CHAPTER IV

RESULTS AND DISCUSSIONS

The different theories previously described were applied to the CPT results. The predicted values of UC, FV and UU strength were computed with depth for each site.

1. <u>Computation of undrained shear strength</u>

1.1 Computation of UC strength

WIROJANAGUD method.

The only data required for this method is cone resistance. The predicted values of UC strength, $UC_{(w)}$, as computed by Eq. (2.3) were shown in Table 4.1.

SCHMERTMANN method.

Data required for this method are cone resistance and the total unit weight of soil. The predicted values of UC strength, $UC_{(s)}$, as as computed by Eq. (2.6) were shown in Table 4.2.

1.2 Computation of FV strength.

Both WIROJANAGUD and SCHMERTMANN method give the same values of the predicted FV strength ($FV_{(w)}$, $FV_{(s)}$). These methods required only the cone resistance in computation. $FV_{(w)}$ and $FV_{(s)}$ from Eq. (2.4) and Eq. (2.7) were shown in Table 4.3.

1.3 Computation of UU strength.

WIROJANAGUD method.

The predicted values of UU strength, $UU_{(w)}$, as computed by Eq. (2.5) from the cone resistance were shown in Table 4.3.

Depth (m)	q_c,(t/m^2)								$UC_{(w)}$,(t/m^2)							
	site								site							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
2–3	–	49	–	47	36	45	51	–	–	2.6	–	2.5	1.9	2.4	2.7	–
3–4	23	52	25	47	38	46	51	40	1.2	2.7	1.3	2.5	2.0	2.4	2.7	2.1
4–5	24	55	26	48	39	47	52	40	1.3	2.9	1.4	2.5	2.1	2.5	2.7	2.1
5–6	24	58	26	49	41	48	53	40	1.3	3.1	1.4	2.6	2.2	2.5	2.8	2.1
6–7	25	60	27	50	44	49	54	41	1.3	3.2	1.4	2.6	2.3	2.6	2.8	2.2
7–8	28	62	28	51	47	49	56	42	1.5	3.3	1.5	2.7	2.5	2.6	2.9	2.2
8–9	31	–	30	53	50	49	59	43	1.6	–	1.6	2.8	2.6	2.6	3.1	2.3
9–10	37	–	32	–	55	49	64	46	1.9	–	1.7	–	2.9	2.6	3.4	2.4
10–11	48	–	35	–	60	–	–	49	2.5	–	1.8	–	3.2	–	–	2.6
11–12	–	–	38	–	68	–	–	53	–	–	2.0	–	3.6	–	–	2.8

TABLE 4.1 Values Of $UC_{(w)}$ For Bangkok Clay

Depth (m)	γ_t, (t/m^3) site								$UC_{(s)}$, (t/m^2) site							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
2-3	–	1.4	–	1.4	1.5	1.5	1.5	–	–	2.5	–	2.4	1.8	2.3	2.6	–
3-4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.0	2.6	1.1	2.3	1.8	2.3	2.6	1.9
4-5	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.0	2.7	1.1	2.3	1.8	2.2	2.5	1.9
5-6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.9	2.7	1.0	2.2	1.8	2.2	2.5	1.7
6-7	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.6	0.8	2.8	0.9	2.2	1.8	2.2	2.4	1.7
7-8	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.6	0.9	2.8	0.9	2.2	2.0	2.1	2.5	1.7
8-9	1.6	–	1.6	1.6	1.6	1.6	1.6	1.6	1.0	–	0.9	2.2	2.0	2.0	2.5	1.6
9-10	1.6	–	1.6	–	1.7	1.7	1.7	1.7	1.2	–	0.9	–	2.2	1.9	2.7	1.7
10-11	1.6	–	1.6	–	1.7	–	–	1.7	1.7	–	1.0	–	2.3	–	–	1.7
11-12	–	–	1.6	–	1.7	–	–	1.7	–	–	1.0	–	2.7	–	–	1.9

TABLE 4.2 Values Of $UC_{(s)}$ For Bangkok Clay

Depth (m)	$FV_{(w)}$, $FV_{(s)}$, (t/m^2)								$UU_{(w)}$, (t/m^2)							
	site								site							
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
2–3	–	3.1	–	2.9	2.3	2.8	3.2	–	–	2.9	–	2.8	2.1	2.6	3.0	–
3–4	1.4	3.3	1.6	2.9	2.4	2.9	3.2	2.5	1.4	3.1	1.5	2.8	2.2	2.7	3.0	2.4
4–5	1.5	3.4	1.6	3.0	2.4	2.9	3.3	2.5	1.4	3.2	1.5	2.8	2.3	2.8	3.1	2.4
5–6	1.5	3.6	1.6	3.1	2.6	3.0	3.3	2.5	1.4	3.4	1.5	2.9	2.4	2.8	3.1	2.4
6–7	1.6	3.8	1.7	3.1	2.8	3.1	3.4	2.6	1.5	3.5	1.6	2.9	2.6	2.9	3.2	2.4
7–8	1.8	3.9	1.8	3.2	2.9	3.1	3.5	2.6	1.6	3.6	1.6	3.0	2.8	2.9	3.3	2.5
8–9	1.9	–	1.9	3.3	3.1	3.1	3.7	2.7	1.8	–	1.8	3.1	2.9	2.9	3.5	2.5
9–10	2.3	–	2.0	–	3.4	3.1	4.0	2.9	2.2	–	1.9	–	3.2	2.9	3.8	2.7
10–11	3.0	–	2.2	–	3.8	–	–	3.1	2.8	–	2.1	–	3.5	–	–	2.9
11–12	–	–	2.4	–	4.3	–	–	3.3	–	–	2.2	–	4.0	–	–	3.1

TABLE 4.3 Values Of $FV_{(w)}$, $FV_{(s)}$ And $UU_{(w)}$ For Bangkok Clay

SCHMERTMANN method.

The predicted values of UU strength, $UU_{(s)}$, as computed by Eq. (2.8) from the cone resistance and total soil unit weight were shown in Table 4.4.

2. Comparison of the predicted and the measured undrained shear strength.

Rather than showing in detail the comparison of all types of undrained shear strength for each method at every site, DONMUANG site is used as an example. However, the results from every site will be compared and indicated later.

DONMUANG site

Details of the subsoil conditions were obtained from 293 shallow borings of 12 m. depth and 8 deep borings of 30 m. depth. This is also confirmed by CPT of 144 bore holes.

The results of the subsoil conditions and CPT were selected from 60 bore holes and 39 locations of CPT, where the soft to very soft clay layers are uniform.

Since the UC and FV strength were obtained from samples taken at the depth of 4.8, 7.8 and 10.8 m., then the CPT will be considered at the same depth. At each depth, a representative value of q_c (average q_c) was determined with the standard deviation as shown in Table 4.5. The test results were plotted with depth as shown in Fig. 4.1.

2.1 Comparison of UC strength.

The predicted values of UC strength and the laboratory test results were shown in Table 4.6.

Depth (m)	UU(s), (t/m²) site							
	A	B	C	D	E	F	G	H
2-3	–	2.8	–	2.7	2.0	2.6	3.0	–
3-4	1.1	2.9	1.3	2.6	2.1	2.6	3.0	2.2
4-5	1.1	3.0	1.2	2.6	2.0	2.5	2.9	2.1
5-6	1.0	3.1	1.1	2.6	2.1	2.5	2.8	2.0
6-7	1.0	3.1	1.1	2.5	2.1	2.5	2.8	2.0
7-8	1.1	3.2	1.1	2.6	2.3	2.4	2.9	2.1
8-9	1.1	–	1.1	2.5	2.3	2.2	2.9	1.9
9-10	1.4	–	1.1	–	2.5	2.1	3.1	1.9
10-11	1.9	–	1.1	–	2.7	–	–	2.0
11-12	–	–	1.2	–	3.0	–	–	2.1

TABLE 4.4 Values Of $UU_{(s)}$ For Bangkok Clay

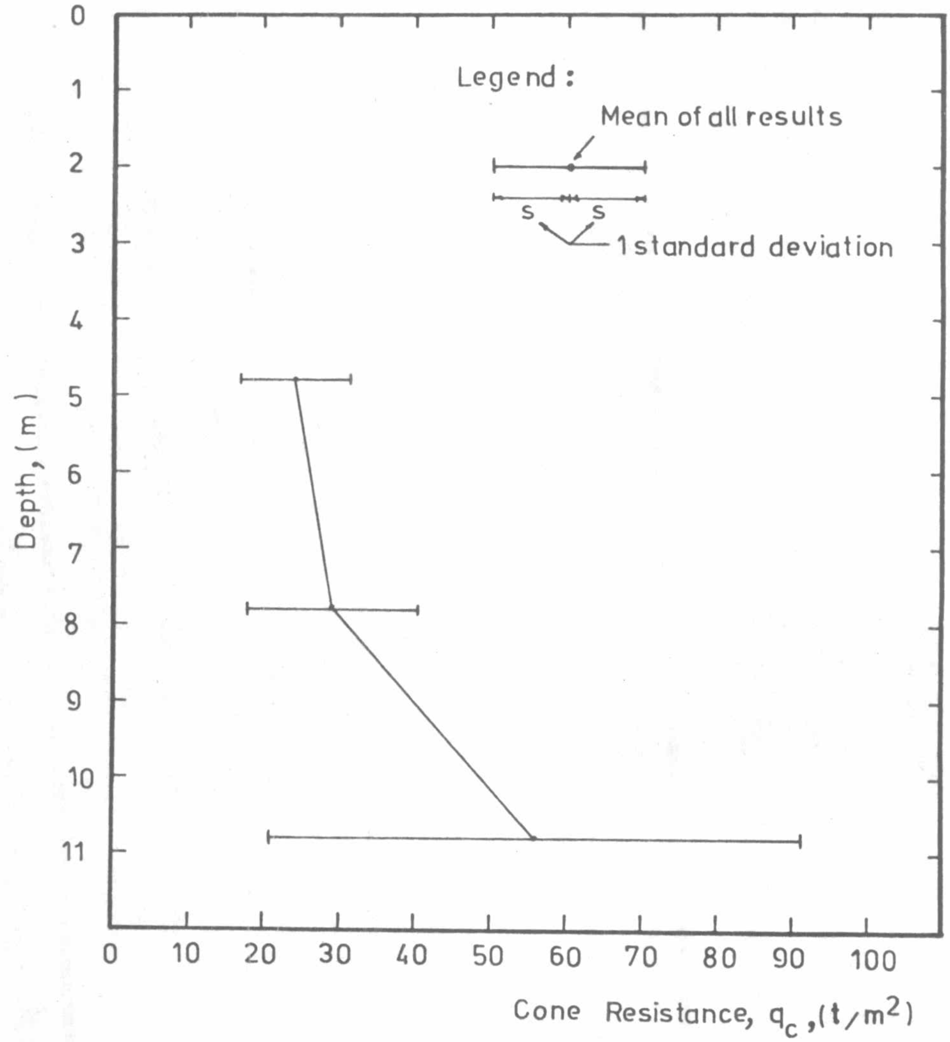

FIG 4.1 q_c V.S Depth (DONMUANG Site)

Depth (m)	q_c Average (t/m2)	Standard deviation	No. of tests	γ_t Average (t/m3)	standard deviation	L L %	P L %
4.8	24	7	39	1.56	0.11	60-95	20-35
7.8	29	11	33	1.54	0.20		
10.8	56	35	14	1.62	0.20		

TABLE 4.5 Test Results At DONMUANG Site

Depth (m)	Laboratory Tests, UC, (t/m^2)			$UC_{(w)}$, (t/m^2)			$UC_{(s)}$, (t/m^2)		
	Lower	Average	Upper	Lower	Average	Upper	Lower	Average	Upper
4.8	0.2	1.0	1.8	0.9	1.3	1.7	0.5	0.9	1.3
7.8	0.2	1.0	1.8	0.9	1.5	2.1	0.4	1.0	1.6
10.8	0.5	1.8	3.1	1.1	3.0	4.9	0.2	2.2	4.1

TABLE 4.6 Comparison Of The Predicted UC Strength And The Measured UC Strength

(DONMUANG Site)

It can be observed that $UC_{(w)} > UC_{(s)} >$ UC strength. At each depth, there was the variation of both the predicted and the measured UC strength. Especially the results from the lower depth, i.e., 10.8 m. depth, $UC_{(w)}$ varied from 1.1 to 4.9 t/m^2, $UC_{(s)}$, from 0.2 to 4.1 t/m^2 and UC varied from 0.5 to 3.1 t/m^2.

Although the results were obtained from samples taken at the same depth where the clay layers are uniform but there was still large variation of every UC strength. In order to reduce this variation the consistency limit approach is used, prior to find the error between the average predicted and the average measured UC strength.

Consistency limit approach

The consistency limit approach was the result from the study of many UC strength and their consistency limits. It was found that UC strength of soft to very soft clay showed some relation with the ratio of natural water content (w) to liquid limit (LL). Each value of w/LL has an unique value of all UC strength with a little variation. These were shown in Table 4.7. For UC strength, the highest variation (at the depth of 10.8 m. and w/LL = 0.7) is 0.9 t/m^2., the average variation for every depth and every w/LL is 0.4 t/m^2. and the lowest variation is 0.2 t/m^2. For $UC_{(w)}$ strength, the highest variation is 1.6 t/m^2., the average variation is 0.4 t/m^2. and the lowest variation is zero. And for $UC_{(s)}$ strength, the highest variation is 1.7 t/m^2., the average variation 0.4 t/m^2. and the lowest variation is zero.

When all types of UC strength were compared, it is found that, the average $UC_{(w)}$ and $UC_{(s)}$ differ from the average UC strength with

Depth (m)	w/LL	q_c (t/m^2)	UC, (t/m^2)			$UC_{(w)}$, (t/m^2)			$UC_{(s)}$, (t/m^2)		
			Lower	Average	Upper	Lower	Average	Upper	Lower	Average	Upper
4.8	1.0	20±0	0.2	0.4	0.6	1.1	1.1	1.1	0.7	0.7	0.7
	0.9	20±3	0.3	0.5	0.7	1.0	1.1	1.2	0.5	0.7	0.9
	0.8	23±4	0.7	1.1	1.5	1.0	1.2	1.4	0.7	0.9	1.1
	0.7	23±6	1.1	1.5	1.9	0.9	1.2	1.5	0.5	0.9	1.3
7.8	1.0	20±0	0.2	0.4	0.6	1.1	1.1	1.1	0.4	0.4	0.4
	0.9	20±0	0.3	0.5	0.7	1.1	1.1	1.1	0.4	0.4	0.4
	0.8	27±9	0.5	0.9	1.3	0.9	1.4	1.9	0.3	0.8	1.3
	0.7	30±10	1.4	1.6	1.8	1.1	1.6	2.1	0.5	1.0	1.5
10.8	0.9	33±11	0.5	0.7	0.9	1.1	1.7	2.3	0.3	0.9	1.5
	0.8	43±15	0.6	1.3	2.0	1.5	2.3	3.1	0.5	1.4	2.3
	0.7	61±30	1.9	2.5	3.1	1.6	3.2	4.8	0.7	2.4	4.1

TABLE 4.7 Comparison Of The Predicted UC Strength And The Measured UC Strength At Each Value Of w/LL (DONMUANG Site)

the maximum error of 67 and 22 %, respectively (with the average error of 37 and 11 %, respectively).

To find the relation between the predicted and the measured UC strength at each value of w/LL, data from Table 4.7 were put in the calculator program of HP 67 type using curve fitting program (The details of curve fitting were shown in the Appendix). The relation were,

$$UC_{(aw)} = UC_{(w)} \times 0.4 \left[\frac{1}{w/LL}\right]^{2.5} = \frac{q_c}{19} \times 0.4 \left[\frac{1}{w/LL}\right]^{2.5}$$

$$= 0.02\ q_c \left[\frac{1}{w/LL}\right]^{2.5} \qquad (4.1)$$

and

$$UC_{(as)} = UC_{(s)} \times 0.8 \left[\frac{1}{w/LL}\right]^{1.5} = \frac{q_c - \gamma_t Z}{18} \times 0.8 \left[\frac{1}{w/LL}\right]^{1.5}$$

$$= 0.04\ (q_c - \gamma_t Z) \left[\frac{1}{w/LL}\right]^{1.5} \qquad (4.2)$$

in which

$UC_{(aw)}$ = adjusted value of $UC_{(w)}$ to UC strength.

$UC_{(as)}$ = adjusted value of $UC_{(s)}$ to UC strength.

γ_t = total unit weight of soil.

The average $UC_{(aw)}$ and $UC_{(as)}$ were computed using Eq. (4.1) and Eq. (4.2). They were compared with the average UC strength at each value w/LL as shown in Table 4.8. $UC_{(aw)}$ and $UC_{(as)}$ differ from UC strength with the maximum error of 20 %.

Depth (m) Z	w/LL	q_c (t/m^2)	UC (t/m^2)	$UC_{(aw)}$ (t/m^2)	$UC_{(as)}$ (t/m^2)
4.8	1.0	20	0.4	0.4	0.4
	0.9	20	0.5	0.5	0.6
	0.8	23	1.1	0.8	0.9
	0.7	23	1.5	1.1	1.4
7.8	1.0	20	0.4	0.4	0.3
	0.9	20	0.5	0.5	0.5
	0.8	27	0.9	0.9	0.9
	0.7	30	1.6	1.5	1.4
10.8	0.9	33	0.7	0.9	0.8
	0.8	43	1.3	1.5	1.3
	0.7	61	2.5	3.0	3.0

TABLE 4.8 Comparison Of The Average $UC_{(aw)}$, $UC_{(as)}$ And UC Strength (DONMUANG Site)

with the average error of 12 and 11 %, respectively.

2.2 Comparison of FV strength.

Both $FV_{(w)}$ and $FV_{(s)}$ were computed with the measured FV strength in Table 4.9. FV strength increases with depth. At each depth, FV strength varies with the highest variation of 0.4 t/m^2. and the lowest variation of 0.3 t/m^2. $FV_{(w)}$ and $FV_{(s)}$ also increase with depth. The average $FV_{(w)}$ and $FV_{(s)}$ differ from the average FV strength with the maximum error of 32 %, which is quite large, and the average error of 22 %. Data from Table 4.9 were put in the calculator program of HP 67 type. The relation of the predicted and the measured FV strength was,

$$FV_{(a)} = 1.5 + 0.5\, FV_{(w)} = 1.5 + 0.5\,\frac{q_c}{16}$$

$$= 1.5 + 0.03\, q_c \qquad \text{(4.3)}$$

in which,

$FV_{(a)}$ = adjusted value of $FV_{(w)}$ or $FV_{(s)}$ to FV strength.

$FV_{(a)}$ were computed using Eq. (4.3). They were compared with the average FV strength as shown in Table 4.9. $FV_{(a)}$ differs from the average FV strength with the maximum error of 8 % and the average error of 5 %.

2.3 Comparison of UU strength.

The results of UU laboratory tests concerned in this study were

Depth (m)	$FV, (t/m^2)$			No Of Tests	$FV_{(w)}, FV_{(s)}, (t/m^2)$			$FV_{(a)}$ (t/m^2)
	Lower	Average	Upper		Lower	Average	Upper	
4.8	1.9	2.2	2.5	48	1.1	1.5	1.9	2.3
7.8	2.0	2.4	2.8	48	1.1	1.8	2.5	2.2
10.8	2.8	3.2	3.6	48	1.3	3.5	5.7	3.3

TABLE 4.9 Comparison Of The Predicted And Measured FV Strength (DONMUANG Site)

selected from the saturated samples (29 samples) from the depth of 3.3, 6.3 and 9.3 m.

The average q_c and the standard deviation at the corresponding depth were determined and they were shown in Fig. 4.2. The test results were shown in Table 4.10. Comparison of the predicted and the measured UU strength were shown in Table 4.11.

It can be observed that the average UU strength is constant for every depth and at each depth, UU strength varies with the highest variation of 0.5 t/m^2. and the lowest variation of 0.4 t/m^2. $UU_{(w)}$ strength increases with depth and at each depth, $UU_{(w)}$ strength varies with the highest variation of 0.7 t/m^2., the average variation of 0.5 t/m^2. and the lowest variation of 0.3 t/m^2. $UU_{(s)}$ strength is constant for every depth and each depth, $UU_{(s)}$ strength varies with the highest variation of 0.7 t/m^2., the average variation of 0.5 t/m^2. and the lowest variation of 0.4 t/m^2.

The average $UU_{(w)}$ strength differs from the average UU strength with the maximum error of 58 % (which is quite large) and the average error of 28 %. The average $UU_{(s)}$ strength differs from the average UU strength with the maximum and the average error of 18 and 14 % respectively which is good enough. The $UU_{(w)}$ strength has to be adjusted in order bring its value close to UU strength. Effect of the depth has to be considered. Both UU and $UU_{(w)}$ strength at every depth from Table 4.11 were put in the calculator program of HP 67 type to find the equation for curve fitting and found to be

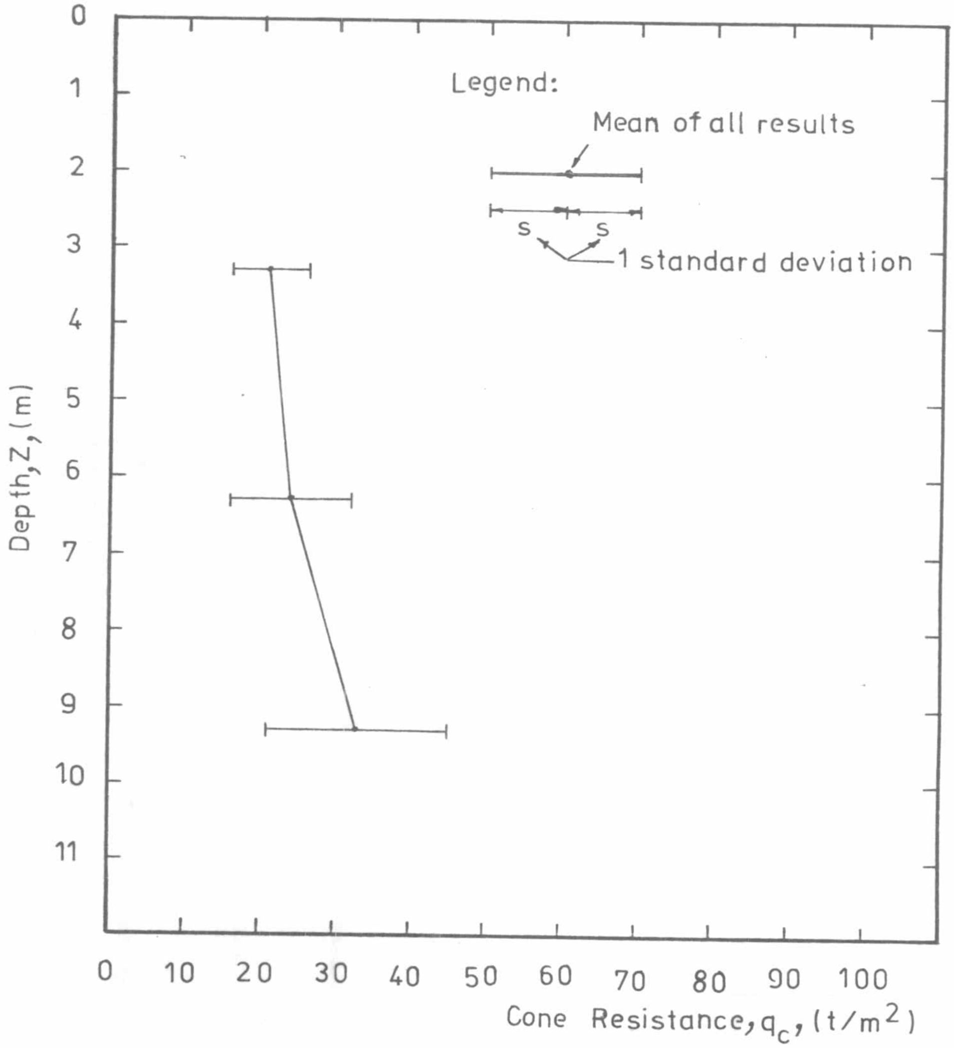

FIG 4.2 q_c V.S Depth (DONMUANG Site)

Depth (m)	q_c Average (t/m^2)	Standard deviation	No. of tests	γ_t Average (t/m^3)	Standard deviation
3.3	21	5	19	1.54	0.10
6.3	24	8	23	1.52	0.10
9.3	33	12	16	1.65	0.20

TABLE 4.10 Test Results At DONMUANG Site

Depth (m)	Laboratory Tests, UU, (t/m^2)			$UU_{(w)}$, (t/m^2)			$UU_{(s)}$, (t/m^2)			$UU_{(aw)}$ (t/m^2)
	Lower	Average	Upper	Lower	Average	Upper	Lower	Average	Upper	
3.3	0.7	1.2	1.7	0.9	1.2	1.5	0.7	1.0	1.3	1.1
6.3	0.6	1.1	1.6	0.9	1.4	1.9	0.4	0.9	1.4	1.1
9.3	0.8	1.2	1.6	1.2	1.9	2.6	0.4	1.1	1.8	1.3

TABLE 4.11 Comparison Of The Predicted UU Strength And The Measured UU Strength (DONMUANG Site)

$$UU_{(aw)} = 1.1\ (UU_{(w)})^{0.1} = 1.1 \times (\frac{q_c}{17})^{0.1}$$

$$= 0.83\ (q_c)^{0.1} \qquad (4.4)$$

in which,

$UU_{(aw)}$ = adjusted value of $UU_{(w)}$ to UU strength

$UU_{(aw)}$ were computed using Eq. (4.4) and they were shown in Table 4.11. $UU_{(aw)}$ differs from UU strength with the maximum and the average error of 8 and 6 % respectively.

When all types of the measured undrained shear strength were compared, it is found that the variation at each depth (from the lower, average and upper values) of the unconfined compression test is greater than the field vane test and the unconsolidated undrained test, because the effect of sample disturbance of UC test is greater than the other tests. For FV test, there is a little sample disturbance because the test is performed in the field and for UU test, the effect of confining pressure can minimize the effect of sample disturbance.

When the average values of the predicted and the measured undrained shear strength were compared, the error of UC > FV > UU strength. This is true for WIROJANAGUD method, because the effect of surcharge is not considered.

Other sites

The measured test results were recorded. The predicted undrained shear strengths for every site were analyzed in the same manner. They were shown in Fig 4.3 in comparison.

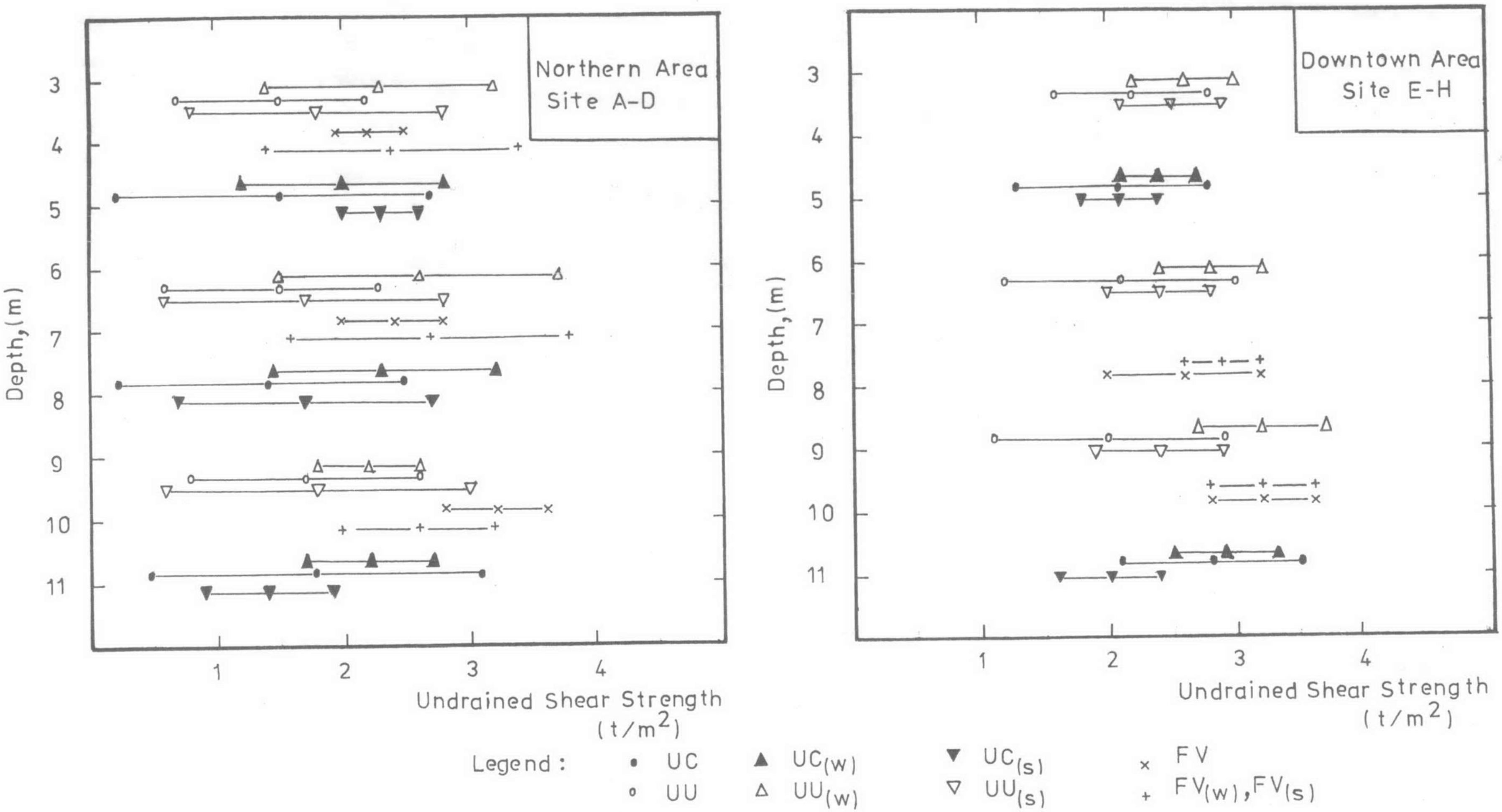

FIG 4.3 Comparison Of Undrained Shear Strength On Bangkok Clay