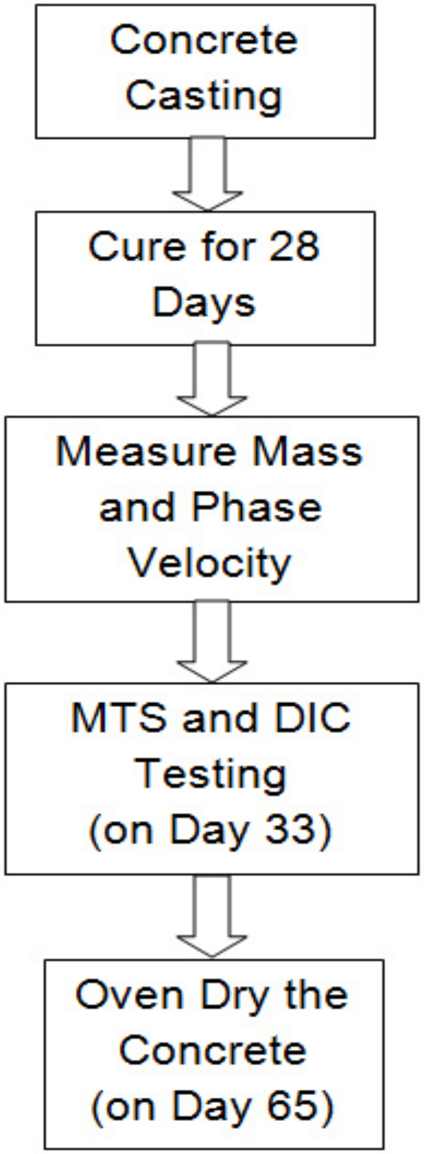
    where E = Young's Modulus, k = Stiffness, H = Length, A = Area.

  - From ACI 318,

    $E=0.043 \times \rho^{1.5} \times {f_c}'^{0.5}$ (in MPa) [ACI 318 Committee (2011)]

    where f_c' = Maximum Compressive Strength of a 28 Days Old Concrete, ρ = Density.

Experimental Approach



Experimental Approach

- Concrete Casting

  Sample Calculation

  - **Assume:** 0.5% water absorption for 3/8" stone

    1.0% water absorption for sand

    Specific gravity(S.G) of sand = 2.70

    Specific gravity(S.G) for 3/8" stone = 2.60

    Specific gravity(S.G) for cement = 3.15

  - **Design Concrete:** W/C=0.50

    Cement:Sand:Stone = 1:2:3

    3"x 6" cylinder (Vol: 0.0245 ft^3)

  - **Calculation:** Weight= (S.G)(r_w)(Volume)

    SSD= Weight/Total volume

Weight of water (W/C=0.5) = 0.5*196.56=98.28 lb

Volume of water = Weight of water/r_w = 98.28/62.4 = 1.575 ft^3

Amount of water absorbed in sand = SSD x 1% = 0.44 lb

Amount of water absorbed in stone = SSD x 0.5% = 0.32 lb

Experimental Approach

- Concrete Casting (continued)

Total weight of water in one cubic foot = 12.97+0.44+0.32 = 13.73 lb/ft^3

Total weight of sand in one cubic foot = 44.45 – 0.44 = 44.01 lb/ft^3

Total weight of stone in one cubic foot = 64.21 – 0.32 = 63.89 lb/ft^3

Material	**Volume (ft3)**	**Weight (lb)**	**wt/ft3 [SSD]**	**wt/ft3 [Dry]**
Cement	1	196.56	25.93	25.93
Sand	2	336.96	44.45	44.01
Stone	3	486.72	64.21	63.89
Water	1.575	98.28	12.97	13.73
Total	7.58			

Weight of cement in 3"x 6" cylinder specimen = 25.93 x 0.0245 = 0.635285 lb

Weight of sand in 3"x 6" cylinder specimen = 44.01 x 0.0245 = 1.078245 lb

Weight of stone in 3"x 6" cylinder specimen = 63.89 x 0.0245 = 1.565305 lb

Weight of water in 3"x 6" cylinder specimen = 13.73 x 0.0245 = 0.336385 lb

Experimental Approach

- Concrete Curing

Figure : Curing Process.

Figure : Curing Process.

Experimental Approach

- Measuring Mass and Phase Velocity

Figure : Weighing Scale.

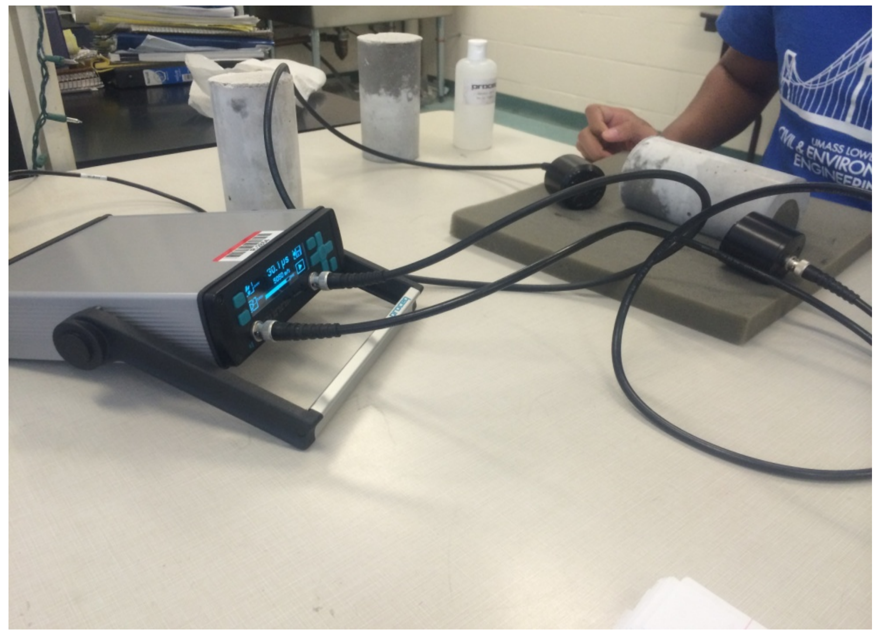


Figure : UT Machine.

Experimental Approach

- MTS Testing

Figure : MTS Machine.

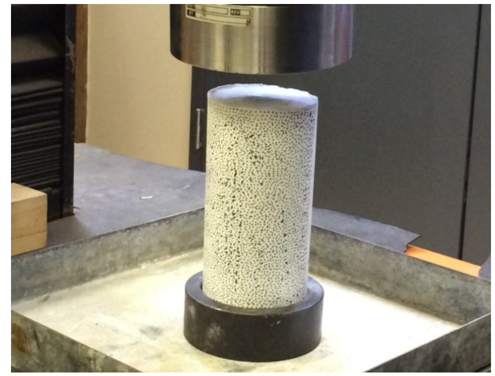


Figure : Before MTS Destructive Testing.

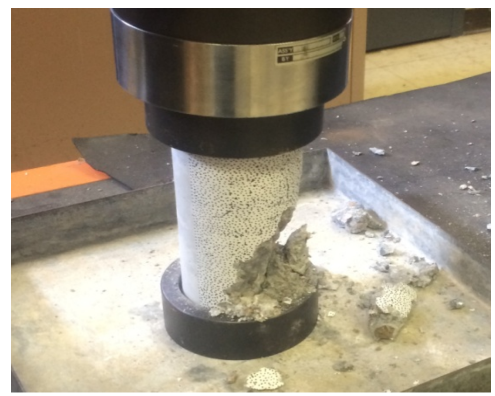


Figure : After MTS Destructive Testing.

Experimental Approach

- DIC Testing
  - Paint half of the concrete specimen that will be used with white.
  - Make black spots on the painted area.
  - Avoid using gloss and water soluble paints.

Figure : DIC Machine.

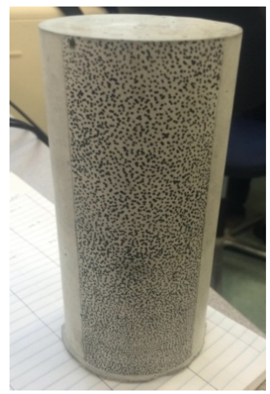


Figure :Painted Concrete.

Figure : Setup of DIC and MTS.

Experimental Approach

- Oven Drying
  - Increase the oven temperature from 25°C to 45°C for 1 hour.
  - Increase the oven temperature from 45°C to 105°C at 20°C increment per hour on a concrete panel of volume 3”x6” cylinder.

Figure : Oven.

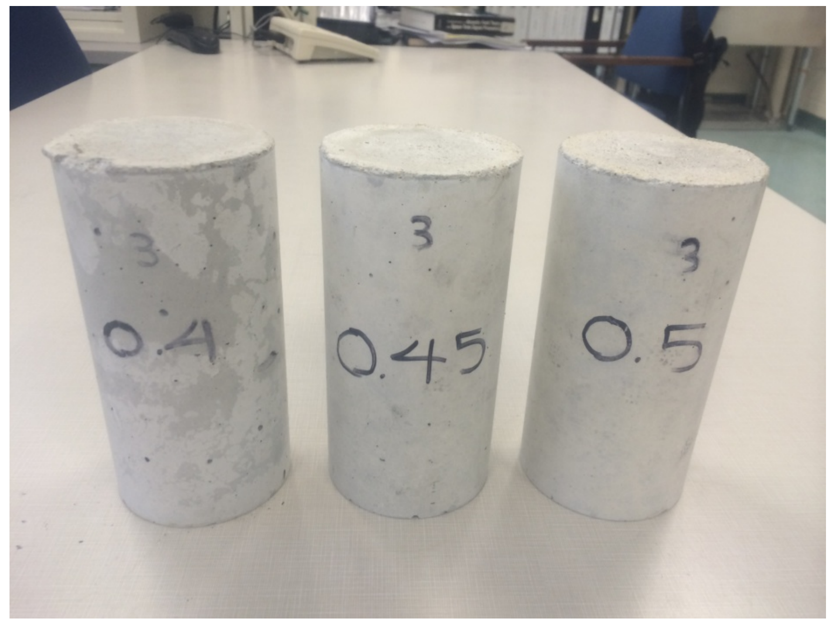


Figure : Oven Dried Concrete (Side View).

Results

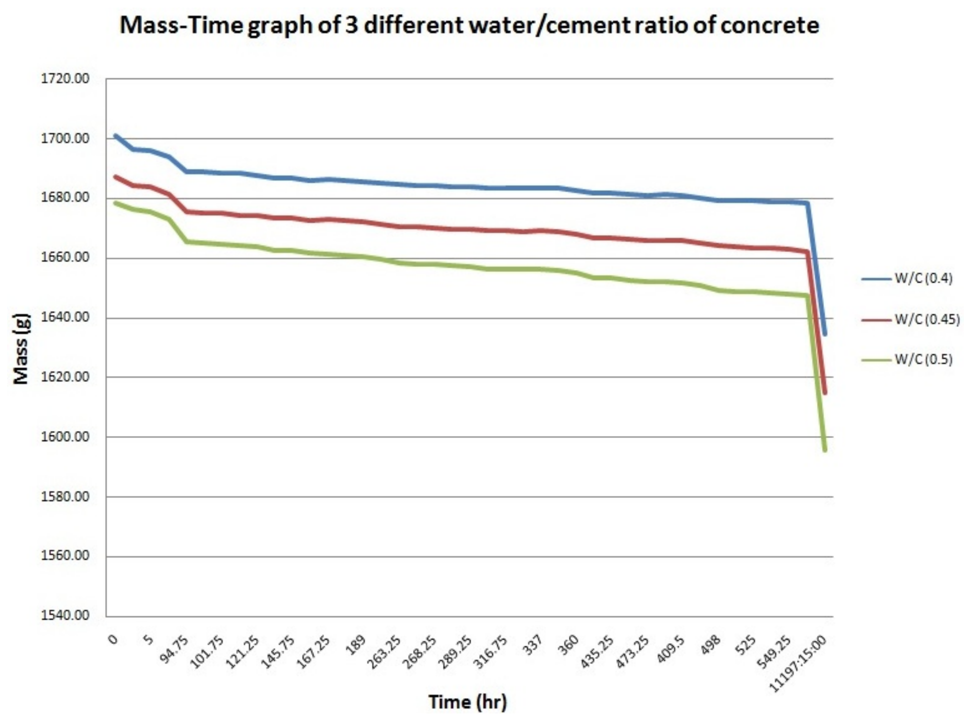
- Mass Loss Calculation (Before and After Oven Dried)

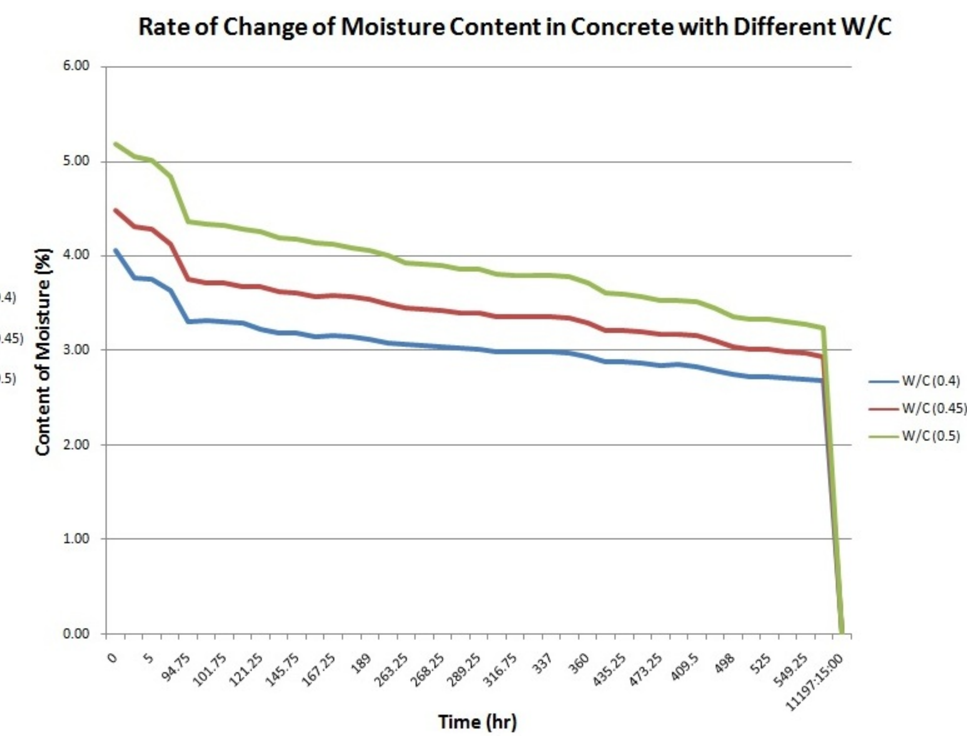
$$\% = [(Before - After)/Before]\ 100\%$$

W/C	**Mass Before OD (g)**	**Mass After OD (g)**	**Mass Loss (%)**
0.40	1667.15	1634.60	1.95
0.45	1650.50	1614.95	2.15
0.50	1634.35	1595.55	2.37

Results

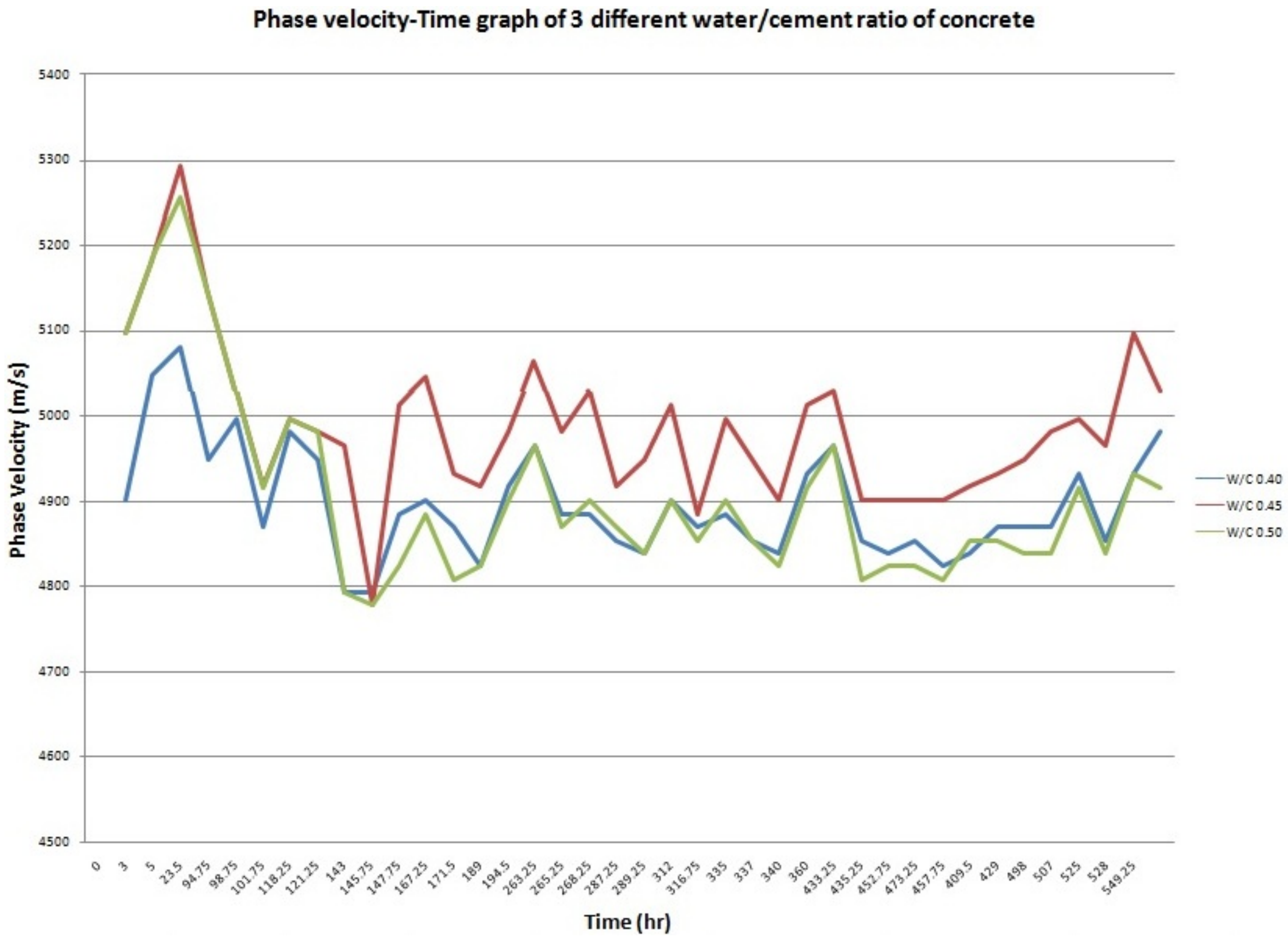
- Mass change data





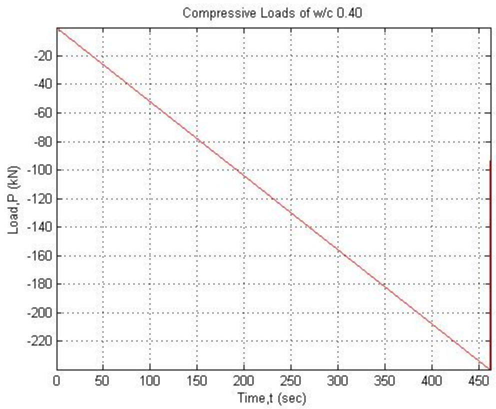
Results

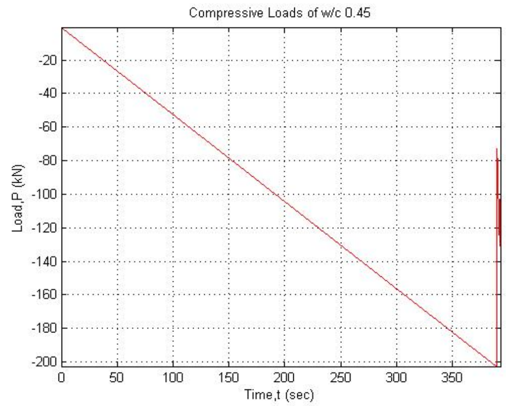
- Phase Velocity change data

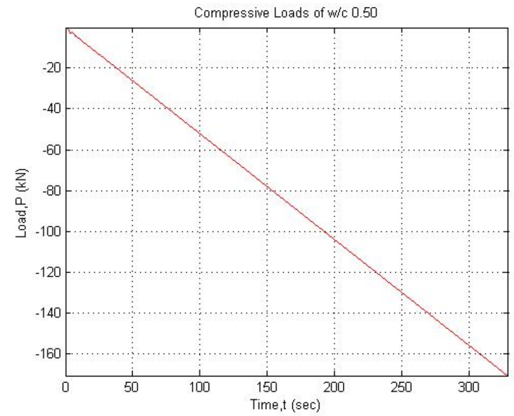


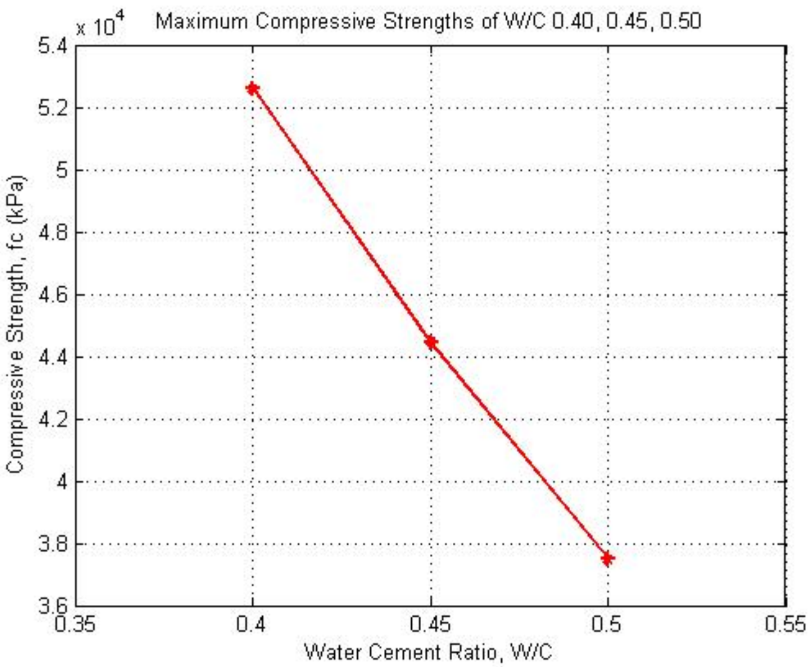
Results

- Data from MTS



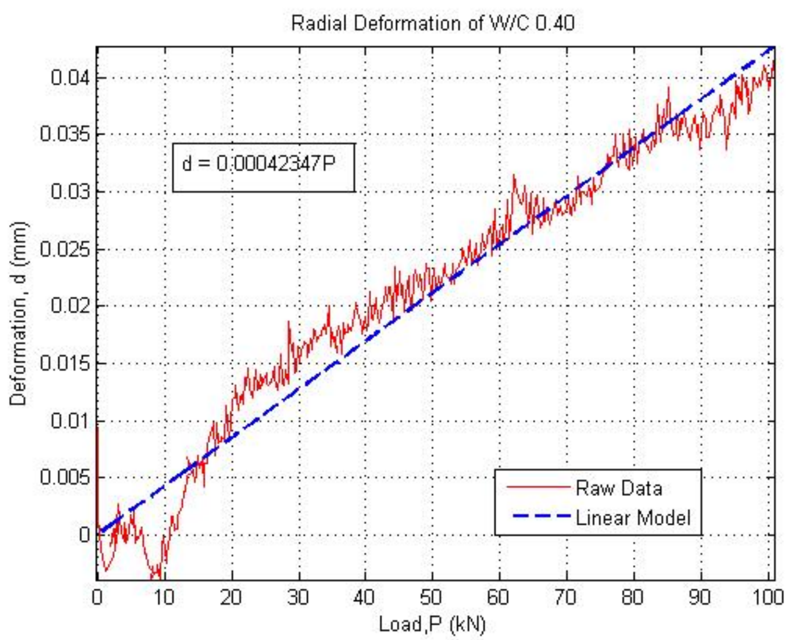


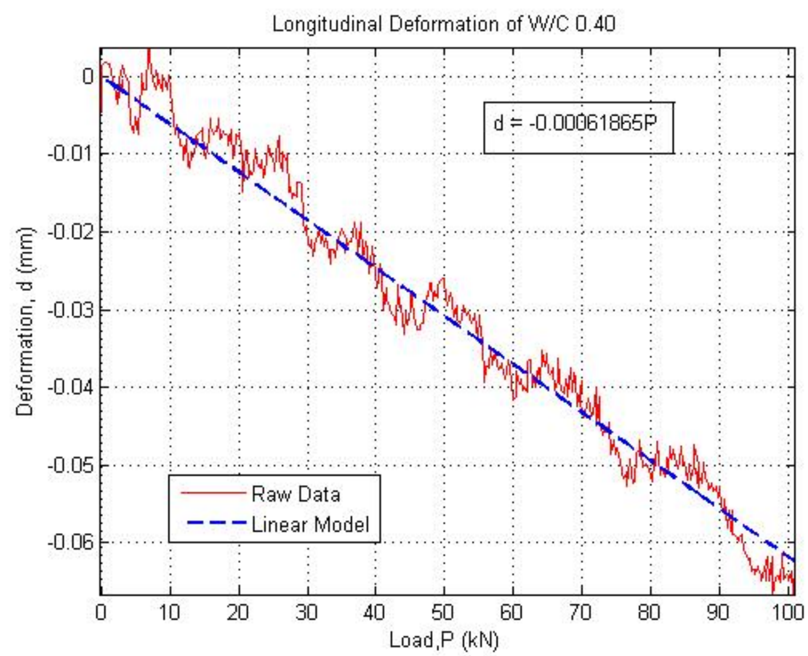




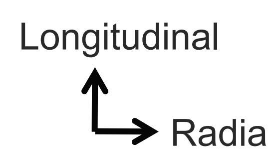
Results

- Data from DIC - Deformation



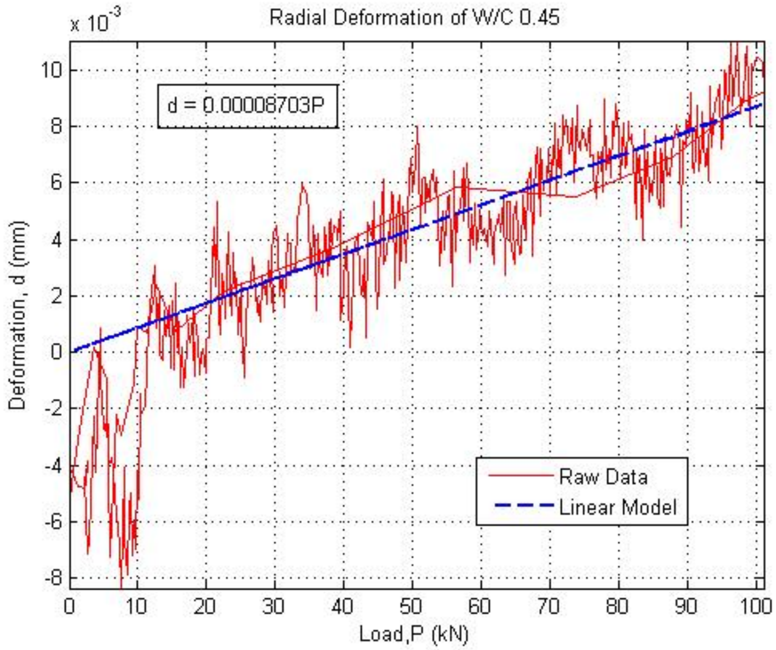


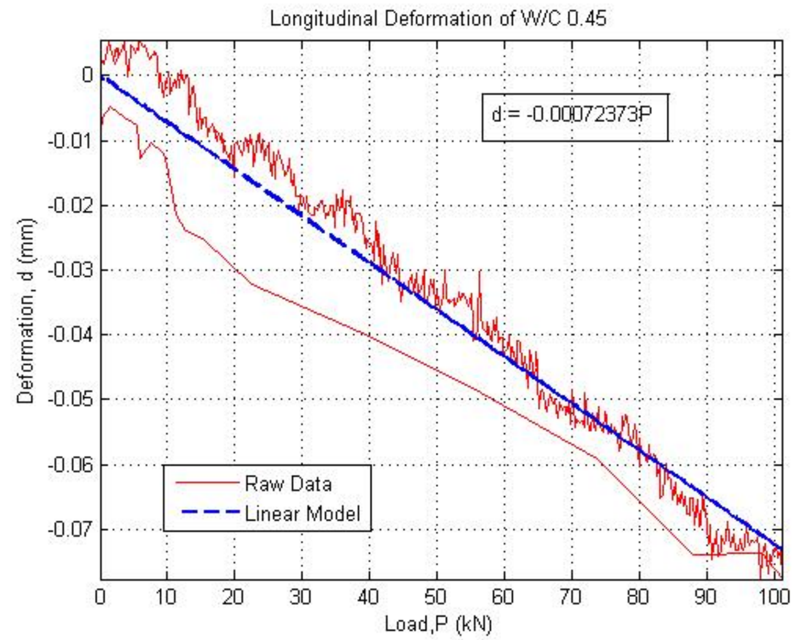
W/C 0.40	Slope (m/kN)	Stiffness, k (kN/m)
Radial	0.00000042347	2341442.37
Longitudinal	0.00000061865	1616422.86



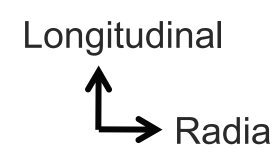
Results

- Data from DIC – Deformation (continued)



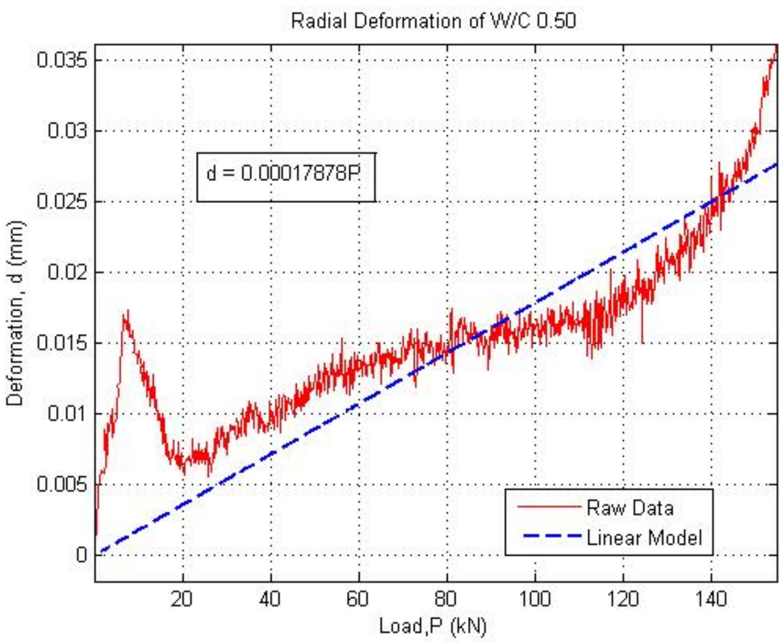


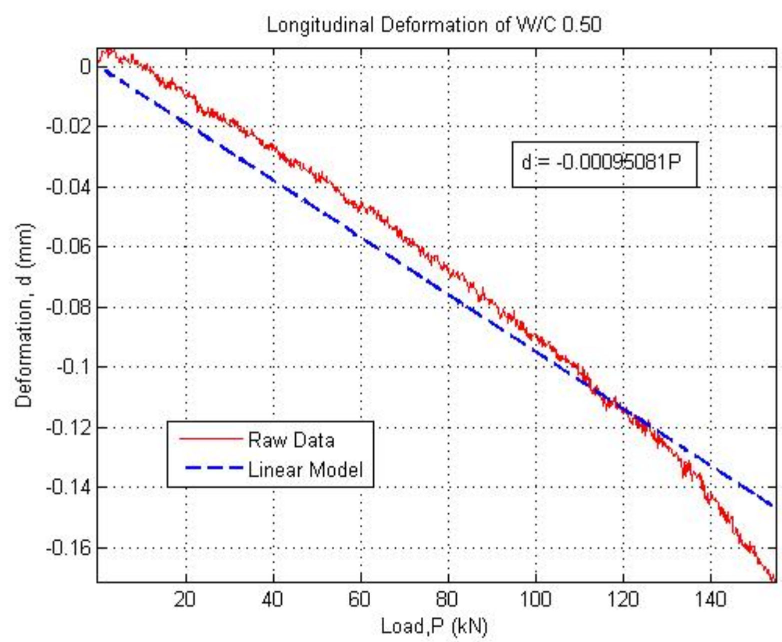
W/C 0.45	Slope (m/kN)	Stiffness, k (kN/m)
Radial	0.00000008703	11490290.70
Longitudinal	0.00000072373	1381730.76



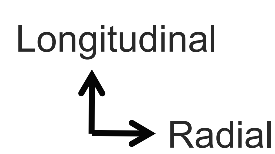
Results

- Data from DIC - Deformation (continued)





W/C 0.50	Slope (m/kN)	Stiffness, k (kN/m)
Radial	0.00000017878	5593466.83
Longitudinal	0.00000095081	1051734.84



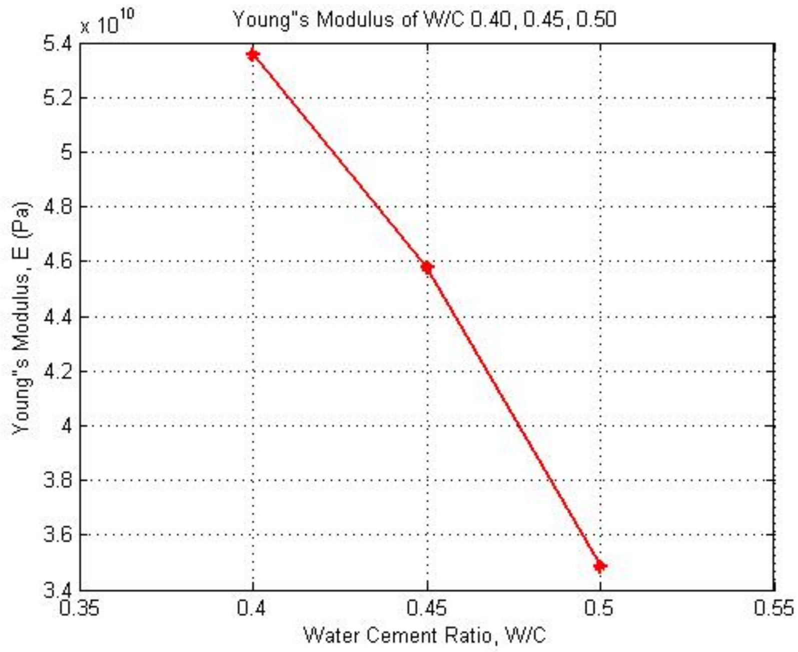
Results

- Calculation of Young's Modulus from Stiffness

$$E = (kH)/A$$

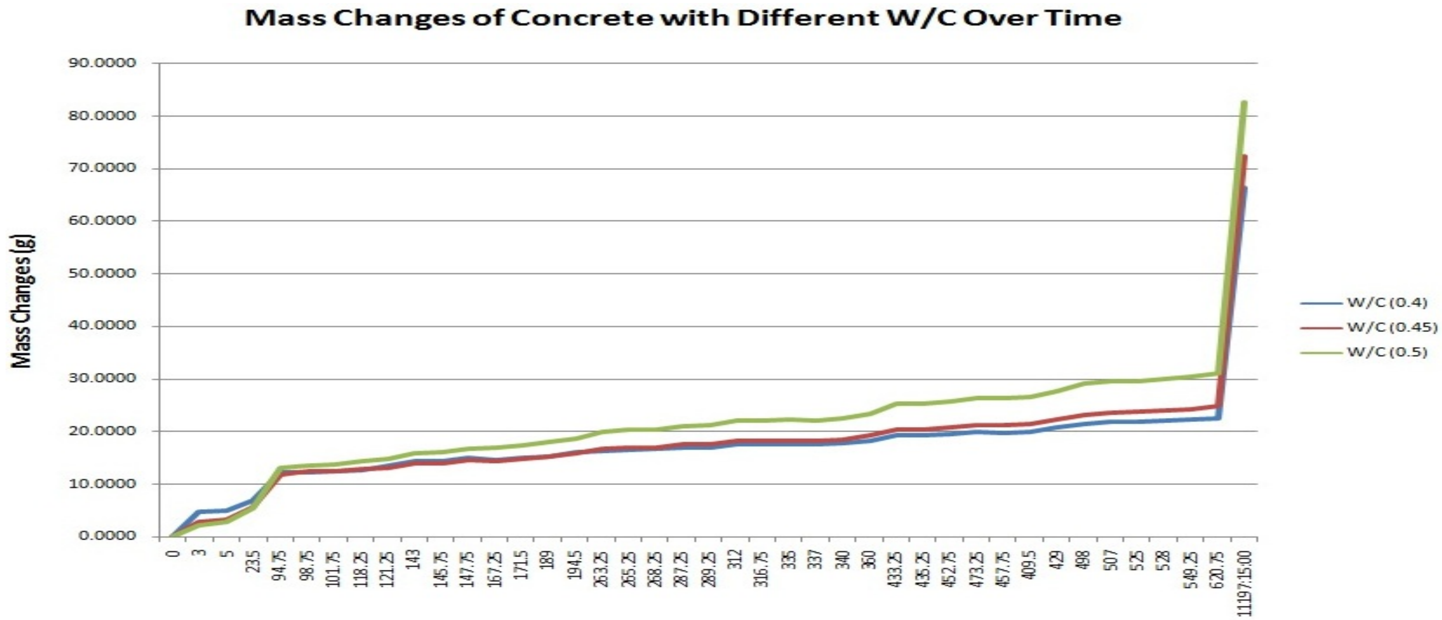
Longitudinal

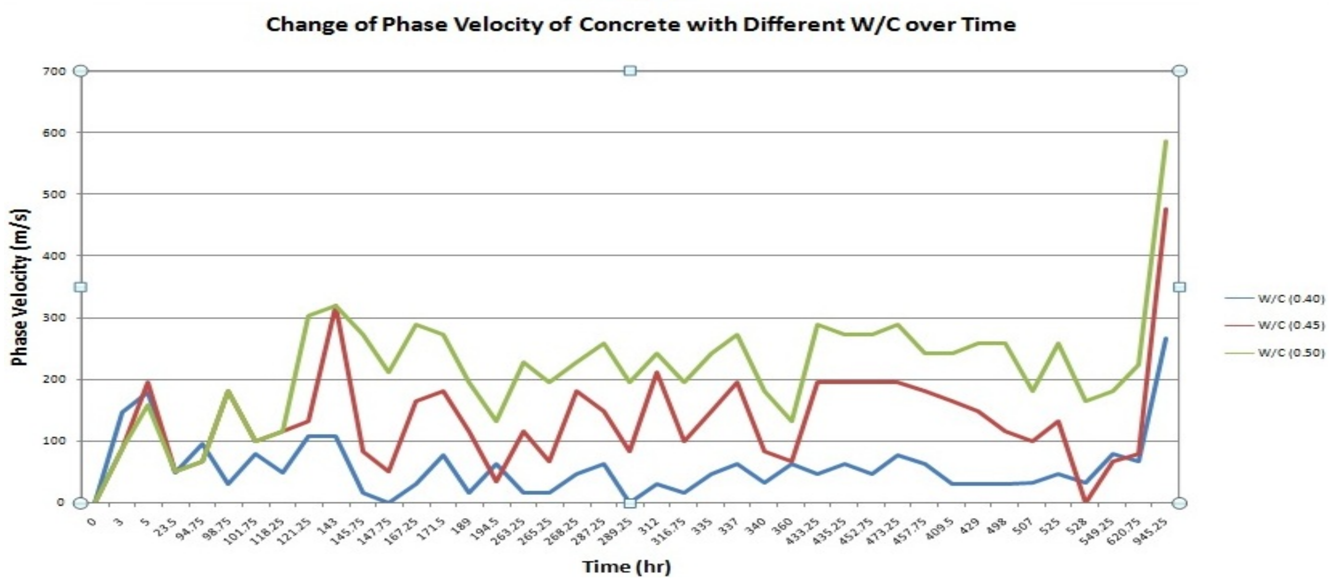
W/C	Moisture Content (%)	H (m)	A (m^2)	k (kN/m^2)	E (kPa)	E (GPa)
0.40	3.31	0.1524	0.0046	1616422.86	53552792.02	53.55
0.45	3.72	0.1524	0.0046	1381730.76	45777340.70	45.78
0.50	4.34	0.1524	0.0046	1051734.84	34844432.41	34.84



Summary

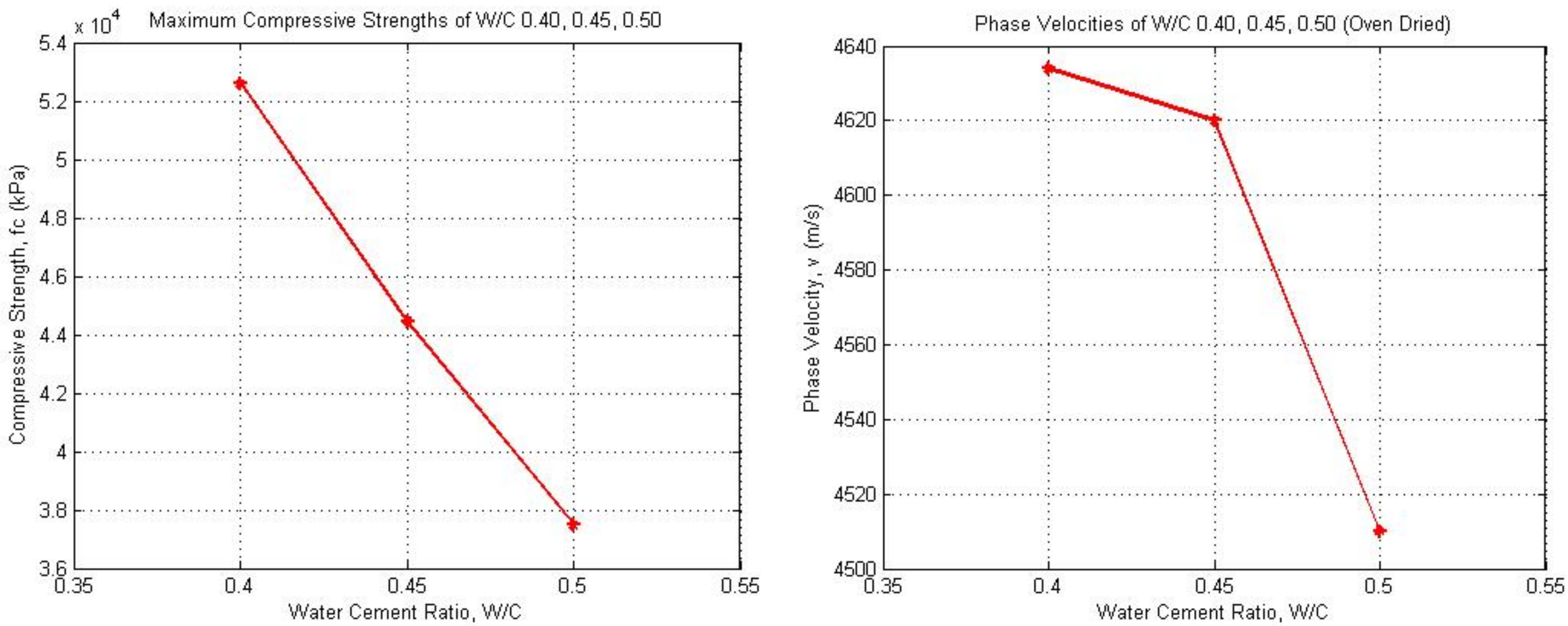
- Phase Velocity is sensitive to moisture.





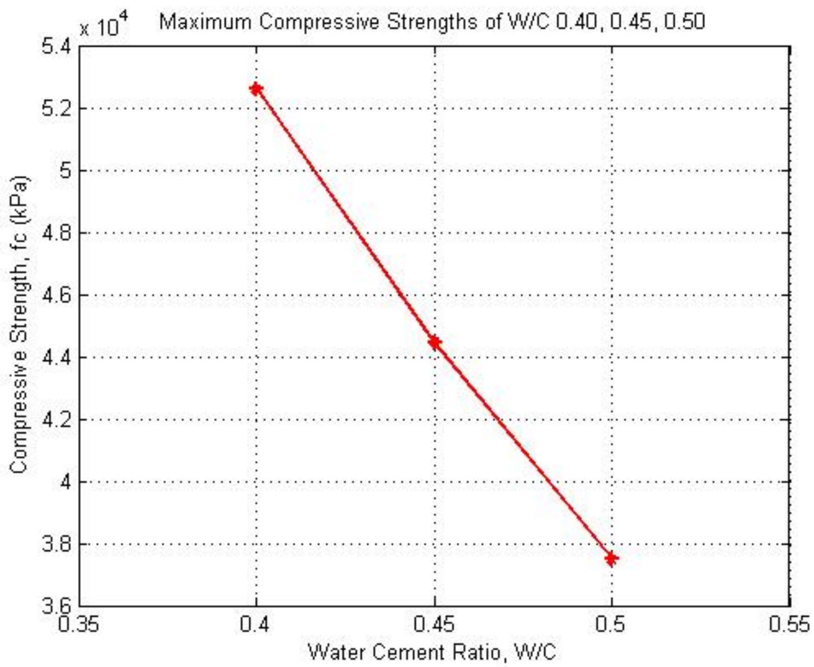
Summary

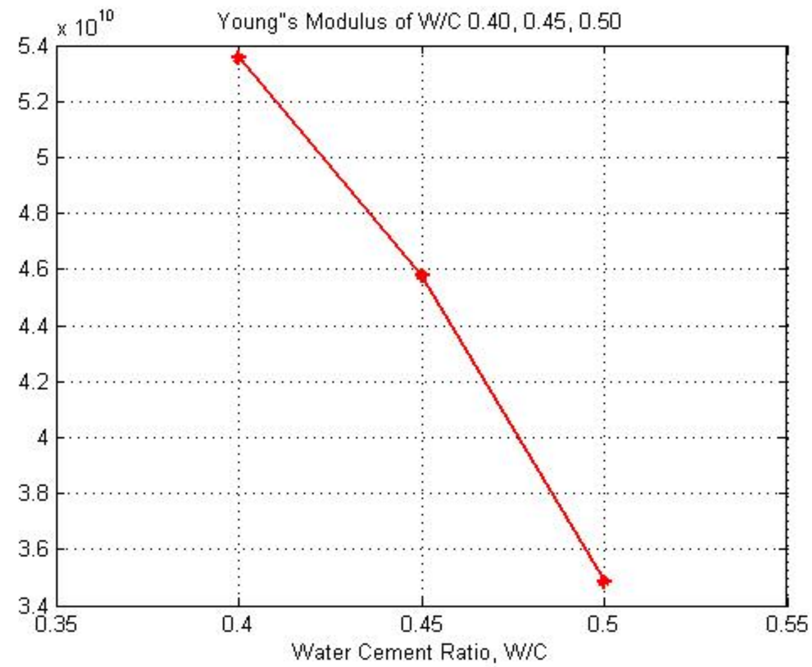
- Concrete with higher Phase Velocity has higher Compressive Strength.



Summary

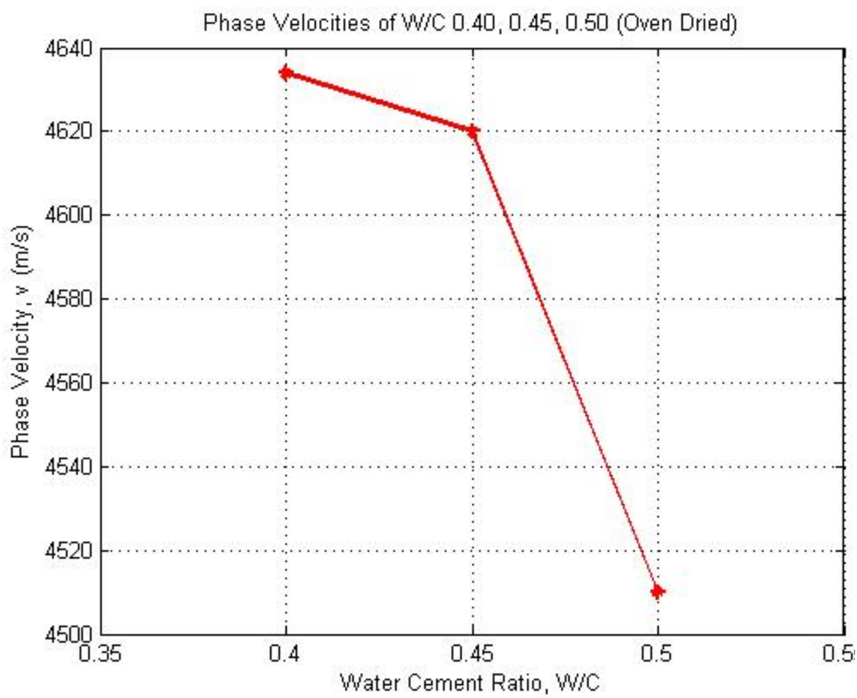
- Concrete with higher Compressive Strength has higher Young's Modulus.

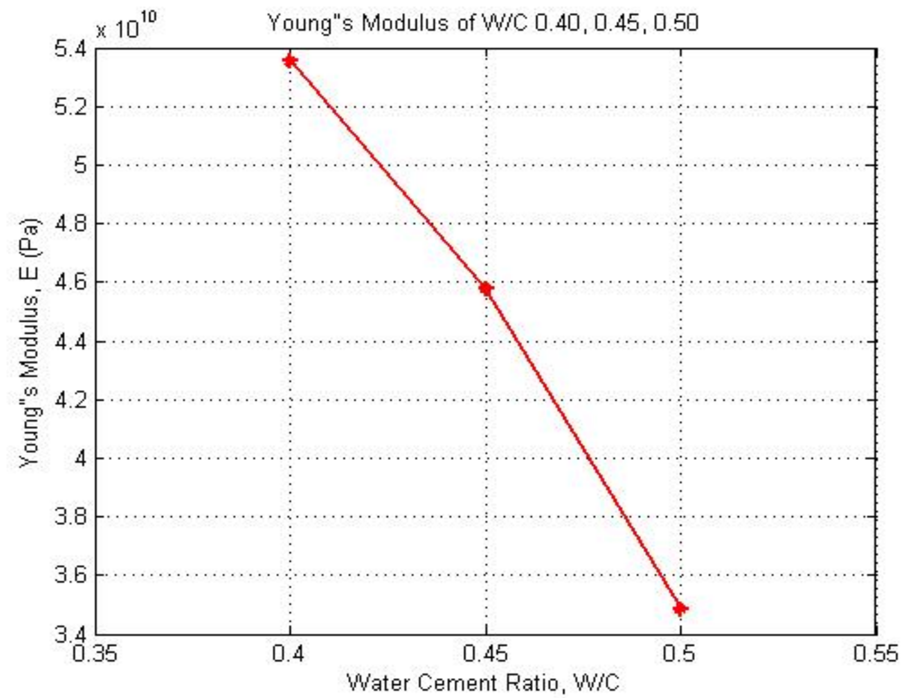




Summary

- Concrete with higher Phase Velocity has higher Young’s Modulus.





References

1) ACI 318 Committee, Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary. Farmington Hills, MI: American Concrete Institute, 2011. Print.

2) Connor, J. J., and Susan Faraji. Fundamentals of Structural Engineering. New York, NY: Springer, 2013. Print.

3) Trtnik, Gregor, Franci Kavčič, and Goran Turk. "Prediction of Concrete Strength Using Ultrasonic Pulse Velocity and Artificial Neural Networks." Ultrasonics (2008): 53-60. Print.

Acknowledgements

- Special thanks to
  - Professor Tzuyang Yu
  - Jones Owusu Twumasi
  - Qixiang Tang

- Also,
  - Gary Howe
  - Peyman Poozesh
  - Nicholas D’Amico
  - Ibrahim Diarra

Thank You!

Questions and Comments?