Tensile Behaviors of Large Sized Anchors in Concrete

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Background of Test for Large Size Anchor Systems

- To develop design criteria for extra-large-sized anchors (not addressed in the App. D of ACI code - greater than 25in embed. depth and 2in anchor diameter, and re-bar effect)

- To check if CC design methods for small sized anchors can be directly extended to extra-large-sized anchors with deep embedment or need some modification

- To evaluate supplementary reinforcement effects on tensile strength of extra-large sized anchor bolt

Summary of Tension Test Specimens

Category	Test Group		Specimen No.	Reinforce-ment	Anchor Diameter D_b (in)	Embed. Depth h_{ef} (in)
Tension	TH	TH-1	T1	None	2.75	25
		TH-2	T2	None	3.75	35
		TH-3	T3	None	4.25	45
	TR	TR-1	T4	Supp. #1	2.75	25
		TR-2	T5	Supp. #2	2.75	25
		TR-3	T1	None	2.75	25

Schematic Sketch of Tension Test Setup

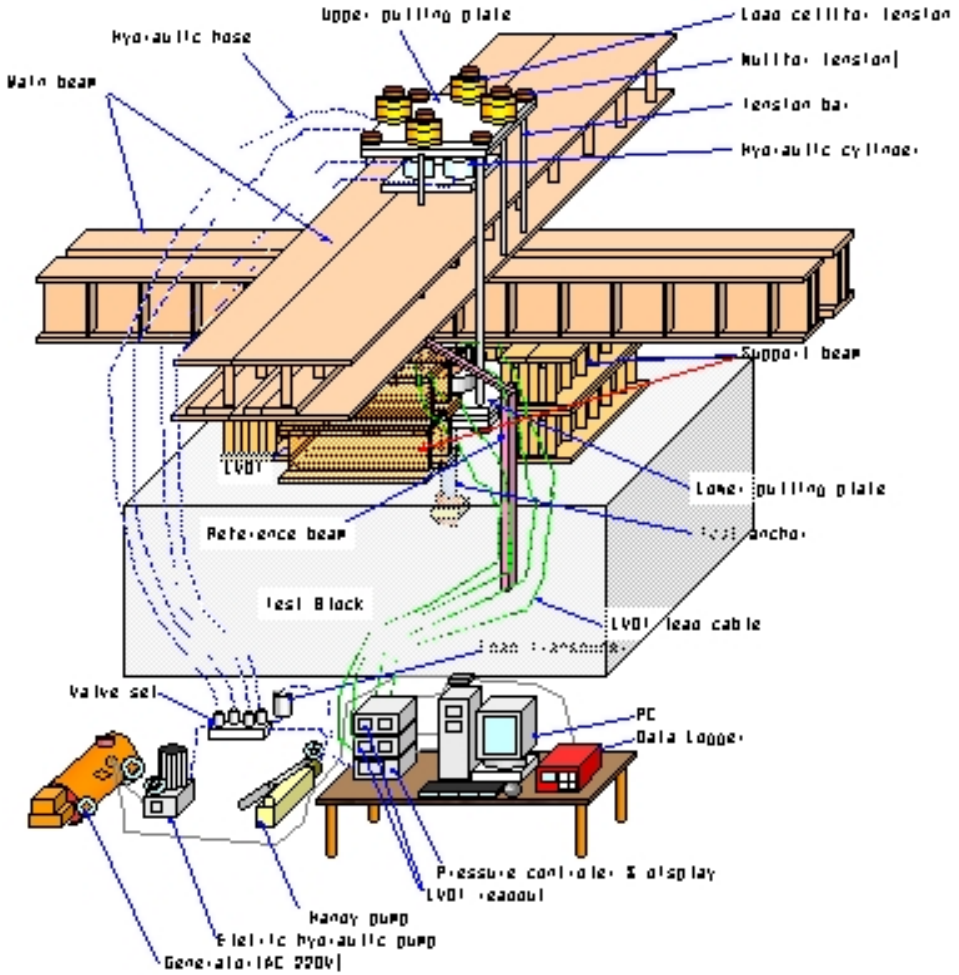
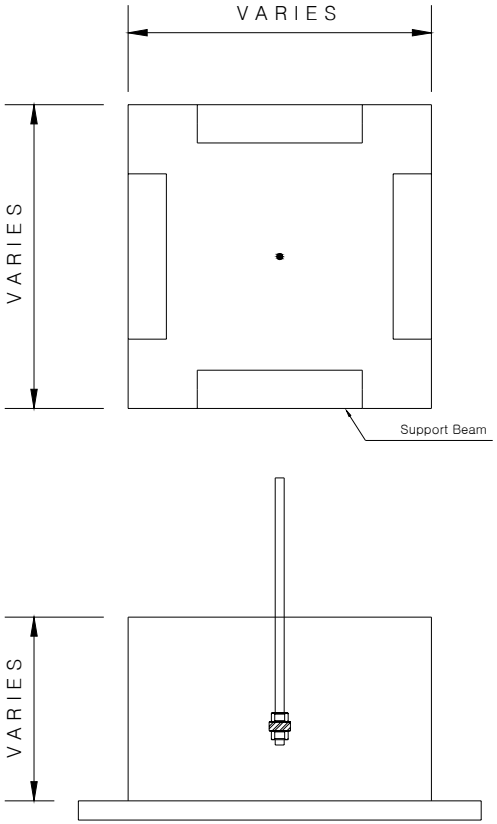
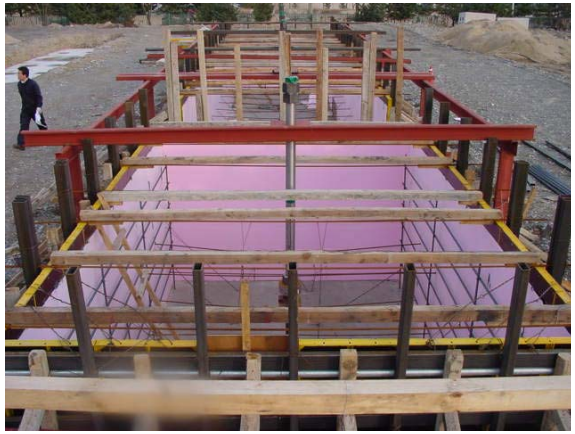
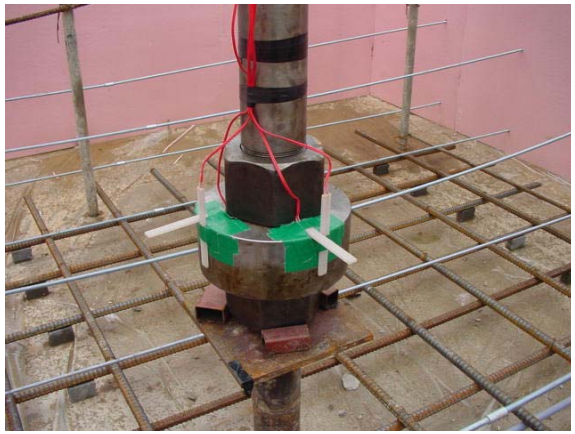


Photo of Tension Test Setup

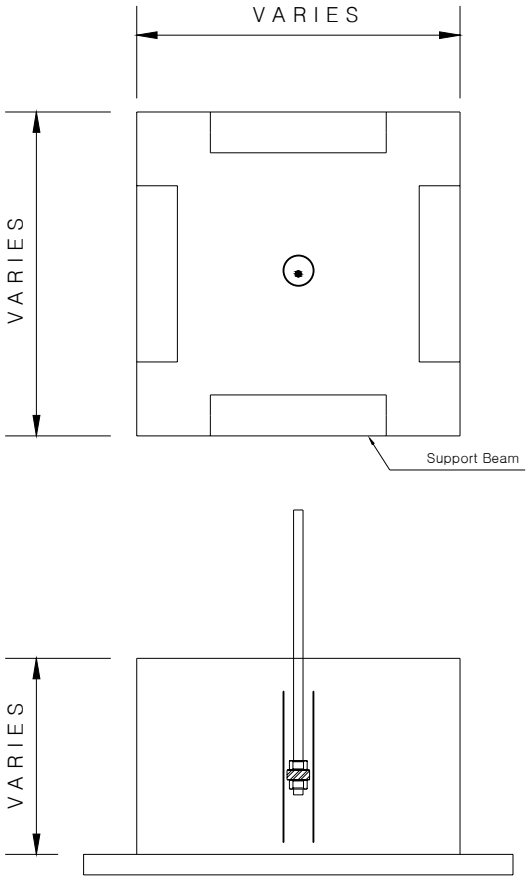
Sketch of Tension Test Specimens (Un-reinforced)

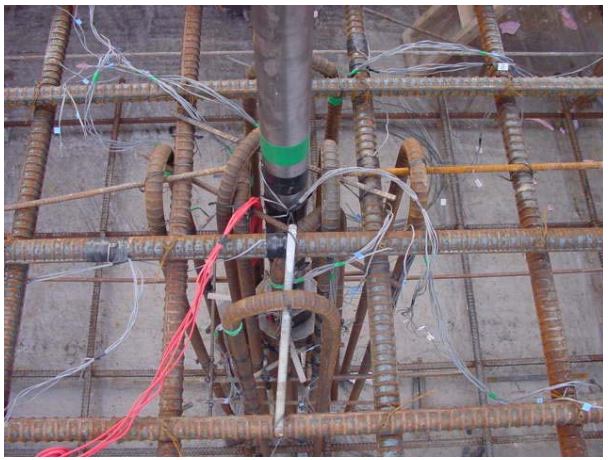




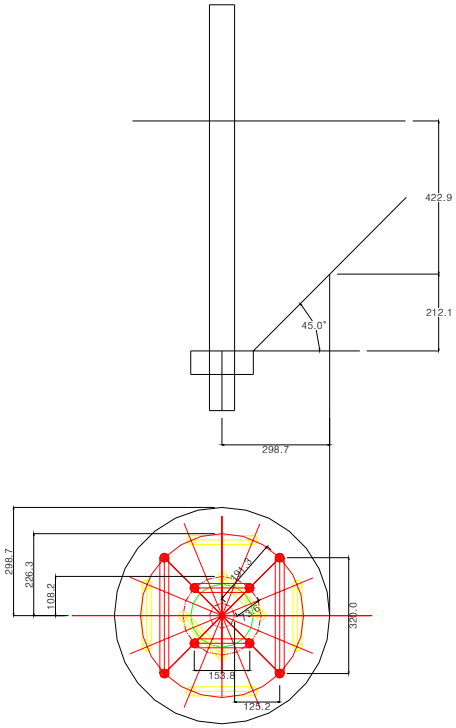


Sketch of Tension Test Specimens (Reinforced)

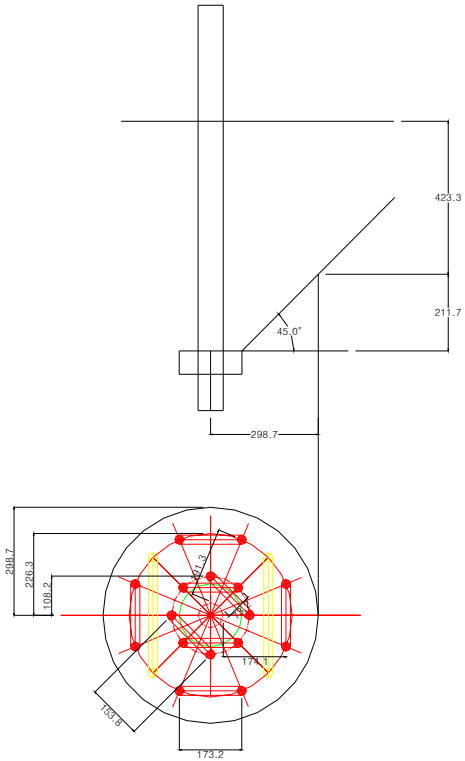




Sketch of Tension Test Specimens(Reinforced)

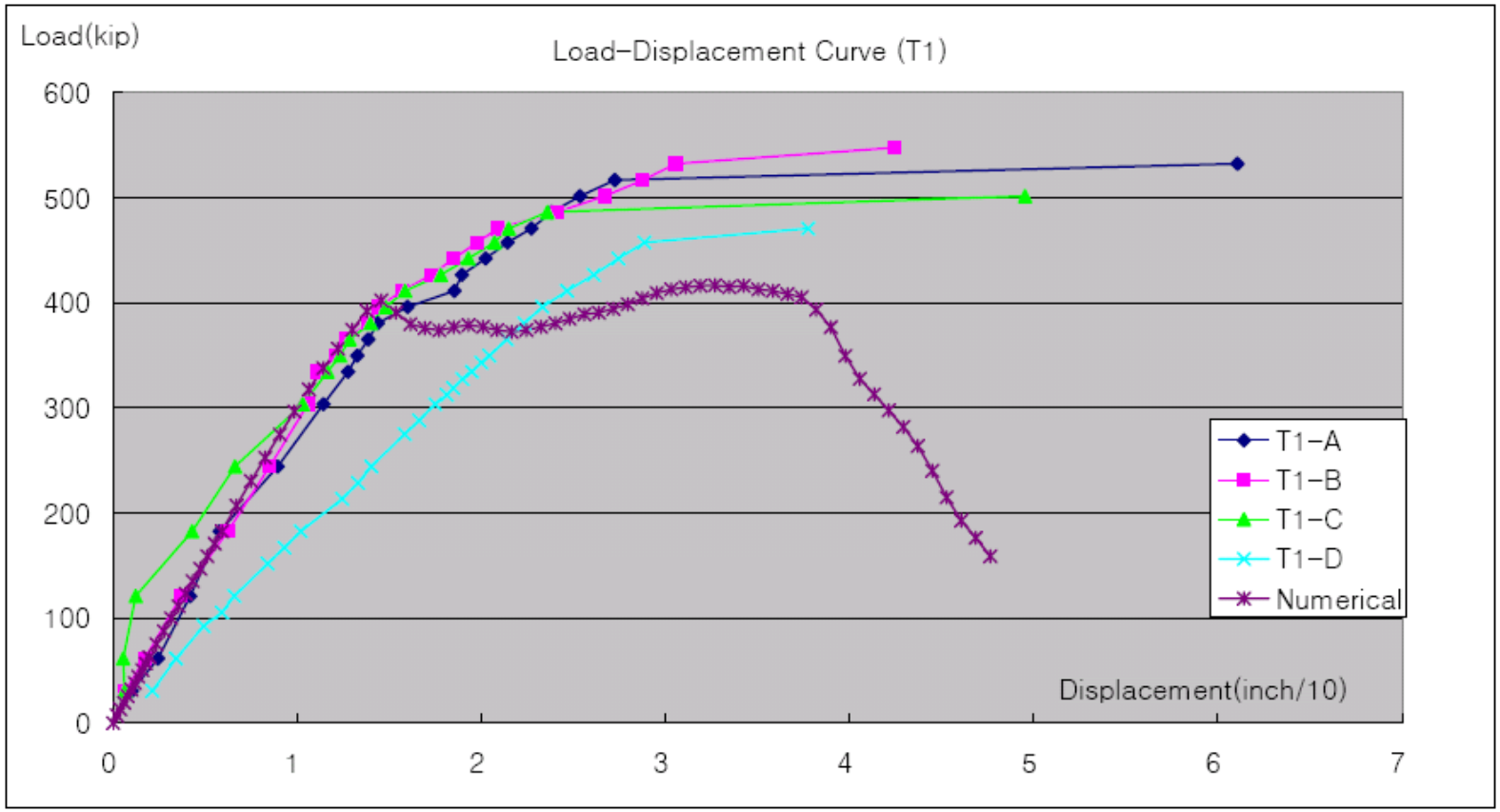


T4 (50%) 8-#8

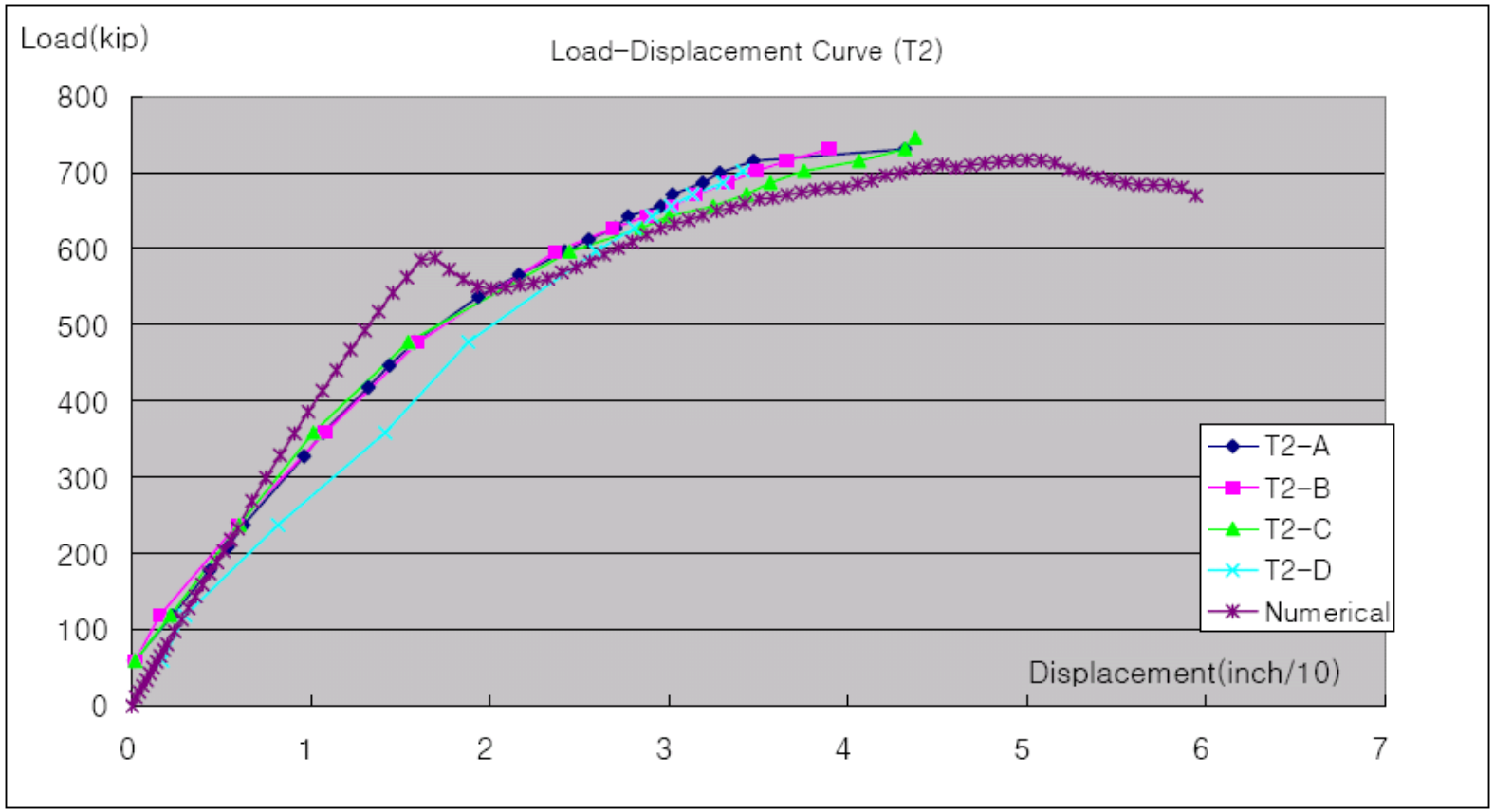


T5 (100%) 16-#8

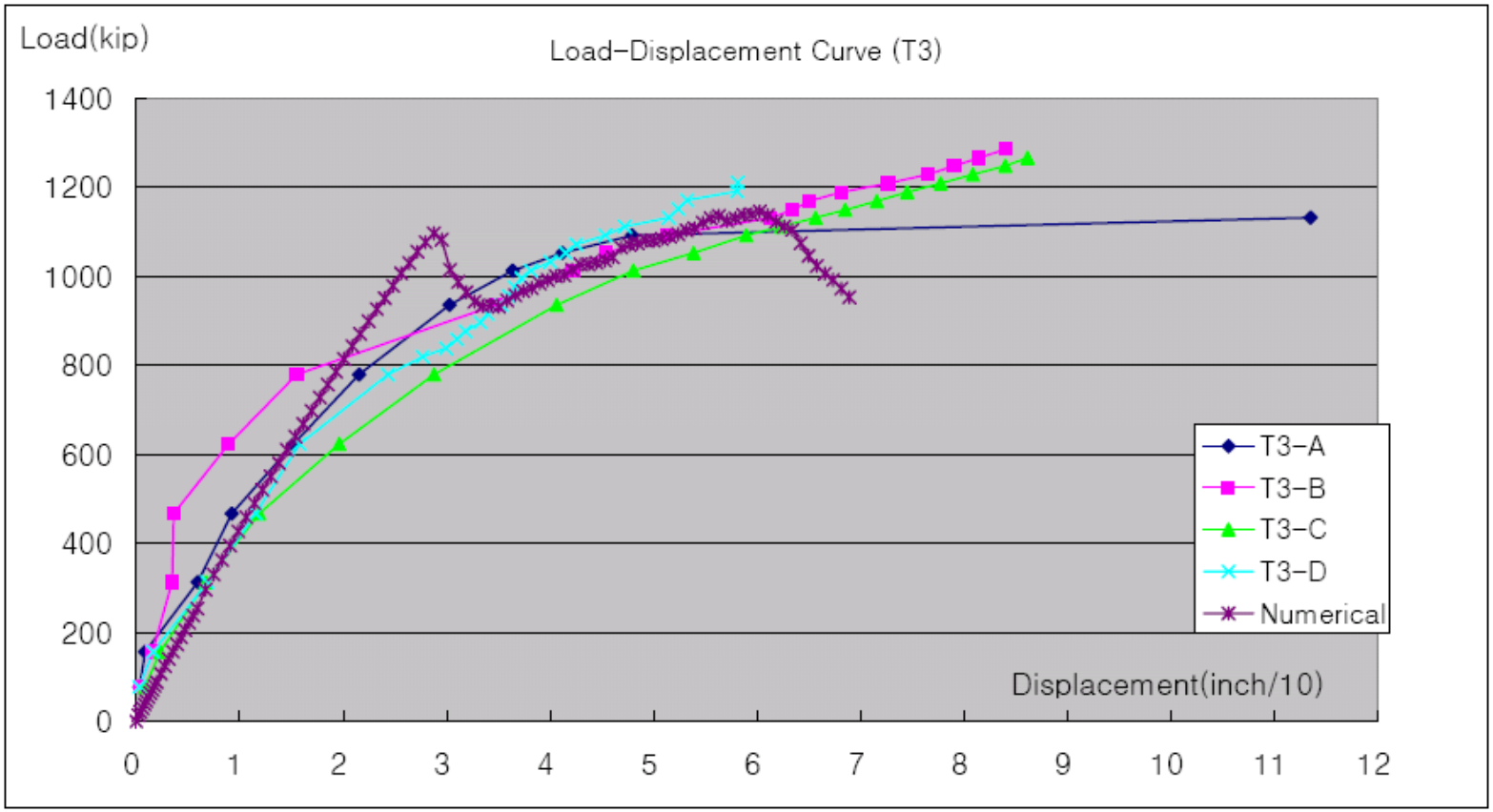
Load - Displacement Curves (T1, hef = 25 in)



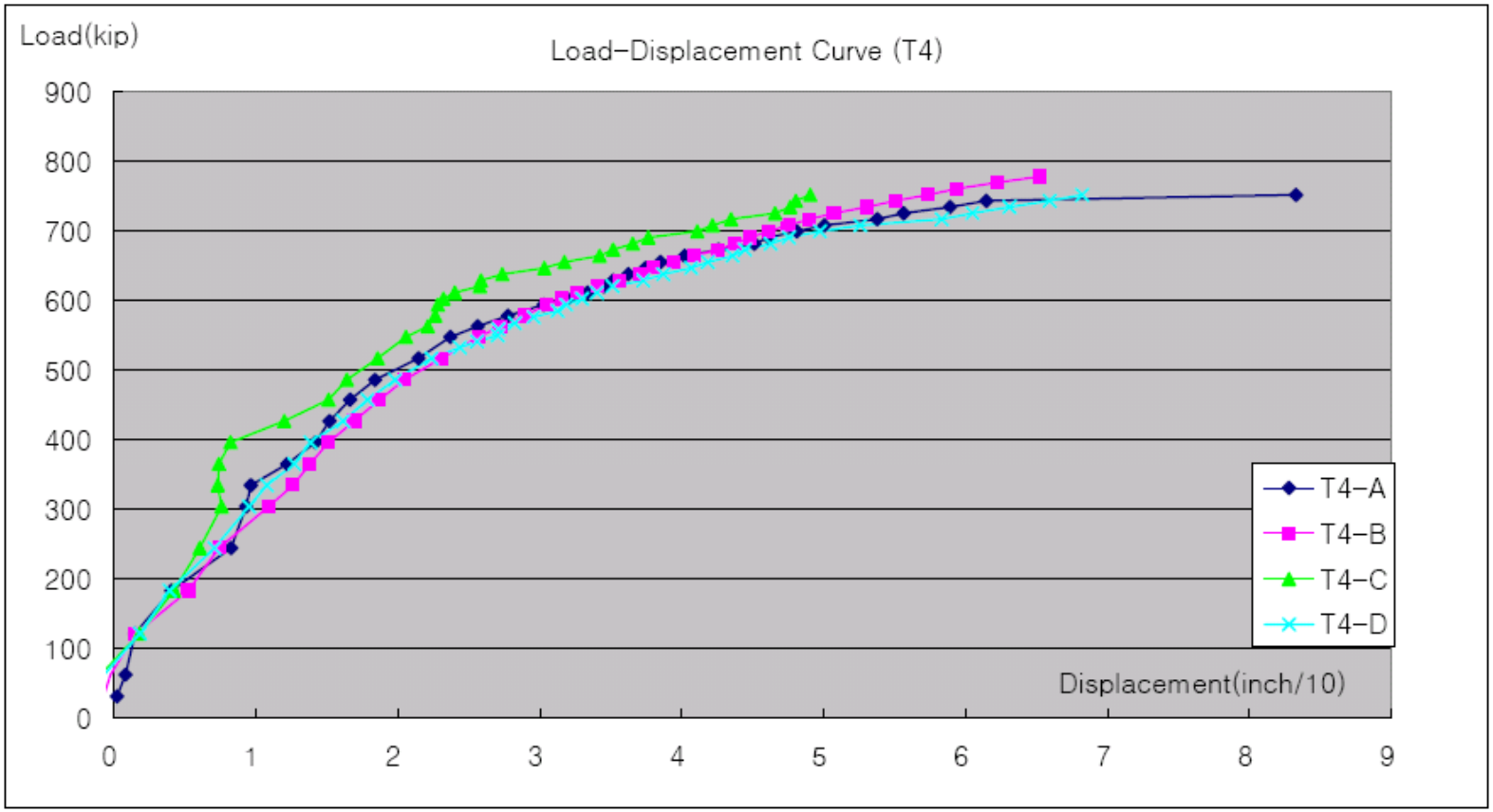
Load - Displacement Curves (T2, hef = 35in)



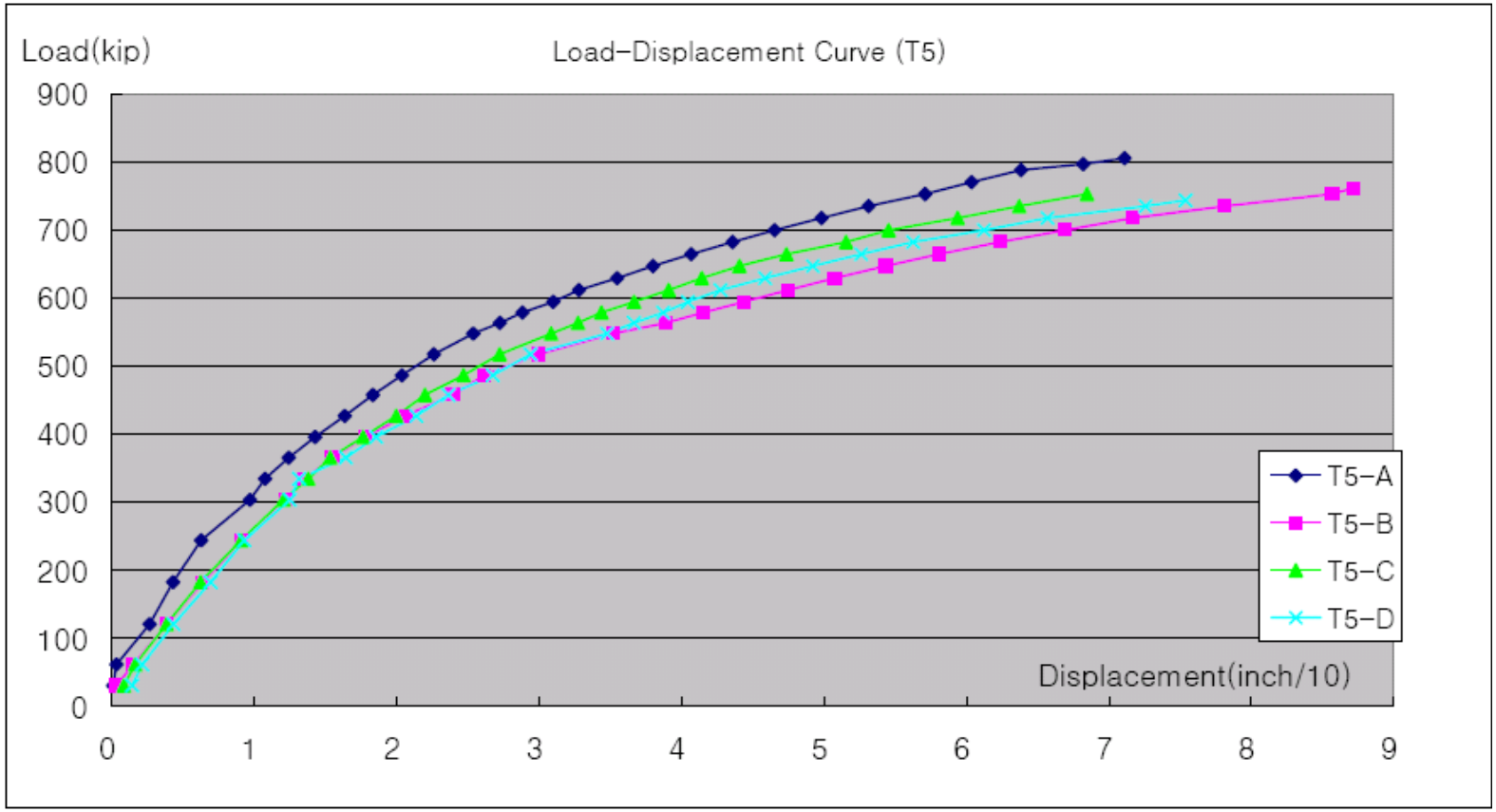
Load - Displacement Curves (T3, hef = 45in)



Load - Displacement Curves



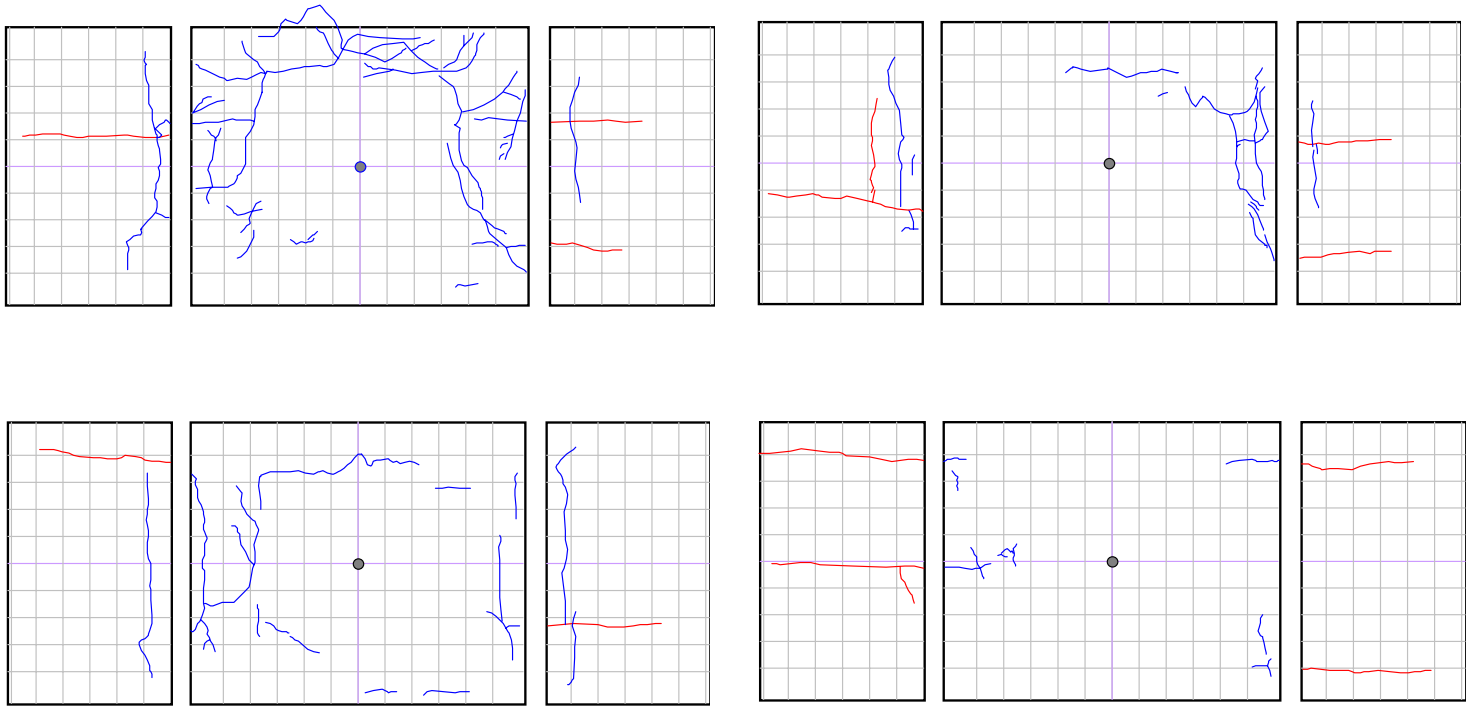
Load - Displacement Curves



Crack Patterns at Top and Either Side

T1-A

T1-B



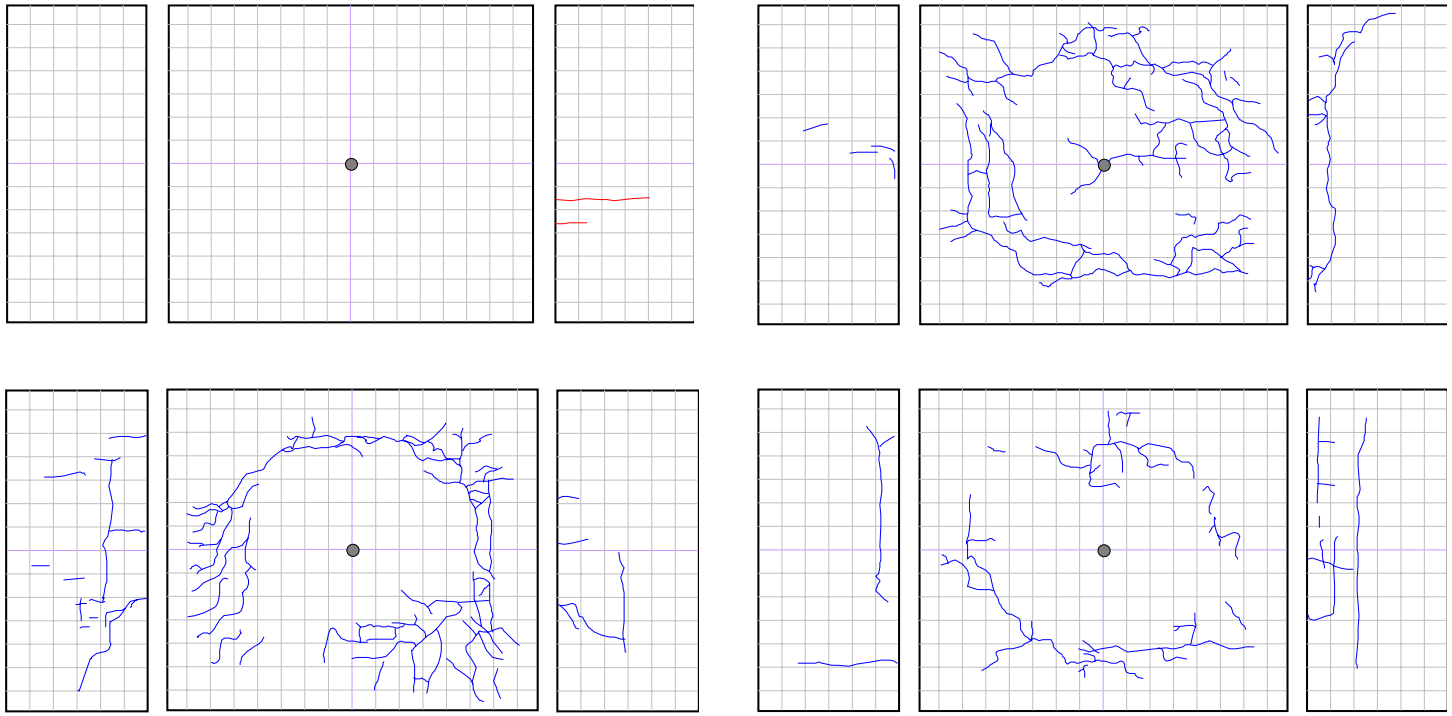
T1-C

T1-D

Crack Patterns at Top and Either Side

T2-A

T2-B

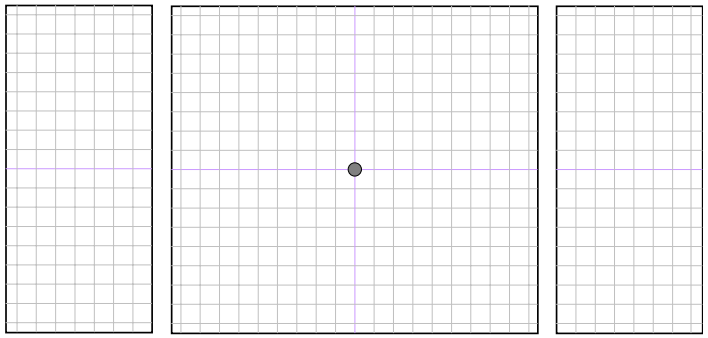


T2-C

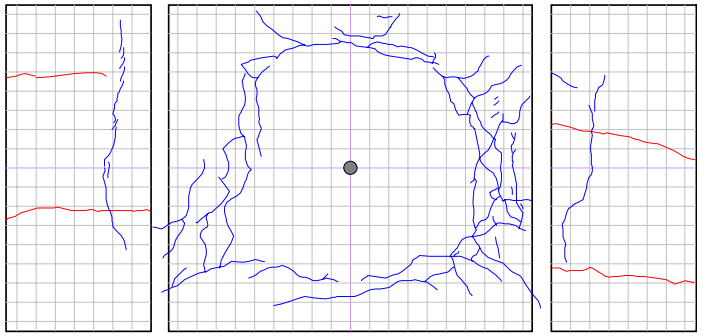
T2-D

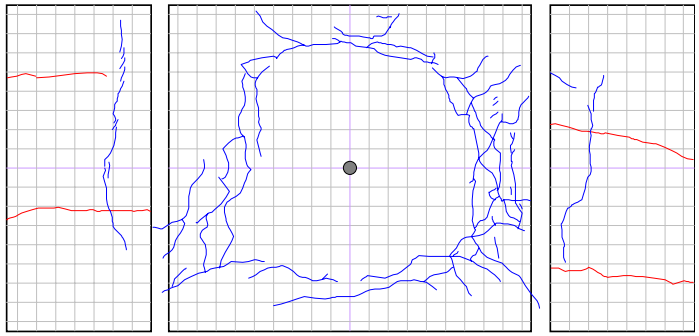
Crack Patterns at Top and Either Side

T3-A

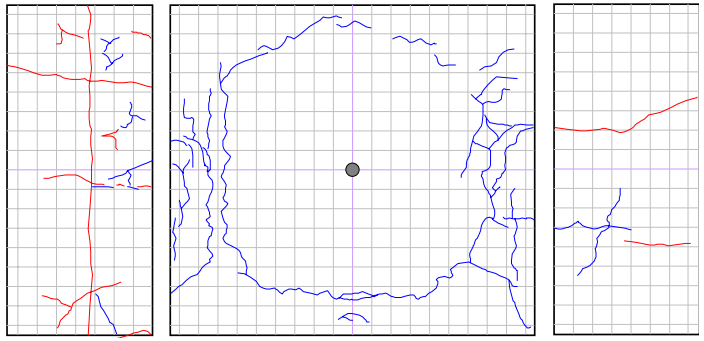


T3-B



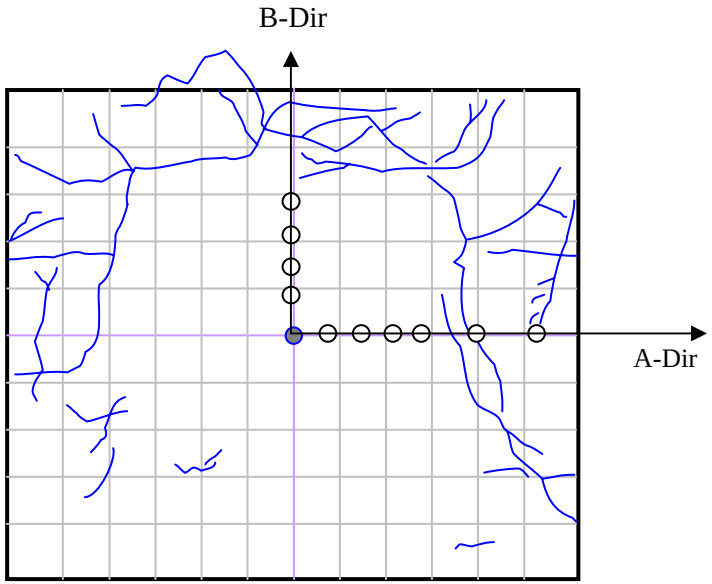


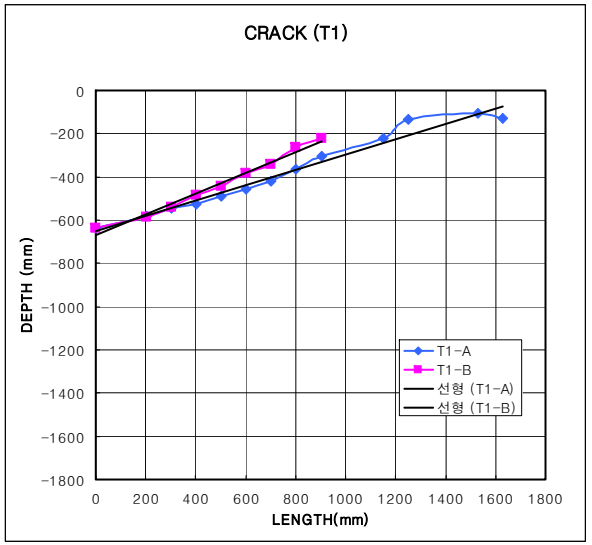
T3-C



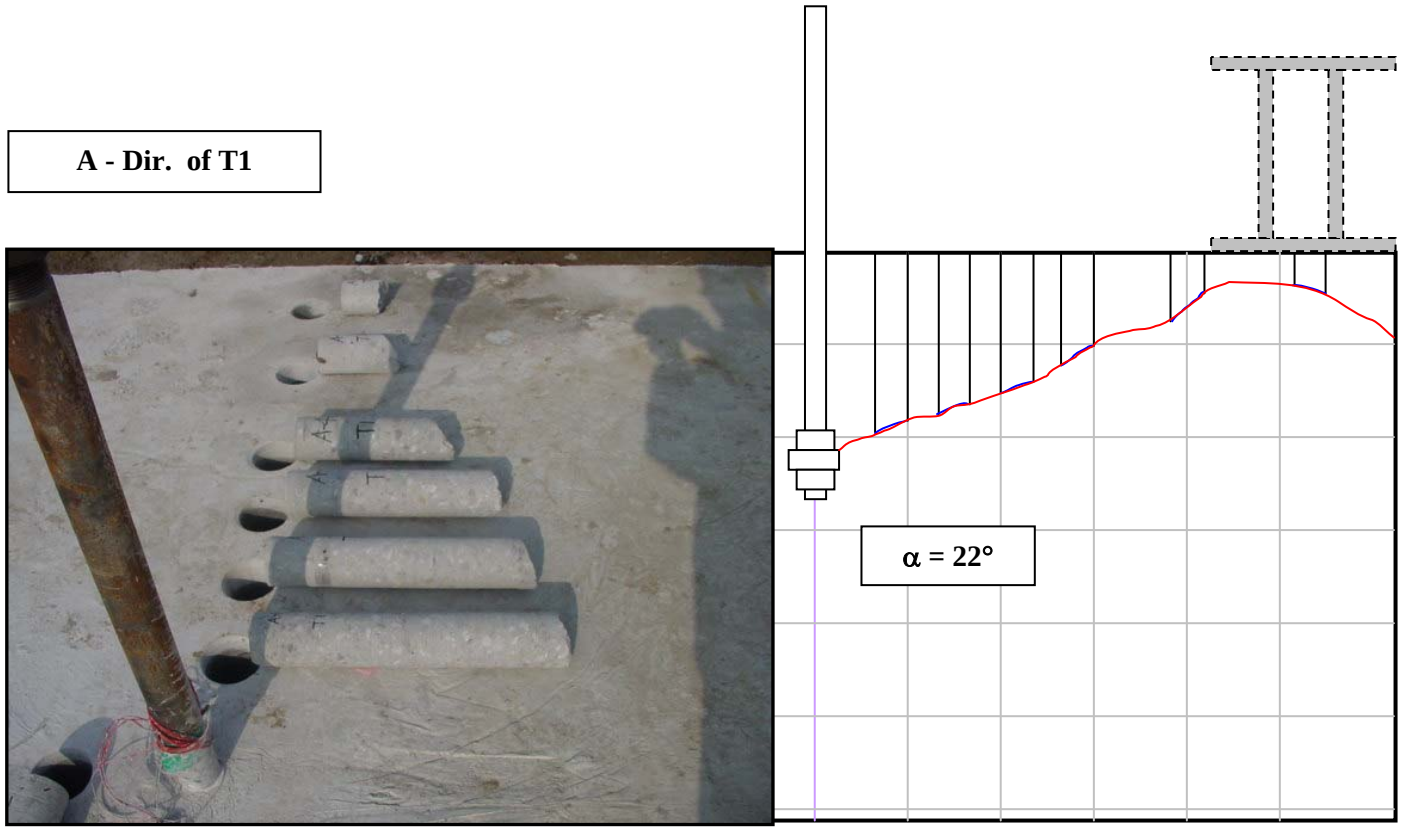
T3-D

Breakout Failure Angle in Specimen

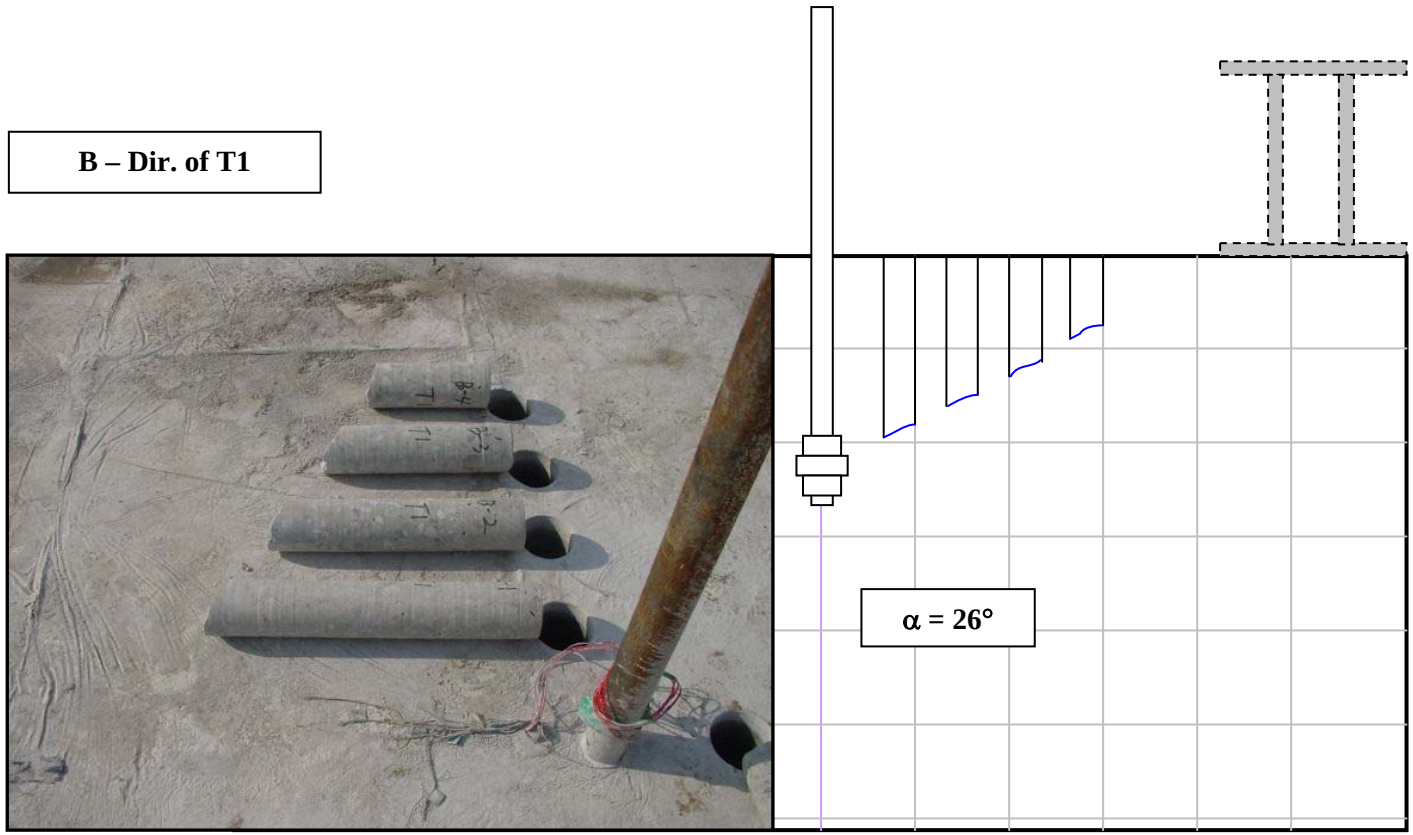




Breakout Failure Angle in Specimen



Breakout Failure Angle in Specimen



Predictions of Tensile Capacity of Test Specimens

Concrete Capacity 1.5@hef $N_n = 39\sqrt{f'_c}\, h_{ef}^{1.5}$

Concrete Capacity 1.67@hef $N_n = 26.4\sqrt{f'_c}\, h_{ef}^{1.67}$

ACI 349-old $N_n = 4\sqrt{f'_c}\, Ac$

ACI 349-new $N_n = 16\sqrt{f'_c}\, h_{ef}^{5/3}$

where,

f'_c = Concrete Compressive Strength (psi)

h_{ef} = Effective Embedment Depth (inch)

Ac = Projected Area of Stress Cones $(= \pi h_{ef}^2 (1 + d_h / h_{ef}))$

Predictions & Test Results of Tensile Capacity

		Concrete Breakout Capacities (kip) by Embedment Depths		
		25 in(T1)	35 in(T2)	45 in(T3)
Predictions (Un-reinforced)	ACI349-old	676	1305	2138
	ACI349-new	254	444	676
	CCD-1.5hef	362	599	873
	CCD-1.67hef	423	742	1129
Test (Un-rinforced)	Mean (4-samples)	509	744	1242
	COV (%)	5.8	2.8	6.1
	5% fractile	393	662	944

Ratio of Predictions & Test Results of Tensile Capacity

		Ratio of Observed to Predictions			
		25 in(T1)	35 in(T2)	45in(T3)	Mean
5% Fractile Value of Test Results	F5% /ACI349-old	0.58	0.51	0.44	0.51
	F5%/ACI349-new	1.55	1.49	1.40	1.48
	F5%/ CCD-1.5hef	1.09	1.11	1.08	1.09
	F5%/ CCD-1.67hef	0.93	0.89	0.84	0.89
Mean Value of Test Results	Mean/ACI349-old	0.75	0.57	0.58	0.63
	Mean/ACI349-new	2.01	1.67	1.84	1.84
	Mean/ CCD-1.5hef	1.41	1.24	1.42	1.36
	Mean/ CCD-1.67hef	1.20	1.00	1.10	1.10

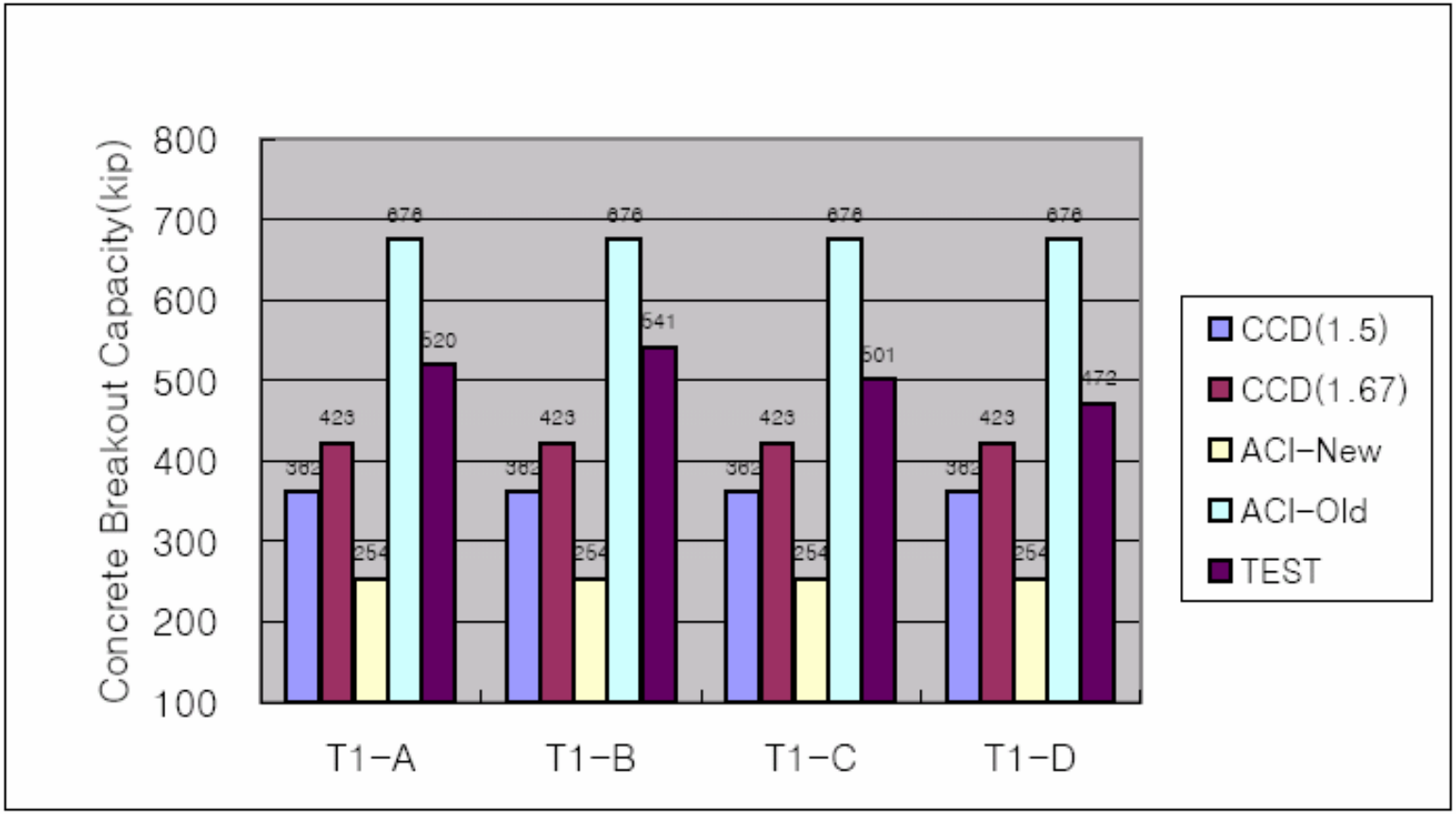
Ratio of Predictions & Reinforced Specimens Capacity

		Concrete Breakout Capacities (kip) by Reinforcing Effect		
		25 in(T4)	25 in(T5)	25in(T1)
Predictions (Un-reinforeced)	ACI349-old	676	676	676
	ACI349-new	254	254	254
	CCD-1.5hef	362	362	362
	CCD-1.67hef	423	423	423
Test (Reinforced)	Mean (4-samples)	733	725	509
	COV (%)	1.7	3.5	5.8
	5% fractile	685	625	393

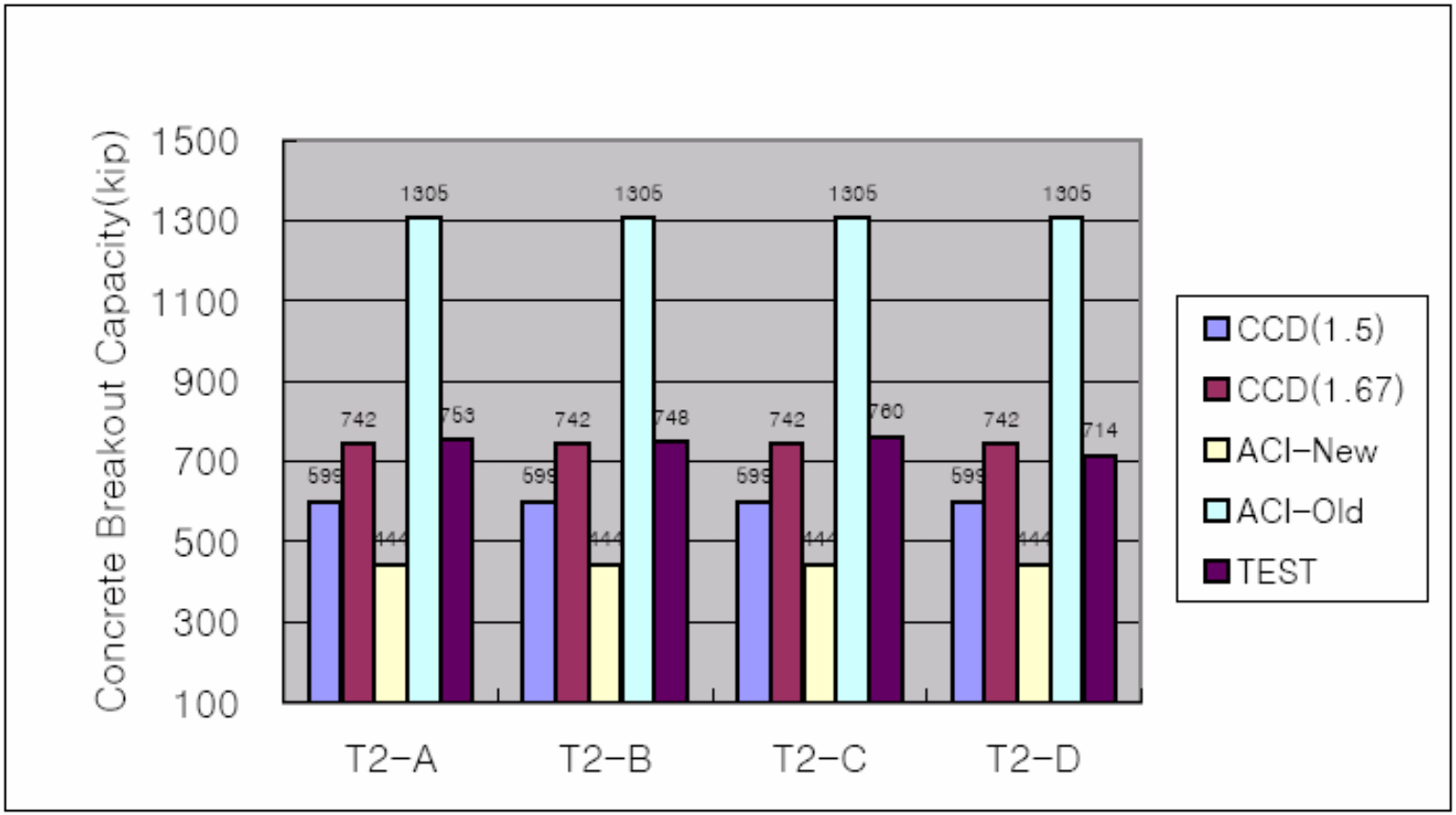
Ratio of Predictions & Reinforced Specimen Capacity

		Ratio of Observed to Predictions			Rein.-Effect
		25 in(T4)	25 in(T5)	25in(T1)	T4/T1
5% Fractile Value of Test Results	F5% /ACI349-old	1.01	1.92	0.58	1.74
	F5%/ACI349-new	2.70	2.46	1.55	
	F5%/CCD-1.5hef	1.90	1.73	1.09	
	F5%/CCD-1.67hef	1.62	1.48	0.93	
Mean Value of Test Results	Mean/ACI349-old	1.08	1.07	0.75	1.45
	Mean/ACI349-new	2.89	2.86	2.01	
	Mean/CCD-1.5hef	2.03	2.01	1.41	
	Mean/CCD-1.67hef	1.73	1.71	1.20	

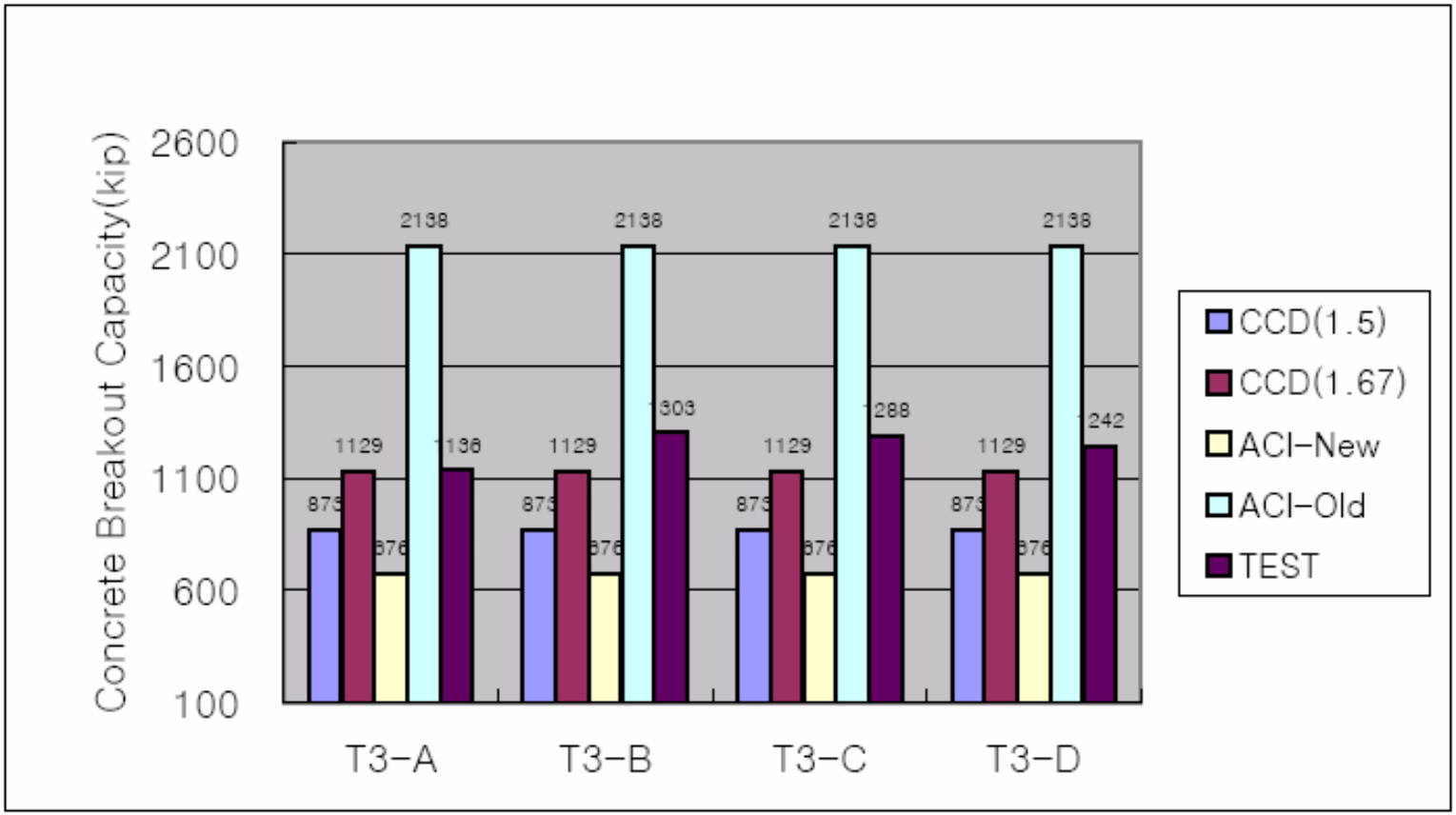
Graphical Comparison of Concrete Breakout Capacity(T1)



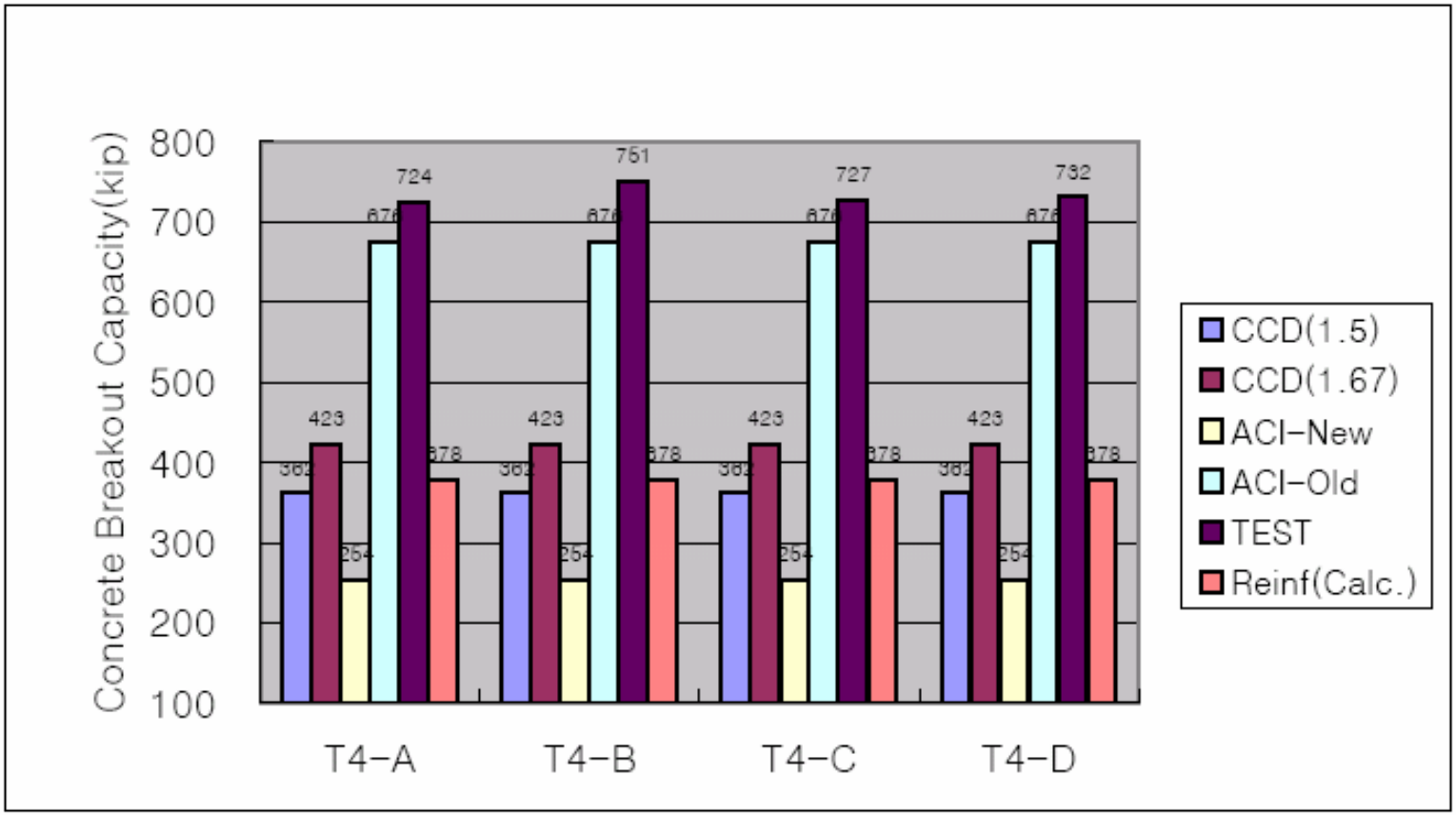
Graphical Comparison of Concrete Breakout Capacity(T2)



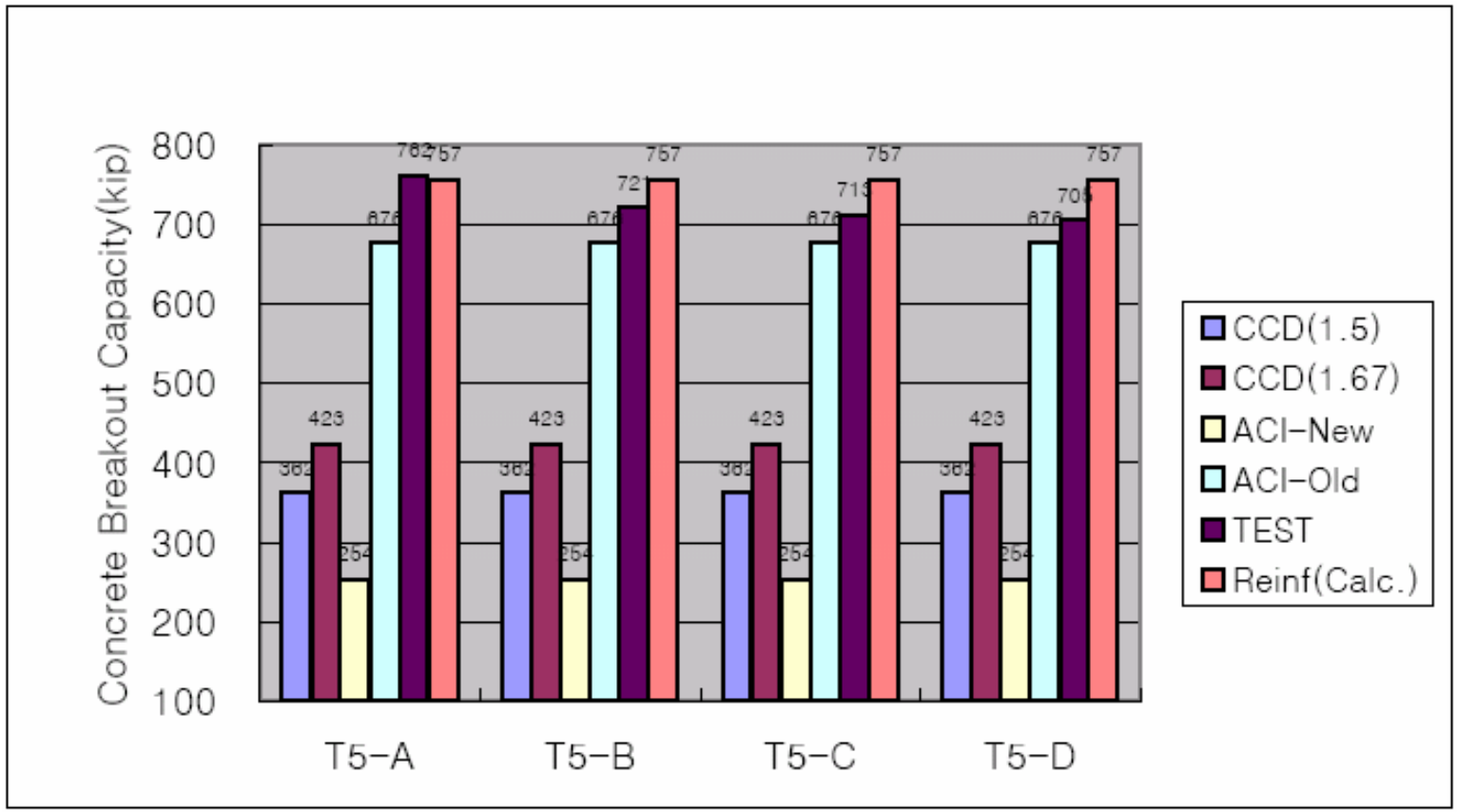
Graphical Comparison of Concrete Breakout Capacity(T3)



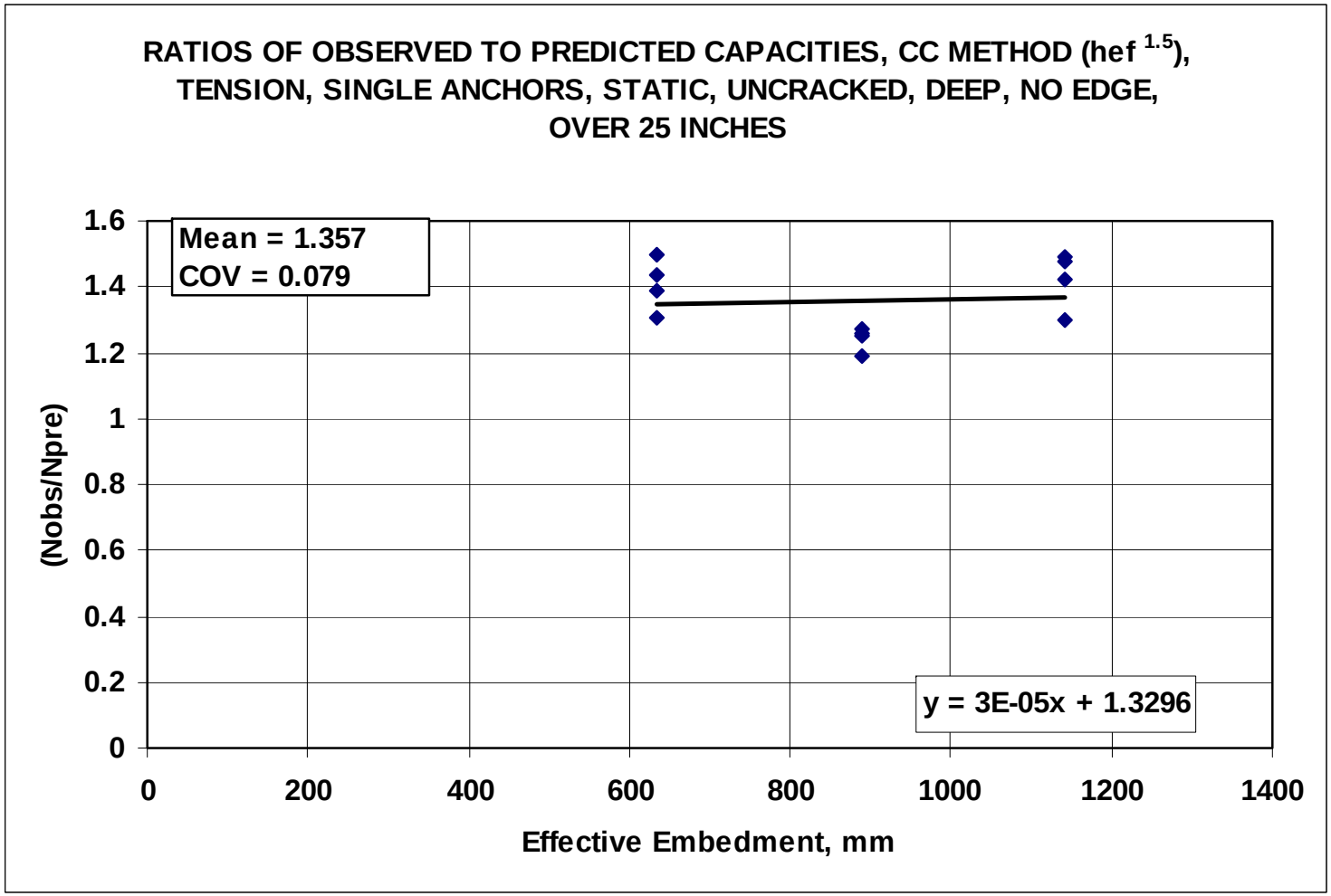
Graphical Comparison of Concrete Breakout Capacity(T4)



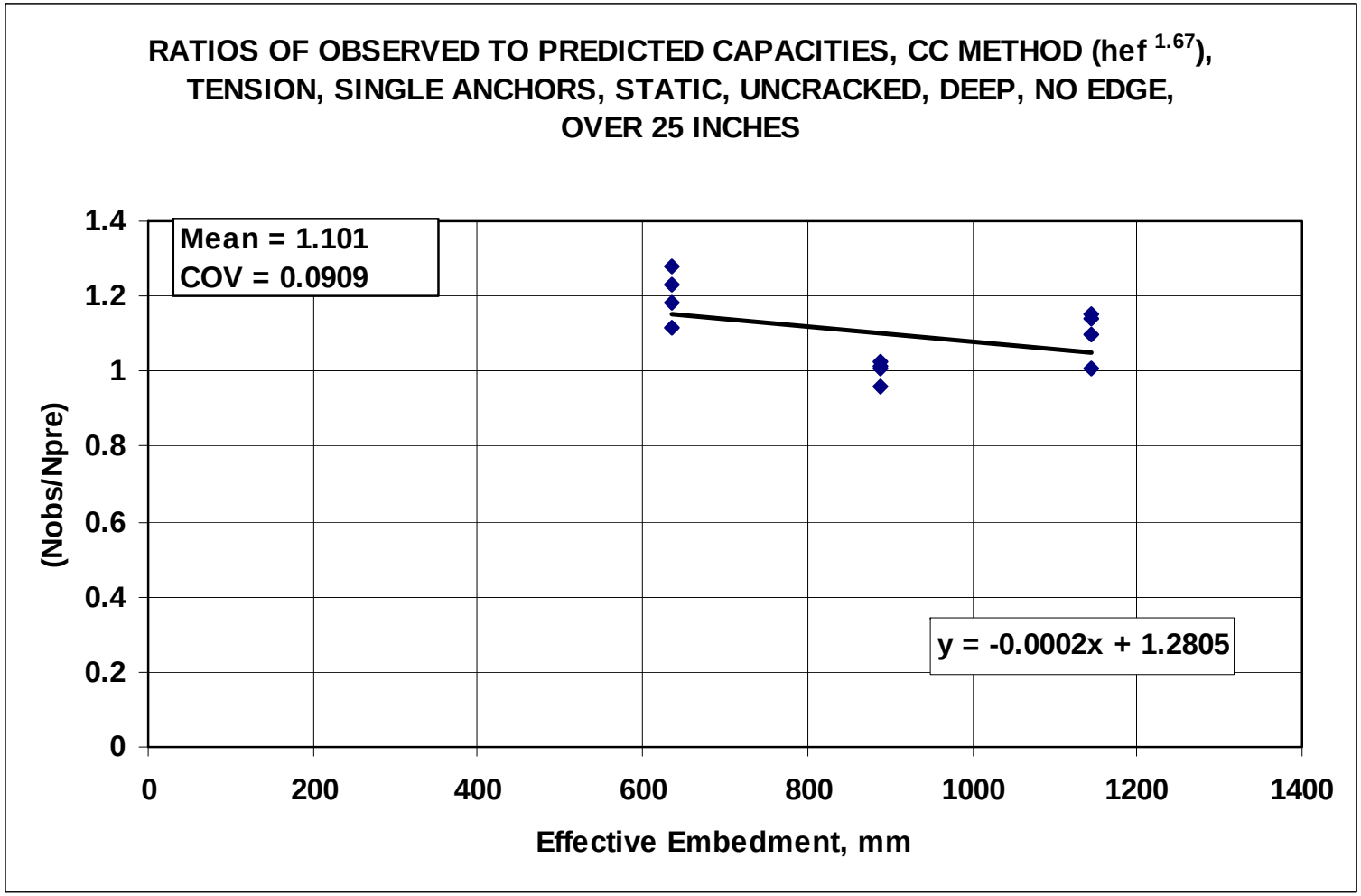
Graphical Comparison of Concrete Breakout Capacity(T5)



Ratio of Observed To Predicted Capacities



Ratio of Observed To Predicted Capacities



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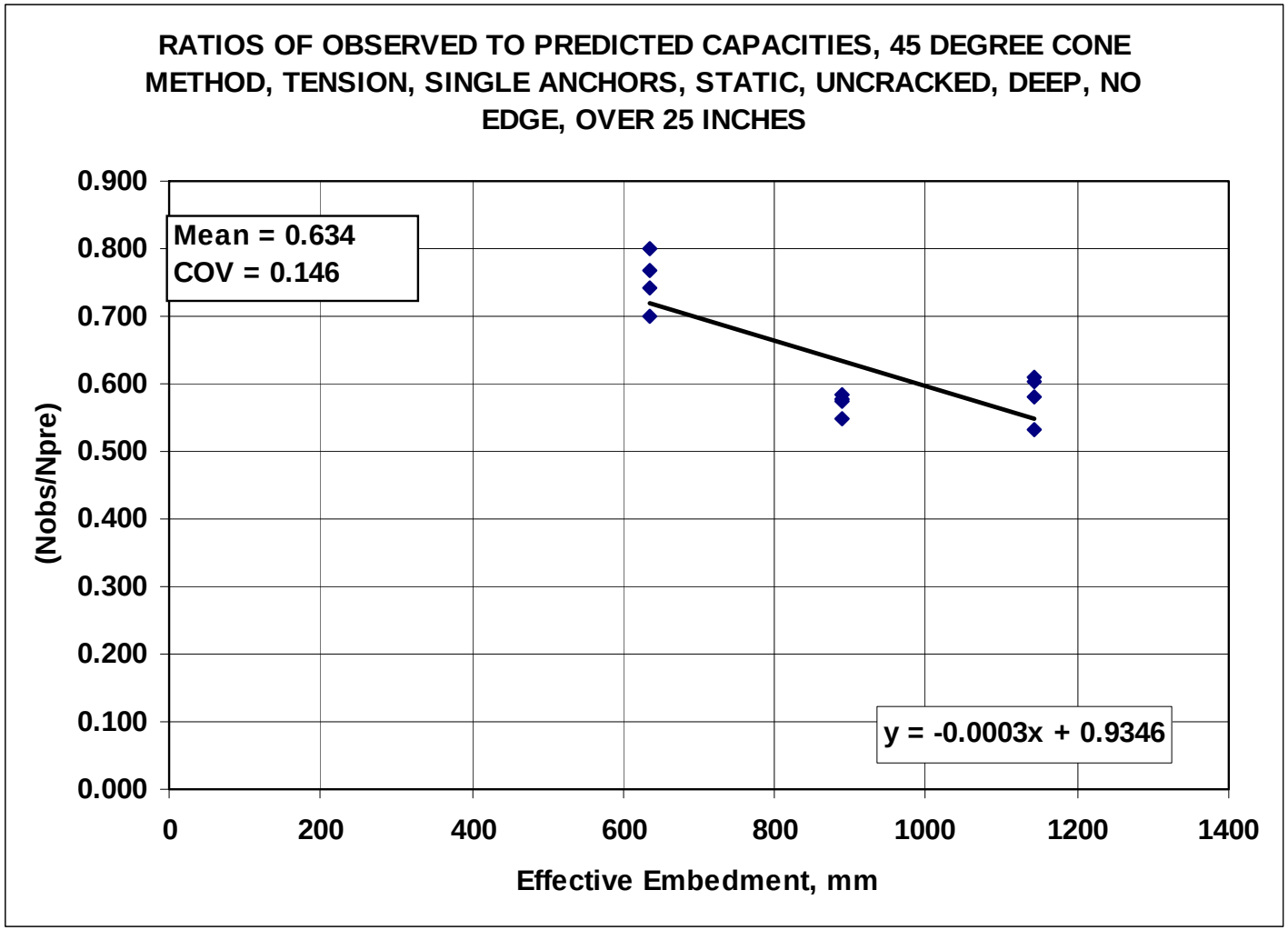
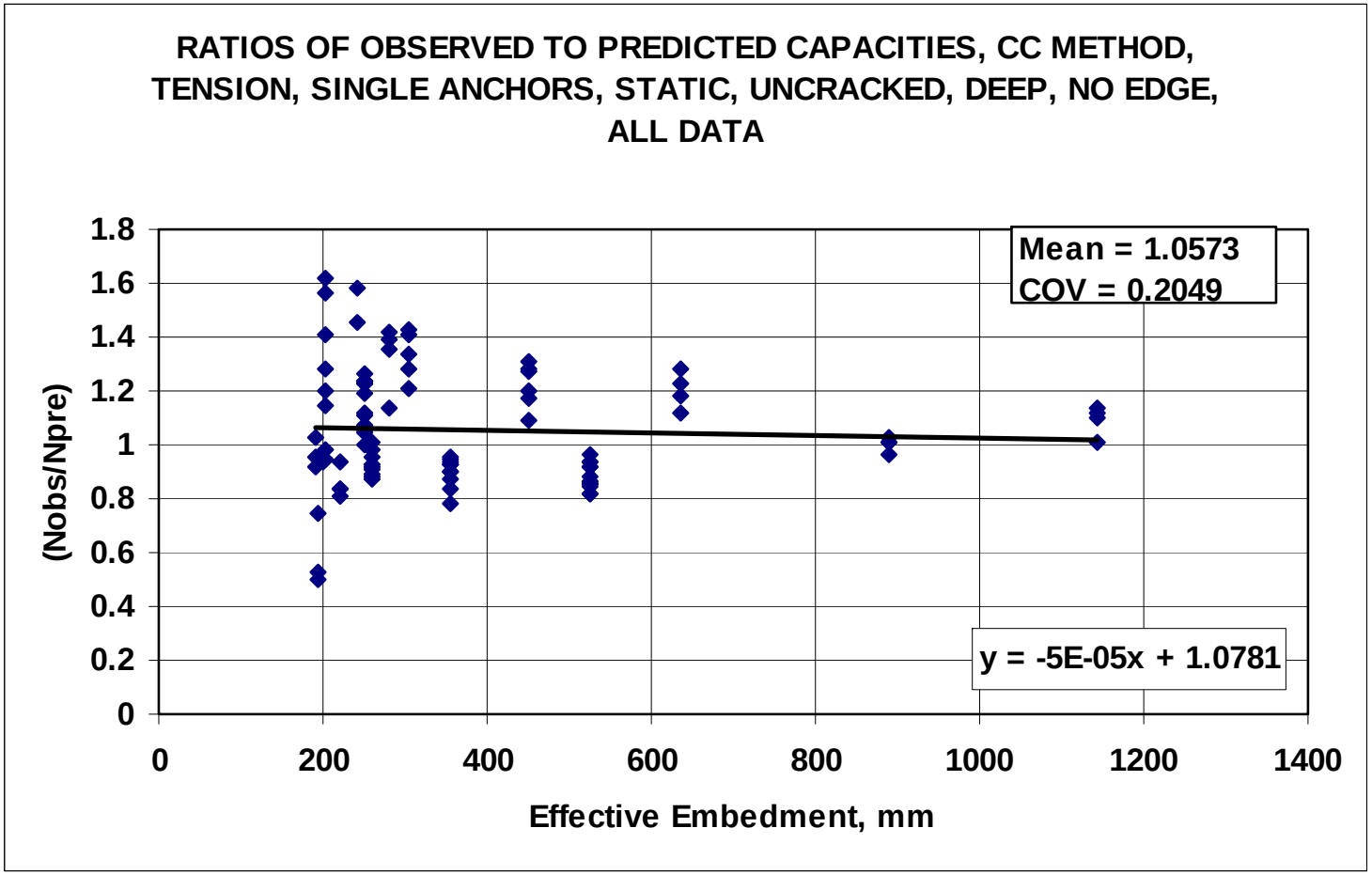
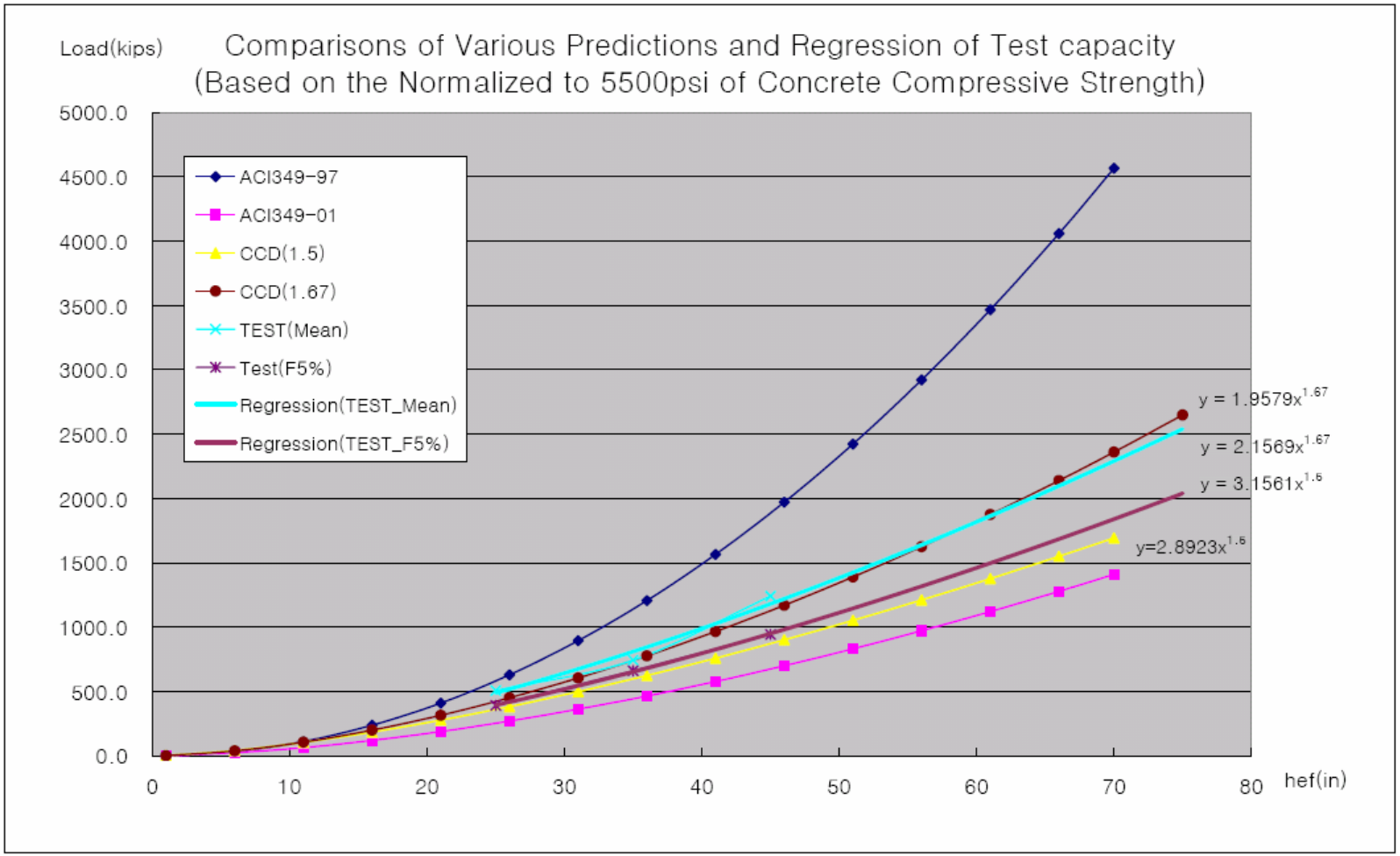
Ratio of Observed To Predicted Capacities



Ratio of Observed To Predicted Capacities

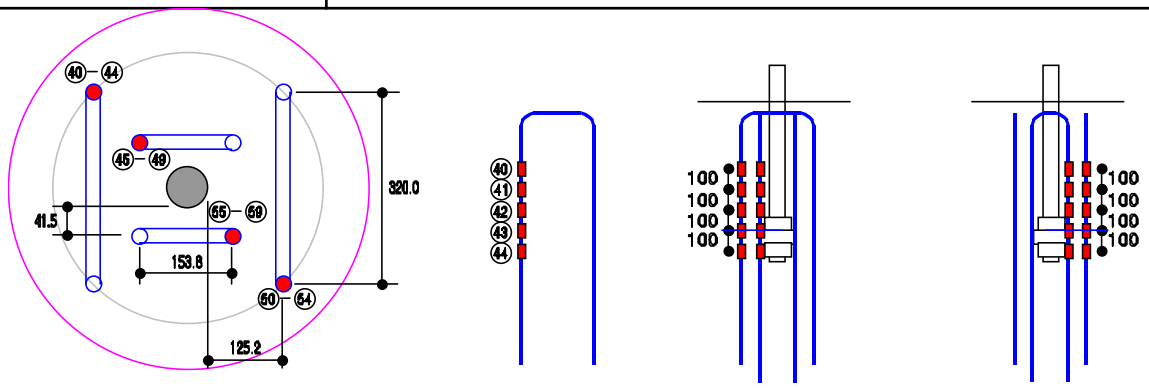


Comparison of Various Predictions & Test Capacity



Supplementary Reinforcement Effects (Typical for T4-A)

		Max. Strain ($*10^{-6}$)	Young's Modulus (E)	Rebar Area (in^2)	Calculated Force(kip)
Inner Circle (3.5 inch from anchor center)	I-1, I-4	3267.9	29000	0.79/ (1-#8)	74.9*2
	I-2, I-3	7291.5			167.0*2
	Sub-total	5279.7	-	-	484.0
Outer Circle (7.625 inch from anchor center)	O-1, O-2	2071.7	29000	0.79/ (1-#8)	47.5*2
	O-3, O-4	2691.5			61.7*2
	Sub-total		-	-	218.0
Ratio of Inner to Outer		2.2	-	-	2.2
Total		-	-	-	702.0
Ratio of Total Force in Rebar to Max. Applied Load		702 / 752 = 0.93(93%)			



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Discussion

- Mean value of test results are well corresponding to the prediction by the formula having an exponent of 1.67 at effective embedment depth
- CC design methods with an exponent of 1.67 at effective embedment depth can predict to some degree the actual capacity for the extra large sized anchors without modification
- Reinforcements close to anchor was contributed more effectively to the tensile capacity and maximum stress was almost same as the stress by the maximum load

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