Interface Shear Strength Characterization Between Subsea Installed Micropile Grout and Textured Rock for Micropiles Anchoring Offshore Renewable Ocean Energy Devices

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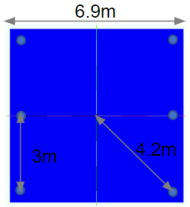
Floating Offshore Wind Turbines

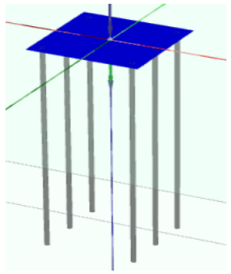
<u>Projected 3-year Wind Farm</u>

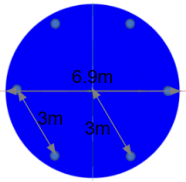
Water Depth: ~ 1000m

Subsurface Exploration: None, Measuring While Drilling



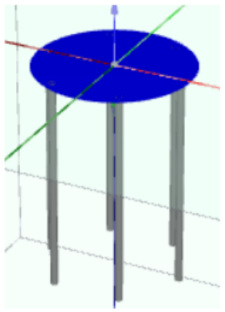
Square pattern





Circular pattern

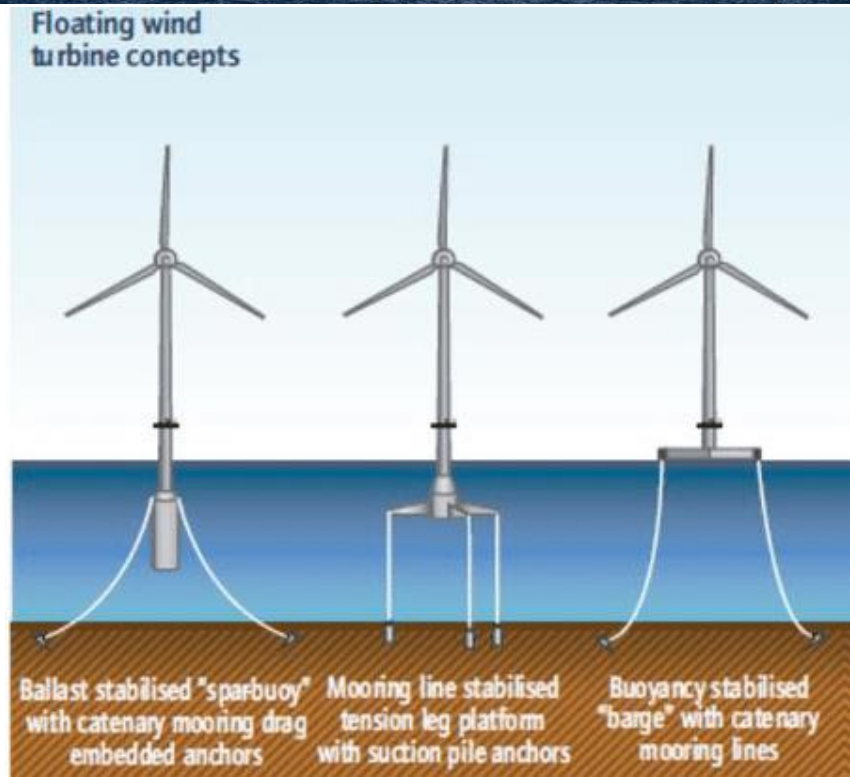
(Dimensions for D = 0.3m)



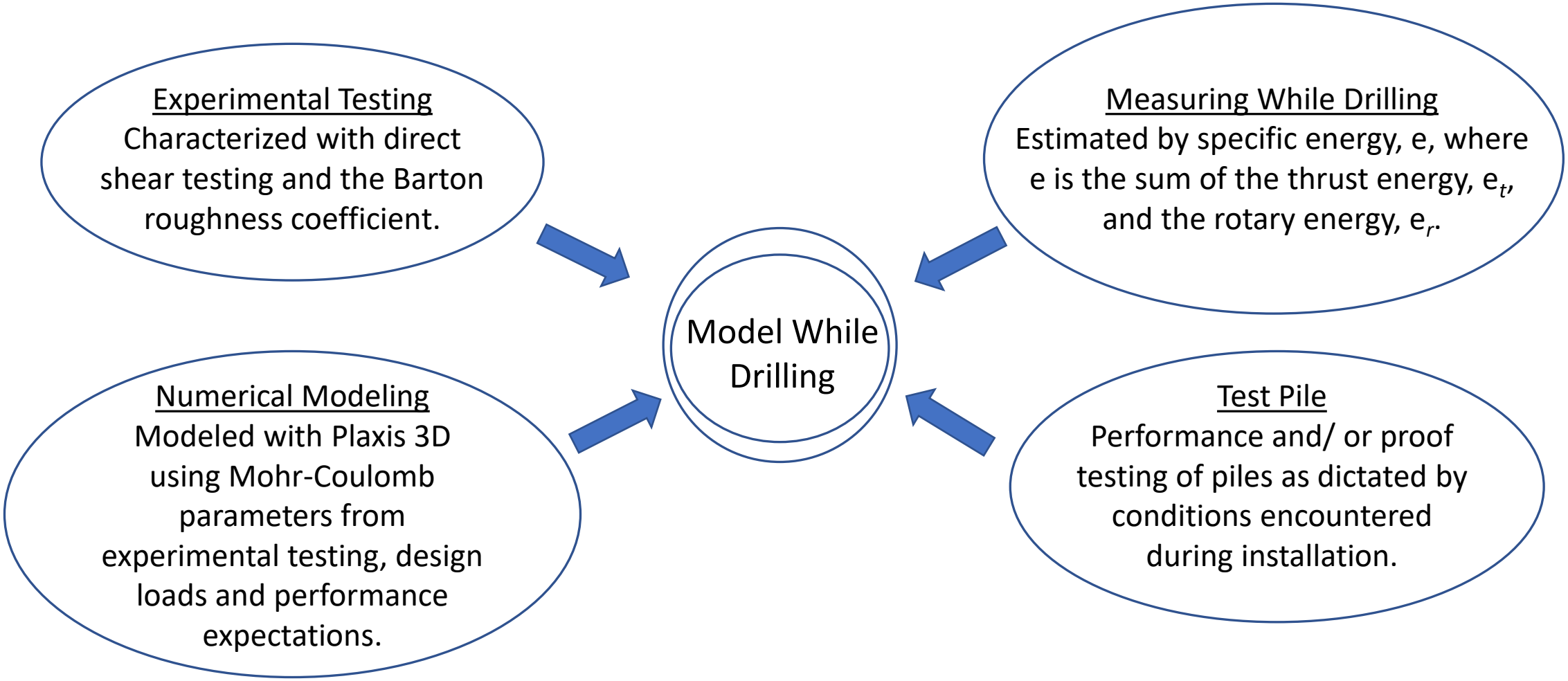
Foundation System: Catenary mooring lines secured to steel platen affixed to seabed with remotely installed micropile group

Axial Tension: Fz ~ 1000 metric tons in tension at ~ 39^{o} with respect to horizontal

Geomaterials: Basalt (overburden removal as necessary)



Micropile Installation Map



Experimental Testing: Characterize the Joint Interface Shear Strength

$$\tau = \sigma_n \tan\left[JRC \log\left(\frac{JCS}{\sigma_n}\right) + \phi_b\right]$$

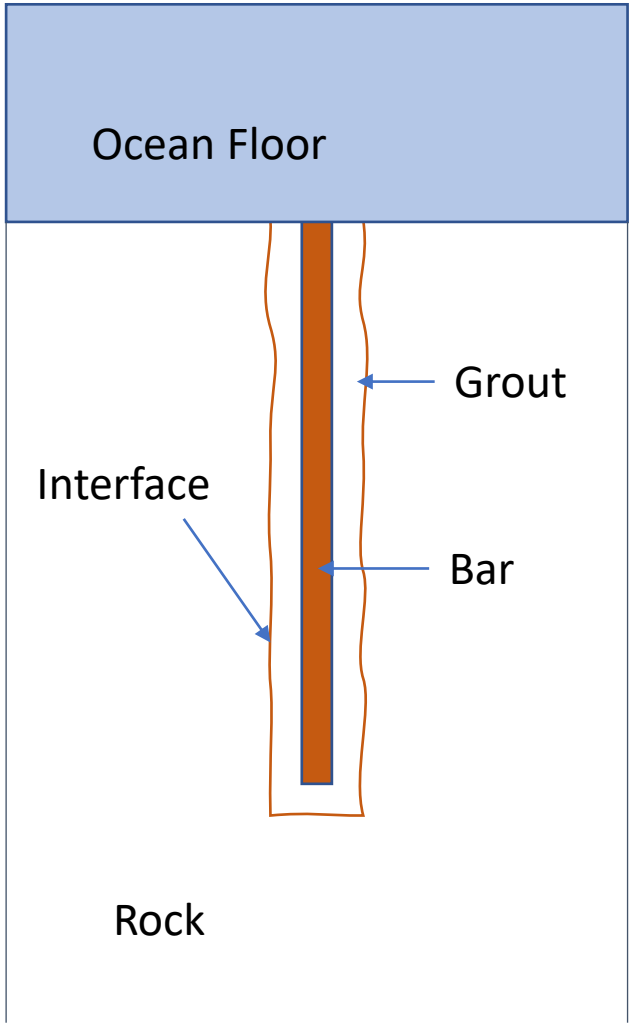
$\boldsymbol{\tau}$: Joint interface shear strength (MPa)

$\boldsymbol{\sigma_n}$: Normal stress (MPa) at joint interface

$\boldsymbol{JRC}$: Joint roughness coefficient

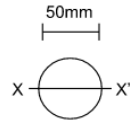
$\boldsymbol{JCS}$: Joint compressive strength (MPa)

$\boldsymbol{\phi_b}$: Basic friction angle

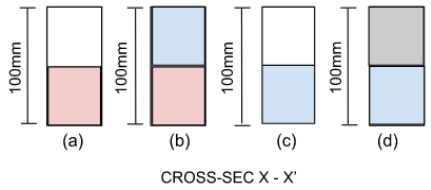


Barton, 1977

Joint Roughness Coefficient (JRC)

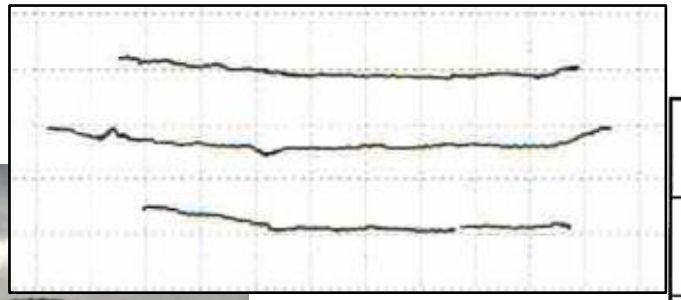


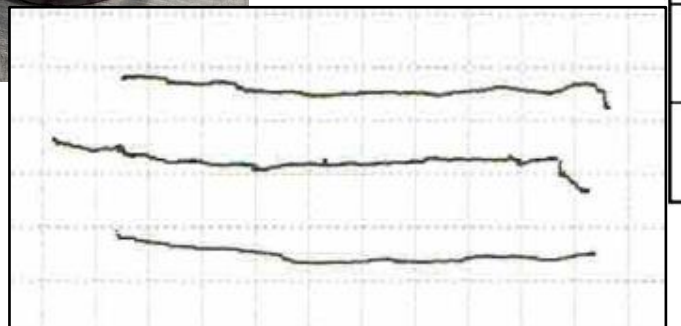
PLAN

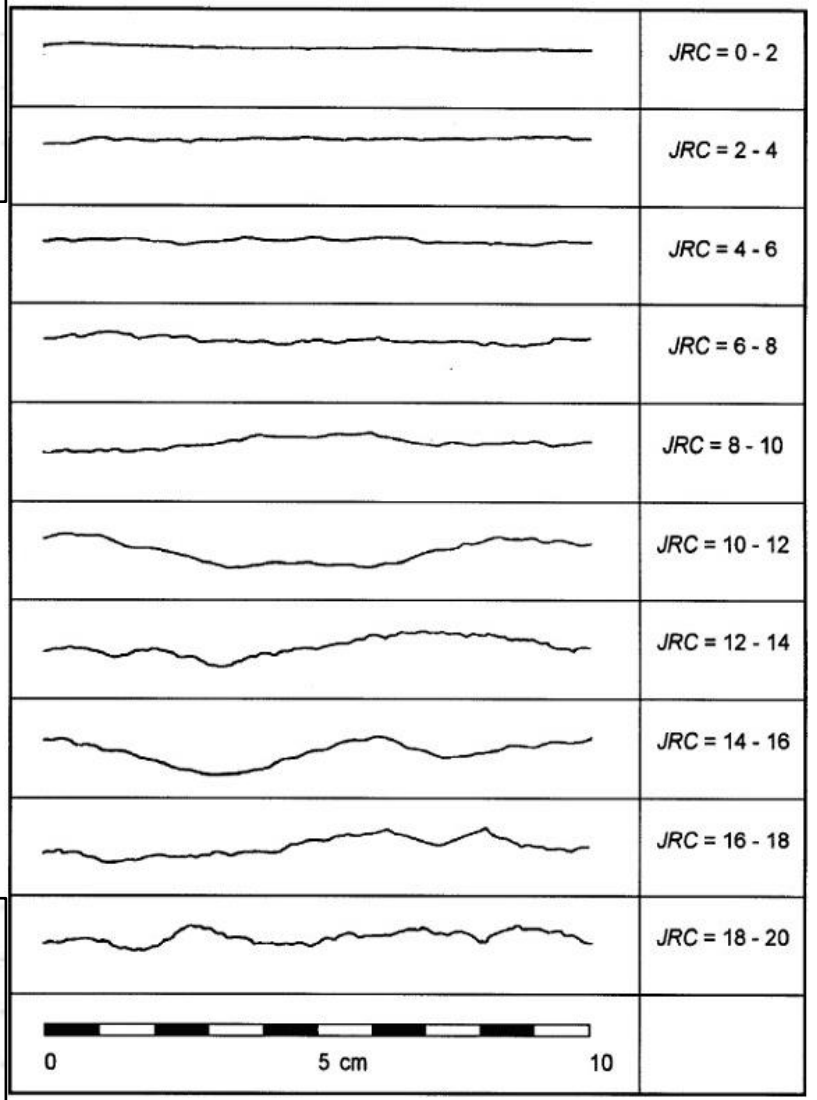


CROSS-SEC X - X'

- Simulated Rock
- Portland Cement Grout
- Texture Mold







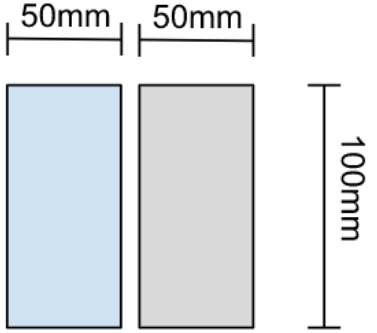
Uniaxial Compressive Strength (UCS) Testing

Simulated Rock Recipes

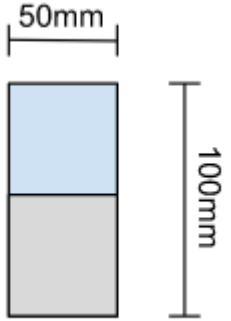
- Sakrete Construction Grout, w/c = 0.145, mixed w/ freshwater cured at 20°C, RH = 65%
- Sakrete Precision Grout, w/c = 0.154, mixed w/ freshwater cured at 20°C, RH = 65% and 100%
- Quikrete Precision Grout, w/c = 0.142, mixed w/ freshwater cured at 20°C, RH = 65%
- Quikrete Precision Grout, w/c = 0.18, mixed w/ freshwater cured at 20°C, RH = 65% and 100%

Grout Recipes

- Ordinary Portland Cement, w/c = 0.45, mixed w/ freshwater cured at 4°C and 20°C, RH = 65% and 100%
- Ordinary Portland Cement, w/c = 0.60, mixed w/ freshwater cured at 4°C and 20°C, RH = 65% and 100%
- Ordinary Portland Cement, w/c = 0.45, mixed w/ seawater cured at 4°C and 20°C, RH = 65% and 100%
- Ordinary Portland Cement, w/c = 0.60, mixed w/ seawater cured at 4°C and 20°C, RH = 65% and 100%



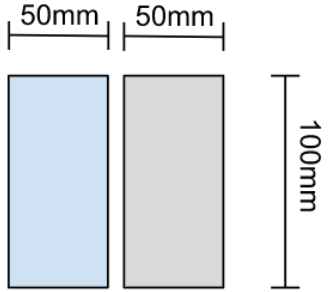
Homogenous: specimens cast from one material



Composite: specimens cast with portion composed of simulated rock and the balance composed of grout.

UCS Results of Homogenous Specimens (MPa)

Materials used in direct shear (DS) testing reported herein



Homogenous: specimens cast from one material

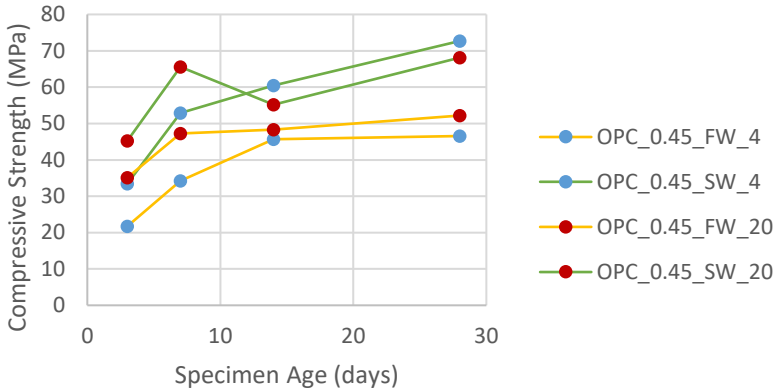
Grout (OPC)						
Cure Temp	Water Type	Age (days)	w/c=0.45		w/c=0.60	
			Unsealed	Sealed	Unsealed	Sealed
20°C	Fresh-water	3	28.3	35.1	21.9	24.7
		7	47	47.3	32.2	31.2
		14	41.9	48.3	37.7	36.0
		28	56.2	52.2	43.3	43.9
	Sea-water	3	48.4, 27.8	45.2	36.4	38.6
		7	45.9	65.6	43.8	42.5
		14	44.9	55.2	46.2	46.0
		28	43.7, 63.3	68.2	51.9	50.4
4°C	Fresh-water	3	No part of proposed scope of work	21.7	No part of proposed scope of work	13.6
		7		34.2		27.6
		14		45.7		35.0
		28		46.6		42.4
	Sea-water	3		33.5		16.7
		7		52.9		31.0
		14		60.5		41.4
		28		72.7		45.0

Simulated Rock - Cured at 20°C mixed with freshwater									
Age (days)	Grainger Sakrete		Grngr Sak + BaSO4		HD Sak	Quikrete Precision Grout			
	w/c=0.145	w/c=0.45	w/c=0.45	w/c=0.145	w/c=0.154	w/c=0.19	w/c=0.18		w/c=0.142
	Unsealed	Unsealed	Unsealed	Unsealed	Unsealed	Unsealed	Unsealed	Sealed	Unsealed
3	32.5	5.6	4.1	31.1	40.9	39.9	41.8	46.3	46.7
7	39.2	7.1	4	41.9	52.3	50.3	44.8	46.4	54.4
14	42.9	8	5	44.5	52.2	58	48.3	53.0	56.5
28	44.9	13.3	5.5	49.5	66.4	58.9	59.7	56.8	63.0

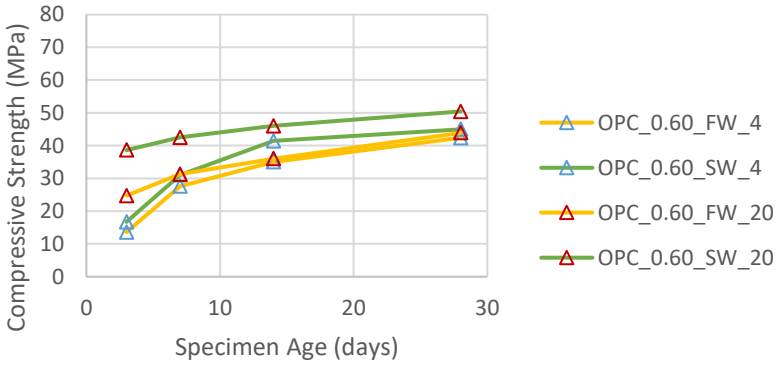
UCS Results of Homogenous Specimens (MPa)

Influence of Temperature

UCS vs. Age
OPC w/c = 0.45 Freshwater or Seawater
Sealed Cure 4°C or 20°C

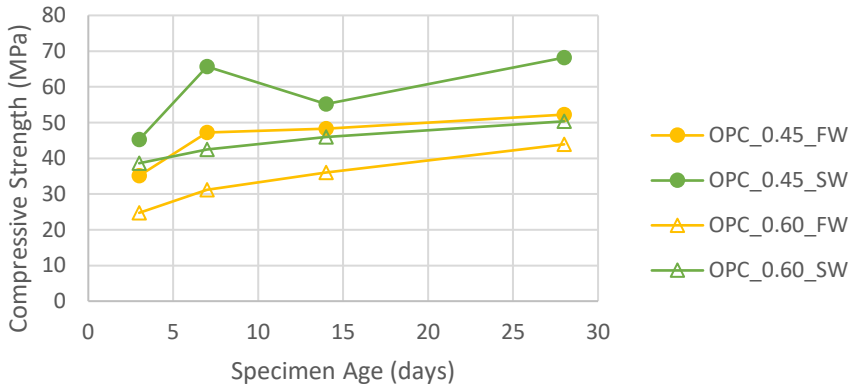


UCS vs. Age
OPC w/c = 0.60 Freshwater or Seawater
Sealed Cure 4°C or 20°C

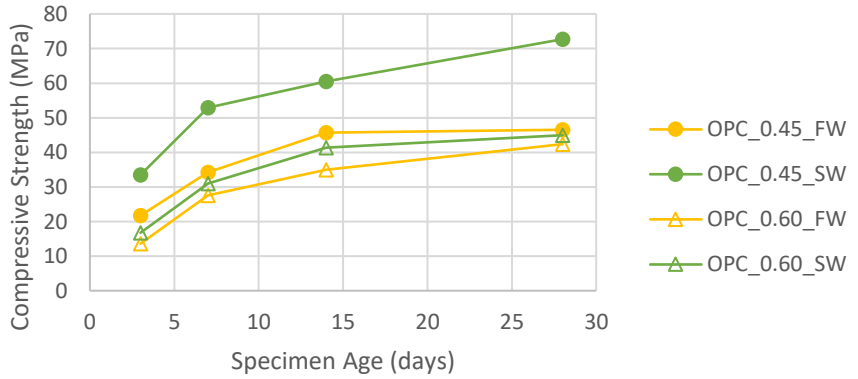


Influence of Seawater

UCS vs. Age
OPC w/c = 0.45 or 0.60 Freshwater or
Seawater Sealed Cure at 20°C



UCS vs. Age
OPC w/c = 0.45 or 0.60 Freshwater or
Seawater Sealed Cure at 4°C

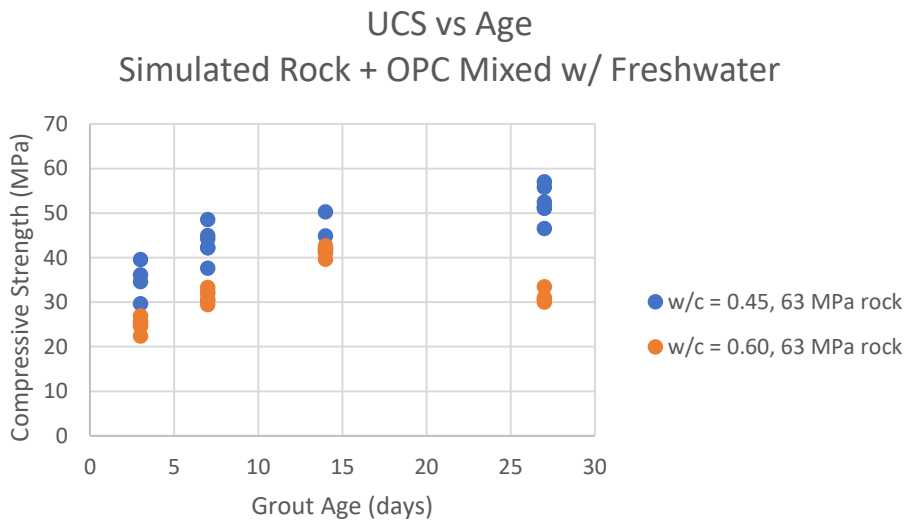


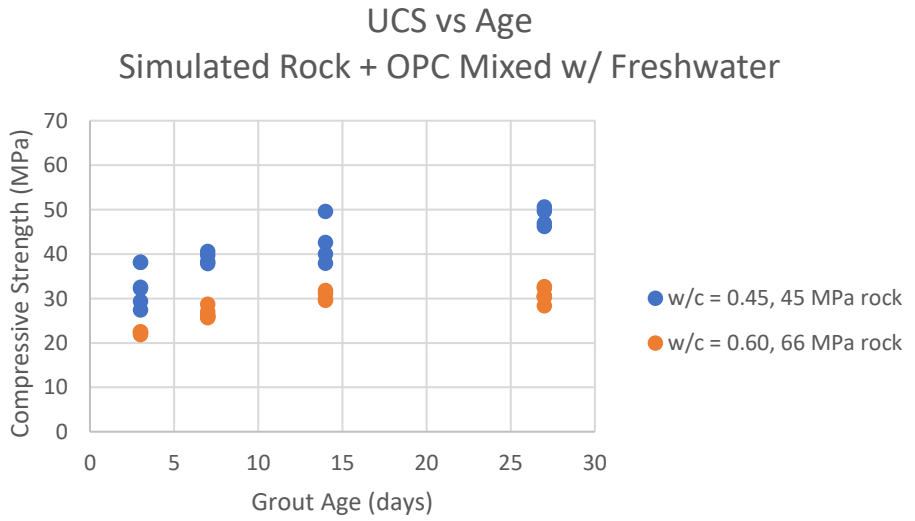
UCS Results of Composite Specimens (MPa)

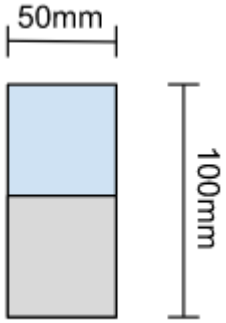
Grout (OPC) Age	Interface Texture	Sakrete w/c = 0.154 Simulated Rock				Quikrete w/c = 0.142 Simulated Rock			
		OPC + Freshwater		OPC + Seawater		OPC + Freshwater		OPC + Seawater	
		w/c=0.45	w/c=0.60	w/c=0.45	w/c=0.60	w/c=0.45	w/c=0.60	w/c=0.45	w/c=0.60
27 day	Sm	46.2	30.5	55.5	39.7	46.6, 51.4, 55.8	30.0	54.1	48.3
	Lo	50.6	32.3	59.5	33.5	51.0	30.5	55.1	42.4
	Md	49.6	32.3, 32.6, 30.3	62.7	37.6	57.1	33.5	56.3	36.5
	Hi	46.9	28.3	56.8	31.7	52.5	31.0	64.0, 62.8, 64.5	43.0
14 day	Sm	40.0	29.5	51.9, 51.8, 56.7	45.8	42.0	42.6	46.0	39.7
	Lo	42.6	31.0	54.3	47.0	50.3	41.1	53.0	45.4
	Md	37.9	29.9	50.6	52.7	44.9	42.0	54.5	44.0, 40.8, 41.6
	Hi	49.562	31.763	54.390	46.5, 41.2, 40.9	41.2	39.7	50.2	44.4
7 day	Sm	32.474	22.177	51.964	36.8	37.6	33.34, 32.4, 32.0	44.8	44.6
	Lo	38.1, 29.3, 27.4	22.4	46.1	35.7, 24.2, 35.3	42.3	30.3	49.0	41.0
	Md	32.2	21.9	46.5	34.9	48.6, 44.2, 42.2	30.7	38.7	37.9, 33.7, 39.5
	Hi	38.1	22.5	39.4	40.3	44.9	29.5	49.0	41.6
3 day	Sm	40.6	28.6	42.8	38.7	36.1	25.6	39.7	38.3
	Lo	39.7	25.7	46.4	37.2	39.6	24.6, 24.8, 25.56	41.6	36.6
	Md	37.9	25.7	49.2, 40.5, 52.8	34.3	29.7	26.9	45.0	40.3
	Hi	38.3	26.0, 26.2, 27.1	52.3	32.0	34.6	22.4	36.7, 45.1, 41.8	38.8

UCS Results of Composite Specimens (MPa)

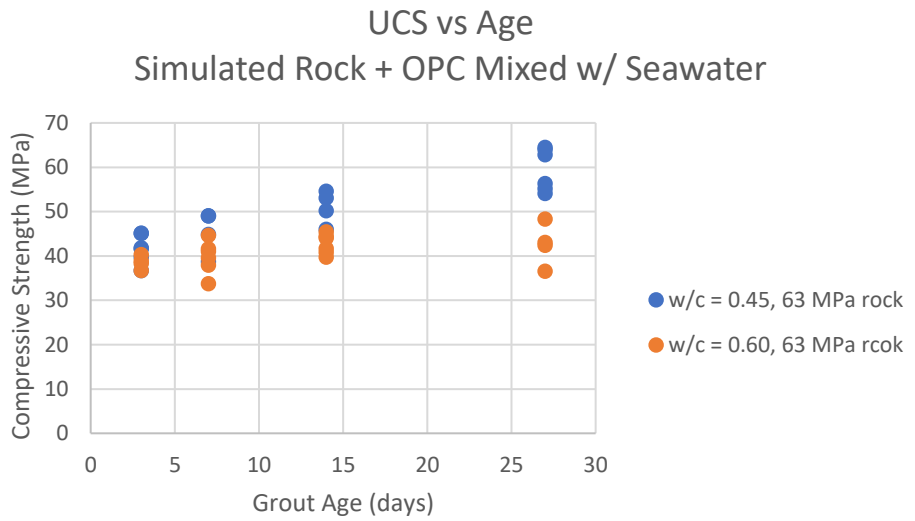
Freshwater Grout

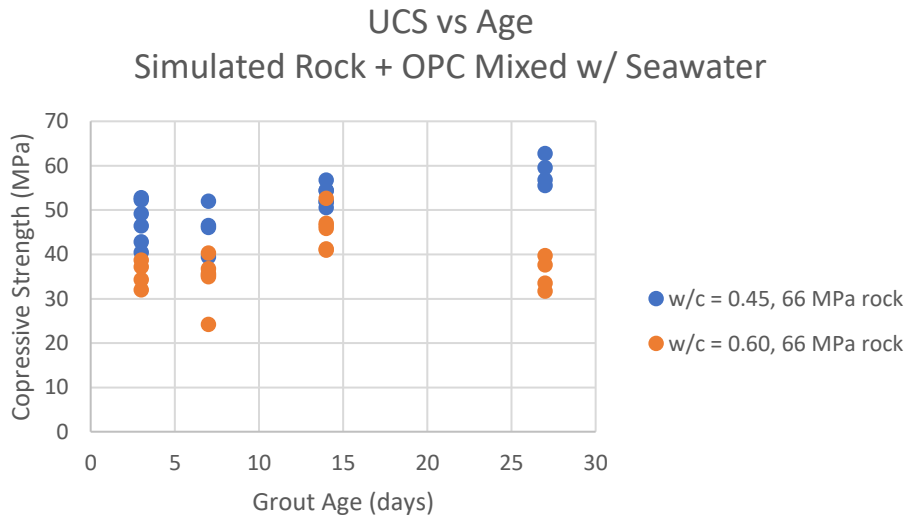




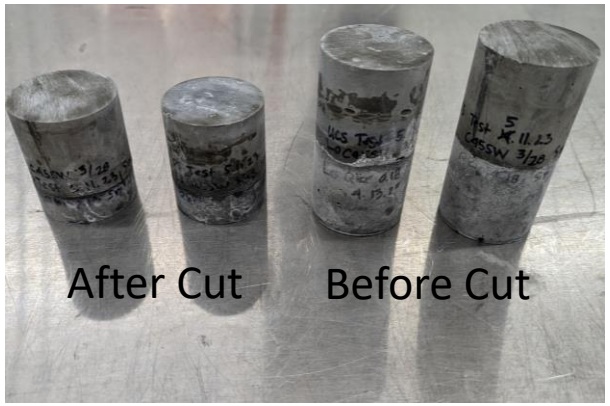


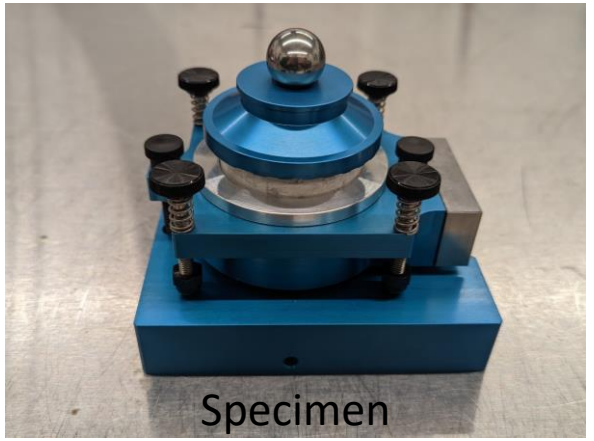
Seawater Grout

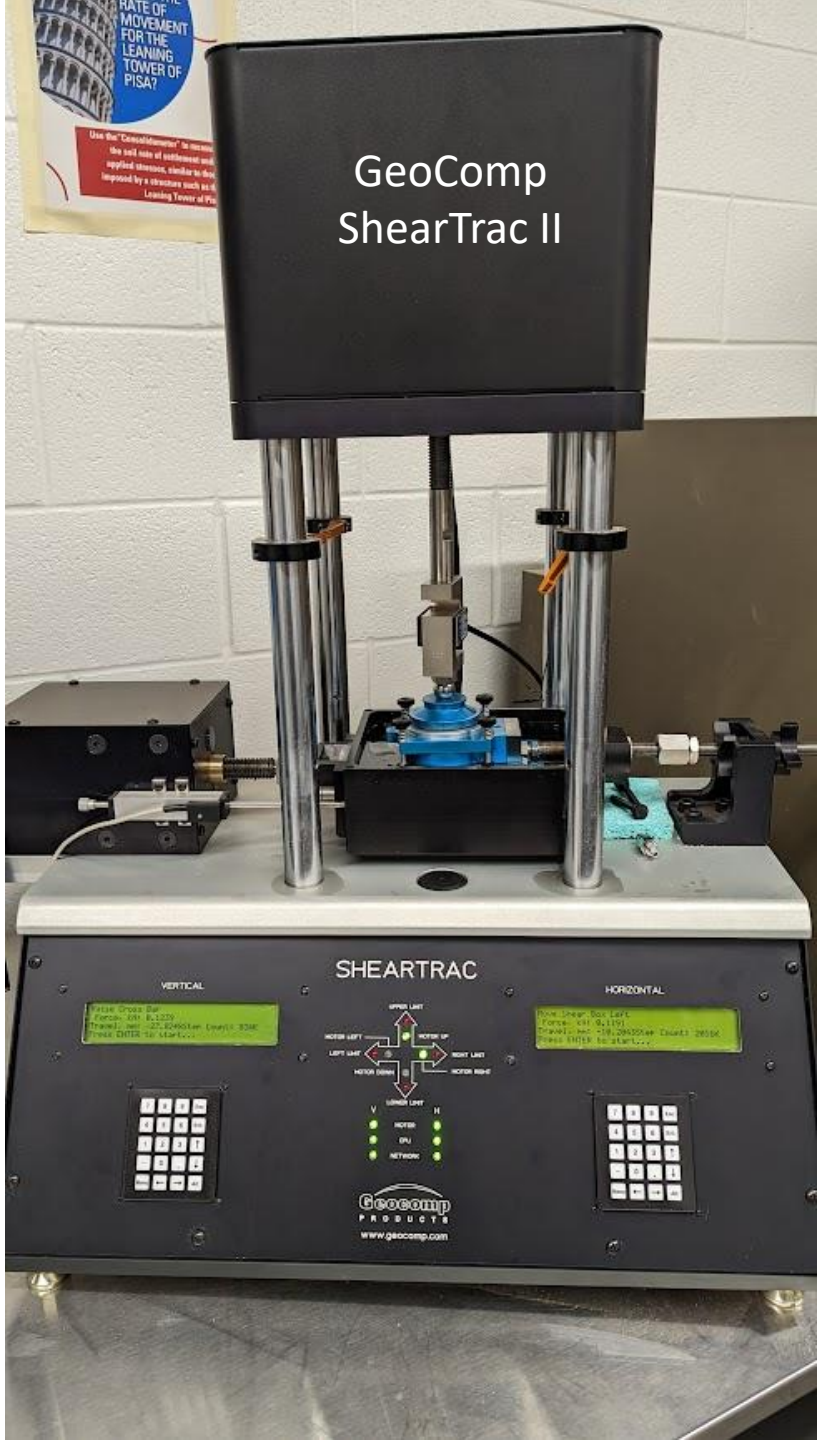




Direct Shear (DS) Testing

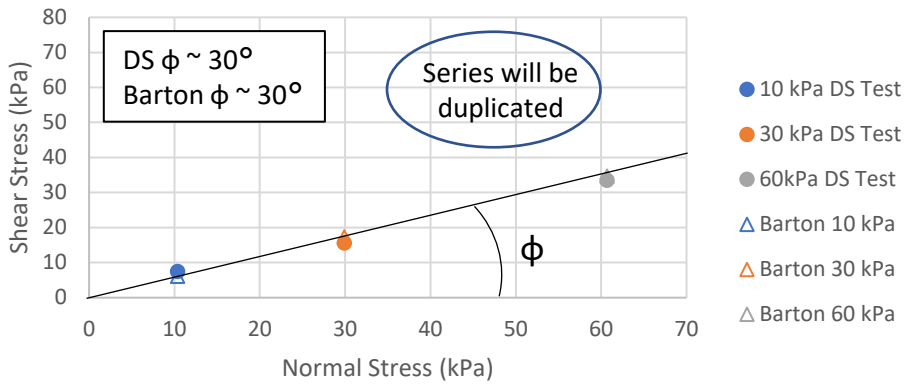




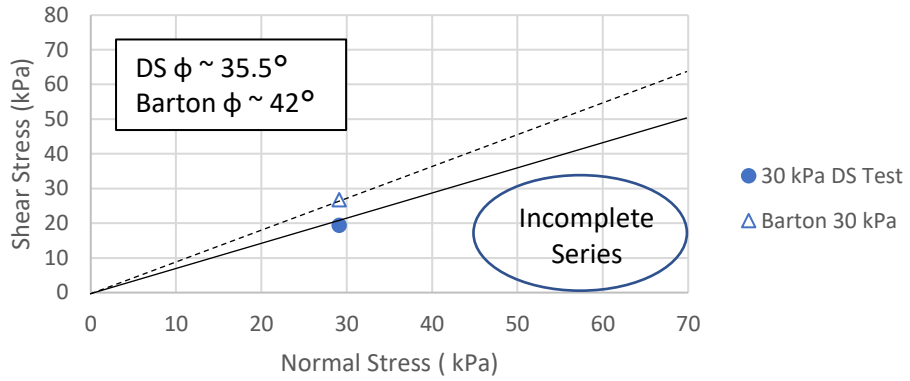


Preliminary Direct Shear Test Results – Freshwater

Shear Strength vs Normal Stress
3-day OPC45FW + Simulated Rock
Smooth Texture

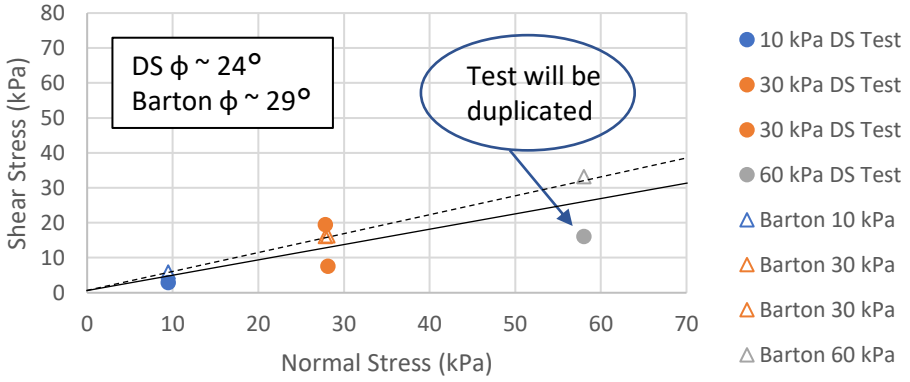


Shear Strength vs Normal Stress
3-day OPC45FW + Simulated Rock
Low Texture

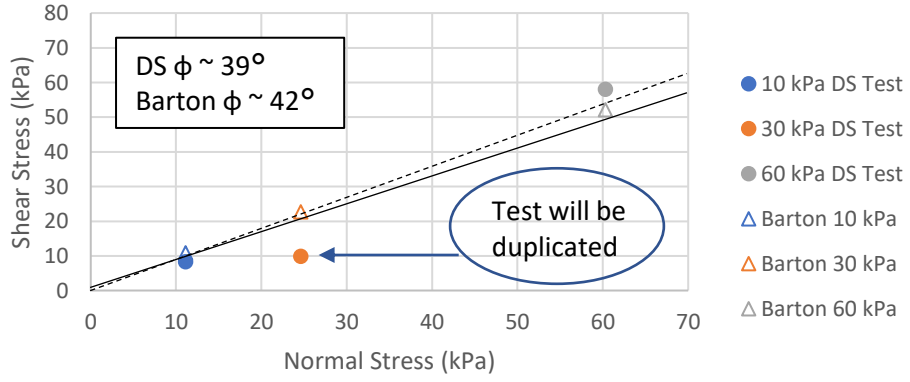


$$\tau = \sigma_n \tan\left[JRC \log\left(\frac{JCS}{\sigma_n}\right) + \phi_b\right]$$

Shear Strength vs Normal Stress
7-day OPC45FW + Simulated Rock
Smooth Texture

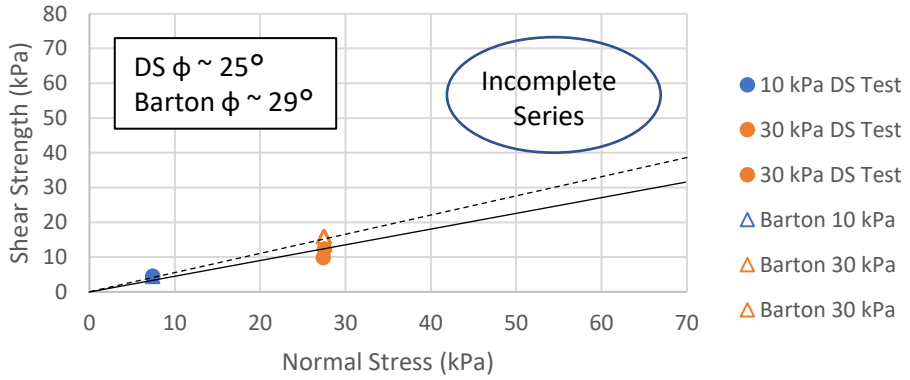


Shear Strength vs Normal Stress
7-day OPC45FW + Simulated Rock
Low Texture

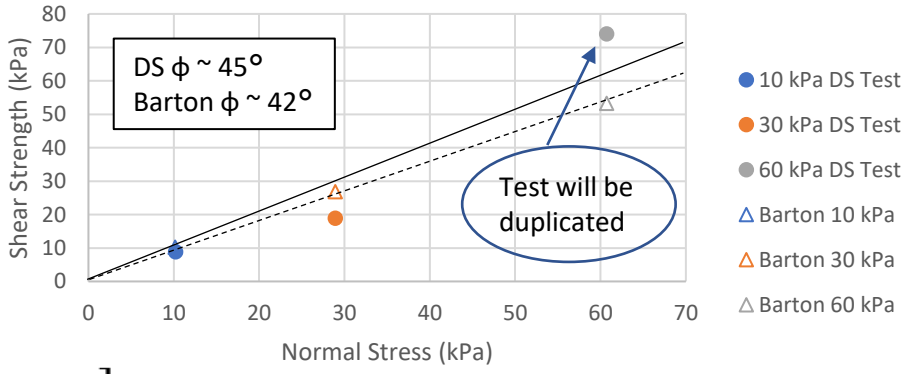


Preliminary Direct Shear Test Results – Seawater

Shear Strength vs Normal Stress
3-day OPC45SW + Simulated Rock
Smooth Texture

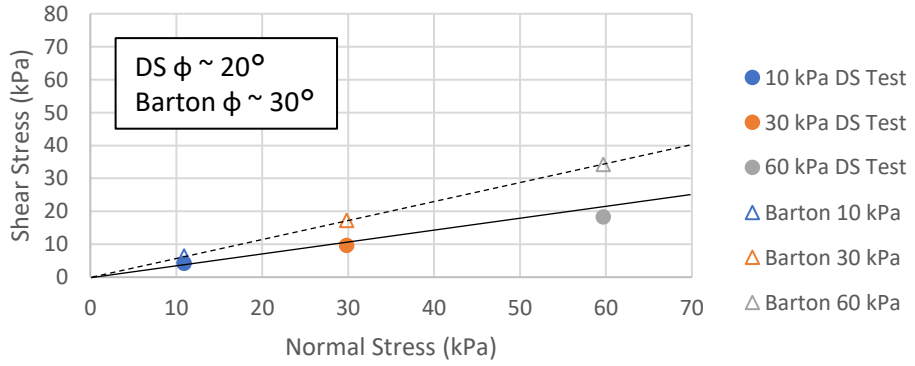


Shear Strength vs Normal Stress
3-day OPC45SW + Simulated Rock
Low Texture



$$\tau = \sigma_n \tan\left[JRC \log\left(\frac{JCS}{\sigma_n}\right) + \phi_b\right]$$

Shear Strength vs Normal Stress
7-day OPC45SW + Simulated Rock
Smooth Texture



Shear Strength vs Normal Stress
7-day OPC45SW + Simulated Rock
Low Texture