# EMPIRICAL RELATIONSHIPS OF CPTu RESULTS AND UNDRAINED SHEAR STRENGTH

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# ABSTRACT

Cone penetration testing (CPTu) and pore pressure measurement have long been used to estimate the undrained shear strength ( $S_u$ ) of clay, although the evaluation of strength from CPTu results in fine-grained soil is mostly empirical. In fact, for various reasons, in-situ methods such as CPTu and laboratory methods may give different results for  $S_u$  for a specific soil. The present study correlated the results of 22 CPTu and 50 uniaxial compression tests conducted on quaternary alluvial clay from southern Iran. Empirical relationships with acceptable coefficients of correlation between  $S_u$  and CPT parameters were obtained and values of the empirical cone factors  $N_k$ ,  $N_{kt}$ ,  $N_{ke}$ , and  $N_{\Delta u}$  are proposed for these clays. A comparison of these values with values proposed in previous studies suggests that the cone factors depend on the type of the reference test used. Although the plasticity and consistency index also affect cone factors, it was not possible to determine an acceptable empirical relationships for these parameters.

Key words: CPTu, undrained shear strength, empirical cone factors.

# 1. INTRODUCTION

The undrained shear strength ( $S_u$ ) of soil is a widely used design parameter in engineering; however, the value obtained depends on the testing apparatus and procedure used (Myftaraga and Koreta 2013) as well as the direction of loading, boundary conditions, stress level, sample disturbance, testing method (failure mode), strain rate, stress path and other factors (Bond 2011; Mayne *et al.* 2009). Uniaxial, triaxial and direct shear tests on undisturbed samples are routine laboratory tests for the determination of  $S_u$ , whereas the field vane shear test is an in-situ test method favored by many.

The increasing use of the CPTu in ground investigations because of its increased reliability, high speed, cost effectiveness, continuous soil profile make it a valuable tool in characterizing subsurface conditions and in assessing soil properties. This has resulted in the need for methods to determine the value of  $S_u$  from the test results. Theoretical correlations based upon bearing capacity theory (Terzaghi 1943; de Beer 1977), cavity expansion (Skempton 1951; Vesic 1975), analytical and numerical methods (Ladanyi 1967) and strain path methods (Teh 1987) have been proposed, but because they require the use of many assumptions, they offer no advantage over empirical methods. Empirical methods allow determination of  $S_u$  using total cone resistance (Eqs. (1) and (2)), effective cone resistance (Eq. (3)) and pore water pressure (Eq. (4)) (Lunne *et al.* 1997) as follows:

$$S_{\mu} = (q_c - \sigma_v) / N_k \tag{1}$$

$$S_{\mu} = (q_t - \sigma_v) / N_{kt} \tag{2}$$

$$S_u = (q_E / N_{ke}) = (q_t - u_2) / N_{ke}$$
(3)

$$S_{u} = (\Delta u / N_{\Delta u}) = (u_2 - u_0) / N_{\Delta u}$$

$$\tag{4}$$

where  $q_c$  is cone resistance,  $q_t$  is corrected cone resistance,  $q_E$  is effective cone resistance,  $u_2$  is pore pressure measured immediately behind the cone tip,  $u_0$  is hydrostatic pore water pressure,  $\sigma_v$  is total vertical overburden stress and  $N_k$ ,  $N_{kt}$ ,  $N_{ke}$ , and  $N_{\Delta u}$  are empirical cone factors that depend on the geological conditions and type of reference test used. Table 1 summarizes the values proposed by different researchers for these empirical cone factors. In addition, Karlsrud *et al.* (1997) has proposed a method for determining  $S_u$  by averaging the results from different methods, as shown in last row in Table 1.

Quaternary geological interpretations prompted by the development of construction on recent alluvium are important (Hawkins 1994). Yim (1993) used geophysical methods, field sampling and field and laboratory testing to study offshore quaternary sediment in Hong Kong. Zastrozhnov et al. (2017) developed regional charts for quaternary deposit in European Russia. Fakher et al. (2007) proposed classification for Tehran alluvium based on a combination of geological and geotechnical data. He et al. (2017) investigated alluvium sediment in Longshan, China and found sediment ranging from boulders to clay in this area. El May et al. (2015) studied geotechnical characterization of quaternary alluvial deposits in Tunis. Ku et al. (2010) studied the reliability of CPT  $I_c$  as an index for mechanical behavior classification of in quaternary alluvium deposits ( $I_c$  is consistency index). Zein (2017) proposed a relationship between undrained shear strength and CPT for fine grained soil from three Sudanese states with different OCR, over consolidation ratio, values.

Hajimohammadi *et al.* (2010) presented a relationship between shear wave velocity and cone tip resistance in the silty clay soil of southern Iran. Cheshomi and Ezzedi (2016) proposed a new soil classification based on CPTu test results for some parts of the quaternary alluvium in southern Iran. Cheshomi *et al.* (2015) compared the results of 43 dissipation tests and 35 onedimensional laboratory consolidation tests in quaternary alluvium in southern Iran with  $C_V$  values obtained from CPTu and onedimensional laboratory consolidation testing ( $C_V$  is coefficient of consolidation).

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Reference	Reference test	$N_k$	$N_{kt}$	$N_{ke}$	$N_{\Delta u}$	Soil type	Location
Kjekstad et al. (1978)	Triaxial compression	17	-	-	-	Non-fissured over-consolidated clays	North Sea
Lunne and Kleven (1981)	Field vane shear	11 ~ 19	-	-	-	Normally consolidated marine clays	North Sea
Senneset et al. (1982)		-	-	6 ~ 12	-	Clays (3% < <i>PI</i> < 50%)	
Lunne et al. (1985)	Triaxial compression	-	-	1 ~ 13	4 ~ 10	Clays $(N_{ke} \text{ varies with } B_q)$	North Sea
Aas et al. (1986)	Triaxial compression, triaxial extension and direct shear	_	8 ~ 16	-	_	Clays $(3\% < PI < 50\%)$ $(N_{kt} \text{ increases with } I_p)$	Norway
La Rochelle et al. (1988)	Vane shear	_	11 ~ 18	_	7~9	Sensitive clay No correlation found between N <sub>kt</sub> and PI	Canada
Rad and Lunne (1988)	Triaxial compression	-	8 ~ 29	-	-	Clays $N_{kt}$ varies with OCR	Nigeria
Powell and Quarterman (1988)	Triaxial compression	_	10 ~ 20	-	-		
Karlsrud (1996)	Triaxial compression	_	6~15	2 ~ 10	6 ~ 8	Soft to medium stiff clay $(N_{kt} \text{ decreases with } B_q)$	Norway
Jörß (1998)		15 ~ 20	-	-	-	Marine clay	Northern Germany
Chen (2001)		5 ~ 12	-	-	-	Klang clay	Indonesia
Gebreselassie (2003)		7.6 ~ 28.4	_	_	_	Sludge, marin young clay, lacustrine soft soil, quaternary clay and clay stone, tertiary clay	Germany
Hong et al. (2010)	Triaxial compression	_	7 ~ 20	3 ~ 18	4~9	Busan clay, 25% < PI < 40%	Korea
Almeida et al. (2010)	Vane shear	_	4 ~ 16	_	_	Very soft clay High plasticity, 42% < PI < 400%	Brazil
Average value Karlsrud et al. (1997)		15.2	13.5	8.1	7.1		

Table 1	Values proposed	l by researchers f	or empirical	l cone factors
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Note: PI: plasticity index; OCR: over consolidation ratio;  $B_q$ : piezocone pore pressure parameter

In the present study,  $S_u$  was determined by comparing the results of 50 uniaxial tests and the cone penetration test extracted from the corresponding depths in southern Iran. Values for the empirical cone factors ( $N_k$ ,  $N_{kt}$ ,  $N_{ke}$ ,  $N_{\Delta u}$ ) are proposed for the fine-grained soil tested. The effects of soil plasticity and stiffness on cone factors were also investigated. The values proposed by different researchers.

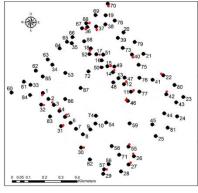
#### 2. STUDY AREA

Sampling and testing was performed in southern Iran, as shown in Fig. 1(a). Table 2 shows the number of boreholes and tests performed in the area and Fig. 1(b) shows the location of the boreholes and CPTu tests. Geotechnical investigation in this area was conducted with the aim of industrial construction. Disturbed and undisturbed samples were taken (usually at intervals of 2 to 3 m). The geological models shown in Fig. 2 were derived based on the results of classification tests.

This area has a surface layer (fill material, sand and gravel) with a thickness of about 2 m. Below this, the subsurface material consists mainly of fine-grained layers (lean clay, little fat clay and clayey silt) with low to high plasticity; thus, the soil variability is low. The groundwater table observed in boreholes was at a depth of  $3 \sim 5$  m below the surface. Below a depth of about 17.5 m, silt and sand layers of variable thickness (0.2 to 1.3 m) were observed in the fine sediment. In these areas, many seasonal and permanent rivers have carried large amounts of sediment eroded from the highland and have deposited the fine material on the plain. This process is the main factor in evaluation of the alluvium from the quaternary period.



(a) Location of the study area in southern Iran



(b) Borehole and CPTu tests location

Fig. 1 Sample and test area in southern Iran

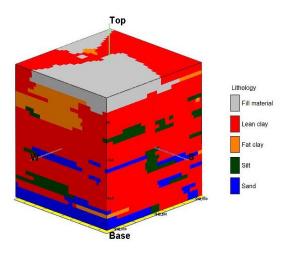


Fig. 2 Geological model for the area studied (in this area after the top soil is a layer of lean clay to depth of about 17.5 meter)

# Table 2Geographical location of study area and number of<br/>boreholes and tests performed in this area

Number of boreholes	Depth of boreholes (m)	Number of uniaxial tests		Geographical coordinates (in center area)	Location
50	15 ~ 30	50	22	30°74'38" N 48°42'41" E	Khouzestan plain

### 3. TEST RESULTS

# 3.1 Identification Tests

Identification testing was performed on all samples and comprised particle size analysis, Atterberg limits and soil classification tests according to ASTM D422-63:2007, ASTM D4318:2010 and ASTM D2487:2010. Table 3 shows the test results, including the designations using the unified classification system (CL and CH), determination of the liquid limit (*LL*) and plasticity (*PI*) and consistency indices (*CI*). Figure 3 shows the changes in the liquid limit, plasticity index and consistency index by depth for all samples. The liquid limit ranged from 25 to 55, the plasticity index from 8 to 28 and the consistency index from 0.18 to 1.5. As shown, the values of *LL*, *PI*, and *CI* varied greatly at any specific depth and did not show a recognizable trend by depth.

#### 3.2 Uniaxial Compression Testing

This test was performed in accordance with ASTM D2166:2006 on undisturbed samples 38 mm in diameter and 76 mm high at loading rates of 1.5% to 2% strain (1.5 mm/min). This test method covers the determination of the unconfined compressive strength of cohesive soil, using strain-controlled application of the axial load. This test method provides an approximate value of the strength of cohesive soils in terms of total stresses. The bore holes were drilled using the rotary method and at 2 ~ 3 m intervals, thin-walled tube sampling (undisturbed) was carried out. The results of all the UCS tests are summarized in Table 3. Figure 4 shows that  $S_u$  varied from 17.85 to 104.38 kPa.

Table 3	Physical properties of soil, uniaxial test results and
	CPTu parameters

BHN         UN         Q        Q         Q         Q				Fine						CPT	u data (	kPa)
BH:7.7.5CL9841100.5337.6828.898.920147BH317.1.4CL99037150.5314.417.1.47.00.1174BH44<-0CL90037150.5315.427.7.90.0174BH44<-0CL90037150.537.5417.90.01010BH-44.7.47.110040100.57.541.0.9<	BH No.	Depth (m)	USCS	content			CI					,
BH-37.7.5.CL9937150.5314.217.21199017BH414-14.4CL01034150.4712.4862.4921.0130130BH-41.5-14.4CL99.9430110.367.5437.792.60.10.1BH-121.5-12CL97.4341511.01.0.77.541.0.83.23.3BH-211.5-12CL94.034151.01.0.97.541.0.83.23.3BH-141.1-1.45CL94.0331.01.0.91.0.97.541.0.81.0.93.33.3BH-157.7.7.4CL94.0331.10.11.0.97.541.0.93.01.0.9BH-167.7.7.5CL94.0331.10.11.0.91.0.91.0.91.0.91.0.9BH-161.7.7.5CL94.0331.01.0.91.0.91.0.91.0.91.0.91.0.91.0.9BH171.2.7.5CL94.0331.01.0.91.0.91.0.91.0.91.0.91.0.91.0.9BH161.2.7.11.2.11.2.11.2.11.2.11.2.11.2.11.0.91.0.91.0.9BH171.2.7.11.2.11.2.11.2.11.2.11.2.11.2.11.2.11.2.11.2.1BH16	BH-1	7 ~ 7.5	CL		41	19	0.53	57.68	28.84	986	20	147
BH414 - 14.4CL10034150.4712.488.2412.08.03.2BH44.6 - 4.9CL9.9930110.367.5.437.79.20.018BH-510 - 0.45CL9.9930120.3810.975.4.412.51.2.92.73BH-127.7.5CL9.4341511.0.07.5.42.0.33.3BH-127.7.5CL9.4311.01.8.18.9.272.2.26.74.1.9BH-127.7.5CL9.9331.40.931.2.65.3.13.3.31.2.0BH-1411 - 1.1.45CL9.90331.01.2.15.3.11.3.03.1.21.2.1BH-157.7.4CL9.903.31.01.2.15.3.11.3.01.2.13.3.11.2.1BH-167.7.5CL9.71.5.11.5.77.5.41.0.51.2.13.3.11.2.13.3.11.2.13.3.11.2.13.3.11.2.11.3.11.3.11.2.11.3.11.3.11.2.13.3.11.2.11.3.1<	BH-3	11 ~ 11.4	CL	99	38	16	0.19	89.27	44.64	1204	27	234
BH44.6-4.9CL99930110.2697.5497.7492.60.010BH-119-9.45CL9.782.881.258.4.44.1213.67.7219BH-1211.5-12CL9.744.0100.891.107.5.42.013.33.3BH-127-7.4CL9.99301.01.849.202.223.74.12BH-141.7.1.4CL0.99301.01.7.49.003.71.07.7.43.01.01.7.4BH-147.7.5CL9.99301.01.71.63.7.81.603.71.0BH-167.7.5CL9.993.01.01.71.63.7.81.603.21.1BH-167.7.5CL9.73.31.00.77.6.81.603.21.1BH-178.7.9CL1.83.11.01.51.6.43.21.01.2BH-1810.5-11CL9.83.11.01.51.2.41.6.41.21.21.6.61.5.11.6.11.2BH-2913.7CL1.81.71.51.5.11.6.11.6.11.71.81.21.51.5.11.51.51.51.51.51.51.51.51.51.51.51.51.51.51.51.51.51.5 <td< td=""><td>BH-3</td><td>7 ~ 7.5</td><td>CL</td><td>99</td><td>37</td><td>15</td><td>0.53</td><td>144.21</td><td>72.1</td><td>1799</td><td>0</td><td>174</td></td<>	BH-3	7 ~ 7.5	CL	99	37	15	0.53	144.21	72.1	1799	0	174
BH-5IO - 10.45CHIOU40210.38IONSF4.941.5021BH-120.7.12CL98288.11.511.1.21.603.73.9BH-127.7.5CL9434151.11.40.07.0.41.223.7BH-127.7.5CL94341.51.11.40.07.0.41.223.7BH-141.1.4.14CL99301.111.88.163.1.2	BH-4	14 ~ 14.4	CL	100	34	15	0.47	124.98	62.49	2108	80	326
BH-119-9.45CH9R2881.258.2441.21.367.72.13BH-1217.5-1CL974015140.007.5.42.183.3BH-127.7.5CL9433141.40.007.0.41.223.7419BH-137.7.4CL99331.71.71.5.48.2.72.226.7419BH-167.7.5CL98331.70.47.4.53.0.03.23.20BH-167.7.5CL98331.70.47.4.63.0.03.63.6BH-167.7.5CL98331.70.47.4.63.6.03.63.6BH-167.7.5CL7.82.91.21.0.43.5.43.63.63.1.7BH-178.5.9CL7.82.91.21.0.43.5.43.63.63.1.71.0.43.5.43.63.63.6BH-211.3.4.1.3CL7.84.84.51.1.21.0.61.0.43.6	BH-4	4.6 ~ 4.9	CL	99	30	11	0.36	75.54	37.77	926	0	108
Bill 2         I.5 I         Circle         Form         Circle         Form         Circle         Form         Circle         Form         Circle         Form         Circle         Sint         Form         Circle         Sint         Form         Circle         Sint         Form         Sint         Form         Sint         Form         Sint         Form         Sint         Form         Sint         Form         Sint         Sint <t< td=""><td>BH-5</td><td>10 ~ 10.45</td><td>CL</td><td>100</td><td>40</td><td>21</td><td>0.38</td><td>109.87</td><td>54.94</td><td>1276</td><td>19</td><td>273</td></t<>	BH-5	10 ~ 10.45	CL	100	40	21	0.38	109.87	54.94	1276	19	273
Harl P         Part P	BH-11	9~9.45	CL	98	28	8	1.25	82.4	41.2	1366	7	219
BH-14     11 ~ 11 ~ 13     CL     100     49     23     109     178.5     89.7     222     67     4       BH-15     7 ~ 7.4     CL     99     30     11     1     18.16     4.0.8     2.00     7.6       BH-16     14 - 14.4     CL     99     30     17     1.4     18.16     9.4.8     2.00     7.6     4.88       BH-16     7 - 7.5     CL     9.8     33     12     7.5     1.5.3     7.6.8     1.60     3.0.3     1.0     1.6.3     1.6.9     1.6.3     1.6.9	BH-12	11.5 ~ 12	CL	97	40	19	0.89	151.07	75.54	2018	52	347
BH-16     7 -7.4     CL     99     33     14     9.39     11.22     5.40     1.23     3.4     9.20       BH-16     7 -7.5     CL     9.80     33     17     0.47     7.1.6     3.08     100     3.0       BH-16     7 -7.5     CL     9.30     33     12     0.75     15.37     3.08     140     3.0       BH-17     12 -12.5     CL     9.30     2.5     10     0.2     10.34     65.24     168     2.7       BH-17     13.5 -14     CL     9.80     3.0     1.0     1.08     4.5.5     3.2.7     168     2.0       BH-20     13.5 -14     CL     9.80     3.0     1.0     1.08     4.5.4     1.08     1.01     3.8       BH-20     13.5 -14     CL     9.90     3.0     1.7     1     1.43.3     7.4.6     1.80     3.9       BH-20     13.5 -14     CL     9.90     3.0     1.7     1     1.43.3     7.4.6     1.81.3     1.7       BH-20     13.5 -14     CL     9.90     3.0     1.7     1     1.43.3     1.4.1     1.3     1.4       BH-20     13.5 -14     CL     9.90     3.1     1.6    <	BH-12	7 ~ 7.5	CL	94	34	15	1	140.09	70.04	1826	102	335
BH-16     IA - 1.4.     CL     SP     30     11     IA     IB.8.16     94.08     230     7.0     14.0     7.0.0     12.0       BH-16     9 - 9.5     CL     9.5     33     12     0.75     15.37     57.68     160     32     12       BH-17     12 - 12.5     CL     7.0     2.0     12     1     50.82     2.41     95.0     2.4       BH-17     13.5 - 14     CL     7.0     2.9     12     1.0     50.82     2.41     95.0     2.4       BH-16     13.5 - 14     CL     9.8     2.9     1.0     1.0.1     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.0.3     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     1.61     <	BH-14	11 ~ 11.45	CL	100	49	23	1.09	178.54	89.27	2222	67	419
BH-16     7 - 7.5     CL     98     33     17     94.16     37.08     104     32     12       BH-16     9 - 9.5     CL     93     12     1.0     15.37     57.68     160     37       BH-17     12 - 12.5     CL     73     25     10     10.2     13.04     65.24     140     50     23       BH-18     10.5 - 11     CL     83     42     19     10.5     10.47     52.4     186     2.2     34       BH-20     13.5 - 14     CL     984     45     19     1.2     70.2     11.63     12.1     13.6     12.1     13.6     12.1     13.6     14.1     13.5     14.1     13.5     14.1     13.5     14.1     13.5     14.1     14.3     14.1	BH-15	7~7.4	CL	99	33	14	0.93	112.62	56.31	1323	31	202
BH-16     9-9.5     CL     95     33     12     0.75     15.37     5.06     160     5.0       BH-17     12-12.5     CL     93     25     10     0.2     10.47     65.24     160     23       BH-17     15.5-11     CL     83     12     10     10.5     10.63     12.4     18.3     2.0       BH-20     13.5-14     CL     984     45     19     1.2     2.0.2     11.63     2.165     3.2       BH-20     13.5-14     CL     970     35     16     1.00     1.4     1.8.3     7.16     1.8.3     1.01     3.8       BH-20     13.5-14     CL     970     35     16     1.00     1.4     1.8.3     7.10     1.8.3     1.00     3.8       BH-30     13.5-14     CL     970     3.5     1.0     1.	BH-16	14 ~ 14.4	CL	99	30	11	1	188.16	94.08	2360	76	488
BH-17     12 - 12.     CL     93     25     10     0.2     13.0.47     52.41     146     50     27.3       BH-18     10.5 - 11     CL     78     29     12     1     50.82     21.41     50.82     21.4     30.4     30.4     30.4     30.47     50.82     16.8     30.4     30.4     30.47     30.47     30.4     30.4     30.4     30.4     30.45     30.47     30.45     31.40     31.5     31.6     30.47     31.64     31.6     31.64     31.	BH-16	7 ~ 7.5	CL	98	33	17	0.47	74.16	37.08	1040	32	192
International         Interna         International         International	BH-16	9~9.5	CL	95	33	12	0.75	115.37	57.68	1605	36	261
BH-18         CD         IC         R3         42         IP         I.05         I.04         I.62         I.83         I.2         I.84         I.25         I.16         I.25         I.16         I.21         III         III         III         III         IIII         IIII         IIIII         IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	BH-17	12 ~ 12.5	CL	93	25	10	0.2	130.47	65.24	1469	50	273
BH-19         13.5 ~14         CL         98         33         13         108         64.55         32.27         1168         52         26           BH-22         13.4 ~1.37         CL         84         45         19         1.21         20.36         10.13         2165         35         419           BH-26         8.5 ~9         CL         100         39         17         1         14.33         7.16         1813         1.07         35           BH-27         12.7 1.25         CL         100         44         22         1         10.43         52.19         1423         26.2         1.11           BH-29         7.5 ~8         CL         100         32         13         0.69         12.2         61.6         1.42         1.42         1.43         1.43         1.42         1.43         1.42         1.43         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.44         1.45         1.44         1.45         1.44         1.45         1.44         1.45	BH-17	8.5 ~ 9	CL	78	29	12	1	50.82	25.41	956	24	177
BH-20         IA - IA         CL         IA         IA         IA         IA         IAA         IIAA         IIAA         IIAA         IIAA <thiia< td=""><td>BH-18</td><td>10.5 ~ 11</td><td>CL</td><td>83</td><td>42</td><td>19</td><td>1.05</td><td>130.47</td><td>65.24</td><td>1863</td><td>22</td><td>304</td></thiia<>	BH-18	10.5 ~ 11	CL	83	42	19	1.05	130.47	65.24	1863	22	304
BH-268.5.~9C.L10039171148.3374.16181310758BH-2712~12.5C.L977351610.6185.4192.71995543BH-2915.5~14C.L100039170.76208.76104.382107.57.4BH-297.5~8C.L99940170.887.1637.081.253.11.093.21.30.69123.261.619463.52.99BH-3113.5~14C.L99930160.7557.682.8.48.023.42.91BH-3212.5~13C.L100032140.844.442.4.29.564.42.12BH-3317~17.5C.L100032140.768.3.784.1831.301.41.30BH-351.5~12C.L10003190.6735.711.881.301.401.30BH-361.5~12C.L10003190.6735.711.881.301.401.30BH-361.5~12C.L100032140.4835.711.483.301.403.31.4BH-371.5~12C.L99431.41.101.10.51.453.43.13BH-361.5~17C.L99331.40.411.41.51.501.501.501.50<	BH-19	13.5 ~ 14	CL	98	33	13	1.08	64.55	32.27	1168	52	268
BH-27I2~12.5CL9735161.06185.492.719955.43BH-29I.5.~14CL10039170.76208.7610.4321.07.5BH-297.5~8CL90940170.887.1.637.0812.33.43.5BH-3013~1.3.5CL9932130.6912.3.26.1.61.9.63.42.9BH-3113.5~1.4CL9936160.7557.6828.4480.23.42.12BH-3212.5~1.3CL10038180.449.4.42.4.29.564.42.12BH-3317.7.7.5CL9943211.1.417.688.8.41.0.31.214.3BH-3511.5~1.2CL100031190.6737.411.8.53.43.123.15BH-3511.5~1.2CL100031190.6737.411.8.53.43.123.15BH-3617.7.5CH9953280.9613.3.46.8.71.3.02.43.13BH-3716.5~17CL9933180.431.4.83.4.33.143.13.1.43.1.43.1.43.1.43.1.43.1.43.1.43.1.43.1.43.1.51.1.53.1.43.1.43.1.43.1.53.1.43.1.43.1.43.1.53.1.43	BH-22	13.4 ~ 13.7	CL	84	45	19	1.21	203.26	101.63	2165	35	419
BH-201.5.~14C.L10030170.76208.76104.3821.707.44.72BH-202.5.~3C.L10044221104.3852.1014232.6111BH-207.5.~8C.L9932130.69123.261.6117063.53.92BH-3113.~13.5C.L9936160.7557.682.8.480.23.4212BH-3212.5.~13C.L10032140.8683.7841.8013.54.0130BH-3317.~17.5C.L99043211.1417.16885.8421.012.04.0BH-3511.5.~12C.L10003190.6737.3468.67130.02.42.8BH-3617.~17.5C.L99053280.9613.3.468.67130.02.42.8BH-3617.~17.5C.L99053280.9613.4468.67130.02.42.8BH-3716.5.~17C.L99033140.430.435.101.453.43.1BH-3716.5.~17C.L99033140.4410.265.1314.53.43.1BH-3817.~17.5C.L99033140.4410.265.1314.53.43.1BH-3916.5.~17C.L99035 <t< td=""><td>BH-26</td><td>8.5 ~ 9</td><td>CL</td><td>100</td><td>39</td><td>17</td><td>1</td><td>148.33</td><td>74.16</td><td>1813</td><td>107</td><td>358</td></t<>	BH-26	8.5 ~ 9	CL	100	39	17	1	148.33	74.16	1813	107	358
BH-292.5 ~ 3CL10044221104.3852.19142326111BH-297.5 ~ 8CL9940170.8874.1637.08124534158BH-3013 ~ 13.5CL9932130.69123.261.6194635299BH-3113.5 ~ 14CL9936160.7557.6828.4880234212BH-3212.5 ~ 13CL10032140.8683.7841.891305400130BH-3317 - 17.5CL9943211.1417.16885.482193121453BH-3511.5 ~ 12CL1003190.6735.7117.8571035158BH-367 - 7.5CH9943151107.1353.5613334307BH-3716.5 ~ 17CL10036151107.1353.5613453336BH-3716.5 - 17CL9933140.64100.650.1314453336BH-3817.1 - 15CL9933140.41101.555.62132765133BH-3716.5 - 17CL9928101.8103.1351.513414533BH-3716.5 - 18CL99351.111.1555.62 <td>BH-27</td> <td>12 ~ 12.5</td> <td>CL</td> <td>97</td> <td>35</td> <td>16</td> <td>1.06</td> <td>185.41</td> <td>92.7</td> <td>1995</td> <td>59</td> <td>433</td>	BH-27	12 ~ 12.5	CL	97	35	16	1.06	185.41	92.7	1995	59	433
BH-297.5 ~ 8CL9940170.887.4.1637.08124534158BH-3013 ~ 13.5CL9932130.69123.261.6194635299BH-3113.5 ~ 14CL9936160.7557.6828.8480234212BH-3212.5 ~ 13CL10032140.8683.7841.89130400130BH-328 ~ 8.5CL10032140.6735.7117.8571035158BH-3317 ~ 17.5CL9943211.1417.16885.47130242289BH-3511.5 ~ 12CL1003190.6735.7117.8571035158BH-367 - 7.5CH9943131010.1335.66130242289BH-3716.5 ~ 17CL199431410.1355.6113034360BH-3716.5 ~ 17CL9933140.46100.2650.13144533260BH-4313.5 ~ 16.5CL9933140.4111.555.62132765132BH-3716.5 ~ 17.5CL9928101.211.1555.62132765132BH-433.7.5CL99281.315.9115.516.2	BH-29	13.5 ~ 14	CL	100	39	17	0.76	208.76	104.38	2170	75	472
BH-3013 ~ 13.5CL9932130.69123.261.619463599BH-3113.5 ~ 14CL9936160.7557.6828.4880234211BH-3212.5 ~ 13CL10038180.4449.4424.7295.644212BH-328 ~ 8.5CL10032140.6683.7841.89130400130BH-3317 - 17.5CL9943211.14171.6885.8421935358BH-3511.5 ~ 12CL1003190.6735.7117.857103534370BH-367 ~ 7.5CH9953280.66137.4168.67130024289BH-3711 ~ 11.5CL10036151107.1353.561453336BH-3711 ~ 11.5CL9943130.46984915466334BH-3711 ~ 11.5CL9928101.211.2555.62132165152BH-3711 ~ 11.5CL9953241.13135.9767.811343430BH-3711 ~ 11.5CL9928101.211.2555.62132152152BH-443 ~ 3.5CL9928101.211.25 </td <td>BH-29</td> <td>2.5 ~ 3</td> <td>CL</td> <td>100</td> <td>44</td> <td>22</td> <td>1</td> <td>104.38</td> <td>52.19</td> <td>1423</td> <td>26</td> <td>111</td>	BH-29	2.5 ~ 3	CL	100	44	22	1	104.38	52.19	1423	26	111
BH-3113.5 ~ 14CL9936160.7557.6828.8480234211BH-3212.5 ~ 13CL10038180.4449.4424.7295644212BH-328 ~ 8.5CL10032140.8683.7841.891395400130BH-3317 ~ 17.5CL9943211.14171.6885.84219121453BH-3617.7 1.5CL1003190.6735.7117.8570135.7158BH-367 ~ 7.5CH9953280.96137.3468.67130024289BH-3716.5 ~ 17CL9933140.64100.2650.13144533260BH-3711 ~ 11.5CL9933140.64102.650.1314453334BH-347.5 ~ 8CL9933140.64102.650.1314453334BH-447.5 ~ 8CL9928101.211.2555.62132.765.152BH-447.5 ~ 8CL9933241.3135.9767.8413913434390BH-447.5 ~ 8CL9935241.15152.6132.765.12265.122BH-447.5 ~ 6CL993817 <t< td=""><td>BH-29</td><td>7.5 ~ 8</td><td>CL</td><td>99</td><td>40</td><td>17</td><td>0.88</td><td>74.16</td><td>37.08</td><td>1245</td><td>34</td><td>158</td></t<>	BH-29	7.5 ~ 8	CL	99	40	17	0.88	74.16	37.08	1245	34	158
BH-3212.5 ~ 13CL10038180.4449.4424.7295644212BH-328 ~ 8.5CL10032140.8683.7841.891395400130BH-3317 ~ 17.5CL9943211.14171.6885.84219121453BH-3611.5 ~ 12CL1003190.6735.7117.8579135158BH-367 ~ 7.5CH9953280.96137.3468.67130024289BH-3716.5 ~ 17CL9940180.83104.3852.19143659353BH-3716.5 ~ 17CL9933140.64100.2650.13144533260BH-4017.5 ~ 18CL9933130.469849154663341BH-423 ~ 3.5CL9928101.2111.2555.62132765152BH-447.5 ~ 8CL9953241.3135.9767.981790165BH-443 ~ 3.5CH9953241.3135.9767.98170142300BH-443 ~ 3.5CH99351241.31135.9767.98170142301BH-4515 ~ 15.5CL9938170.48104.38 <td>BH-30</td> <td>13 ~ 13.5</td> <td>CL</td> <td>99</td> <td>32</td> <td>13</td> <td>0.69</td> <td>123.2</td> <td>61.6</td> <td>1946</td> <td>35</td> <td>299</td>	BH-30	13 ~ 13.5	CL	99	32	13	0.69	123.2	61.6	1946	35	299
BH-32 $8 ~ 8.5$ CL         100         32         14         0.86         83.78         41.89         1395         4.0         130           BH-33         17 ~ 17.5         CL         999         43         21         1.14         171.68         85.84         2193         121         453           BH-35         11.5 ~ 12         CL         100         31         9         0.67         35.71         17.85         791         35         158           BH-36         7 ~ 7.5         CH         999         33         28         0.96         137.34         68.67         1300         24         289           BH-37         16.5 ~ 17         CL         990         40         18         0.83         104.38         52.19         143         53           BH-37         11.5         CL         990         33         14         0.64         100.26         50.13         145         33         260           BH-40         17.5 ~ 18         CL         998         34         13         0.46         98         49         154         633         341           BH-43         3 ~ 3.5         CL         998 <t< td=""><td>BH-31</td><td>13.5 ~ 14</td><td>CL</td><td>99</td><td>36</td><td>16</td><td>0.75</td><td>57.68</td><td>28.84</td><td>802</td><td>34</td><td>291</td></t<>	BH-31	13.5 ~ 14	CL	99	36	16	0.75	57.68	28.84	802	34	291
BH-33         17 ~ 17.5         CL         999         43         21         1.14         171.68         85.84         2193         121         433           BH-35         11.5 ~ 12         CL         100         31         9         0.67         35.71         17.85         791         35         158           BH-36         7 ~ 7.5         CH         999         53         28         0.96         137.34         68.67         1300         24         289           BH-36         11 ~ 11.5         CL         100         36         15         1         107.13         53.56         1453         34         307           BH-37         16.5 ~ 17         CL         999         33         14         0.64         100.26         50.13         1445         33         260           BH-40         17.5 ~ 18         CL         999         28         10         1.2         11.25         55.62         132         65         152           BH-44         7.5 ~ 8         CL         998         45         20         1.15         133.6         61.8         1838         210         320           BH-44         3 ~ 3.5         CH	BH-32	12.5 ~ 13	CL	100	38	18	0.44	49.44	24.72	956	44	212
BH-35         11.5 ~ 12         CL         100         31         9         0.67         35.71         17.85         791         35         18           BH-36         7 ~ 7.5         CH         99         53         28         0.96         137.34         68.67         1300         24         289           BH-36         11 ~ 11.5         CL         100         36         15         1         107.13         53.56         1453         34         307           BH-37         16.5 ~ 17         CL         99         40         18         0.83         104.38         52.19         1436         593         353           BH-37         11 ~ 11.5         CL         99         33         14         0.64         988         49         1546         633         334           BH-40         17.5 ~ 18         CL         99         28         10         1.2         111.25         55.62         1327         65         152           BH-44         3 ~ 3.5         CH         99         53         24         1.13         135.97         67.98         179         0         165           BH-44         1.5 ~ 15.         CL         9	BH-32	8 ~ 8.5	CL	100	32	14	0.86	83.78	41.89	1395	40	130
BH-36 $7 \sim 7.5$ CH         99         53         28         0.96         137.34         68.67         1300         24         289           BH-36         11 ~ 11.5         CL         100         36         15         1         107.13         53.56         1453         34         307           BH-37         16.5 ~ 17         CL         99         40         18         0.83         104.38         52.19         1436         59         353           BH-37         11 ~ 11.5         CL         99         33         14         0.64         100.26         50.13         1445         33         260           BH-40         17.5 ~ 18         CL         998         34         13         0.46         98         49         154         63         334           BH-42         3 ~ 3.5         CL         99         28         10         1.5         123.61         61.8         1838         21         320           BH-44         7.5 ~ 8         CL         998         53         24         1.13         135.97         67.98         170         18           BH-44         1.5 ~ 15.         CL         99         2	BH-33	17 ~ 17.5	CL	99	43	21	1.14	171.68	85.84	2193	121	453
BH-36         11 ~ 11.5         CL         100         36         15         1         107.13         53.56         1453         34         377           BH-37         16.5 ~ 17         CL         99         40         18         0.83         104.38         52.19         1436         59         353           BH-37         11 ~ 11.5         CL         99         33         14         0.64         100.26         50.13         1445         33         260           BH-40         17.5 ~ 18         CL         98         34         13         0.46         98         49         154         63         334           BH-42         3 ~ 3.5         CL         99         28         10         1.2         11.25         55.62         1327         655         152           BH-44         7.5 ~ 8         CL         99         53         24         1.13         135.97         67.98         170         165         120         165           BH-44         1.5 ~ 15         CL         99         33         24         1.13         135.97         67.98         170         186           BH-44         1.5 ~ 15.5         CL	BH-35	11.5 ~ 12	CL	100	31	9	0.67	35.71	17.85	791	35	158
BH-37         16.5 ~ 17         CL         99         40         18         0.83         104.38         52.19         1436         59         353           BH-37         11 ~ 11.5         CL         99         33         14         0.64         100.26         50.13         1445         33         260           BH-40         17.5 ~ 18         CL         98         34         13         0.46         98         49         1546         633         334           BH-42         3 ~ 3.5         CL         99         28         10         1.2         11.25         55.62         1327         655         1327           BH-44         7.5 ~ 8         CL         98         45         20         1.15         123.61         61.8         1838         21         320           BH-44         7.5 ~ 8         CL         99         53         24         1.13         135.97         67.98         175         60         182           BH-44         1.5 ~ 12         CL         99         38         17         1.88         104.38         52.19         131         142         390           BH-48         5.5 ~ 6         CL         99	BH-36	7 ~ 7.5	CH	99	53	28	0.96	137.34	68.67	1300	24	289
BH-37         II ~ 11.5         CL         99         33         14         0.64         100.26         50.13         1445         33         260           BH-37         II ~ 11.5         CL         998         34         13         0.66         988         49         1546         633         334           BH-40         17.5 ~ 18         CL         998         28         10         1.2         111.25         55.62         1327         655         152           BH-44         7.5 ~ 8         CL         998         45         20         1.15         123.61         61.8         1838         21         320           BH-44         3 ~ 3.5         CH         995         53         24         1.13         135.97         67.98         175         0         196           BH-44         12 ~ 12.5         CL         955         28         10         0.8         104.38         52.19         1316         182         30           BH-45         15.7         CL         955         28         10         0.8         104.38         52.19         1316         142         30           BH-48         5.5 ~ 6         CL	BH-36	11 ~ 11.5	CL	100	36	15	1	107.13	53.56	1453	34	307
BH-40         17.5 ~ 18         CL         98         34         13         0.46         98         49         1546         6.3         34           BH-40 $3 ~ 3.5$ CL         99         28         10         1.2         11.25         55.62         1327         655         152           BH-44 $7.5 ~ 8$ CL         99         53         24         1.13         135.97         67.98         175         0         196           BH-44 $3 ~ 3.5$ CH         99         53         24         1.13         135.97         67.98         175         0         196           BH-44 $1.5 ~ 12$ CL         955         28         10         0.8         104.38         52.19         1316         18.2         230           BH-45         15.5 ~ 6         CL         99         25         0.92         182.66         91.33         1915         42         300           BH-48         5.5 ~ 6         CL         99         38         17         1.8         103.01         51.5         102         132         132           BH-49         8 ~ 8.5         CL         99         3	BH-37	16.5 ~ 17	CL	99	40	18	0.83	104.38	52.19	1436	59	353
BH-42 $3 \sim 3.5$ CL         99         28         10         1.2         111.25         55.62         1327         65         152           BH-44         7.5 $\sim 8$ CL         98         45         20         1.15         123.61         61.8         1838         21         320           BH-44         3 $\sim 3.5$ CH         99         53         24         1.13         135.97         67.98         1795         0         196           BH-46         11.5 $\sim 12$ CL         95         28         10         0.8         104.38         52.19         1316         18         263           BH-48         12 $\sim 12.5$ CL         100         49         25         0.92         182.66         91.33         1915         42         390           BH-48         5.5 $\sim 6$ CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-49         15 $\sim 15.5$ CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50         7.5 $\sim 8$ CL <td>BH-37</td> <td>11 ~ 11.5</td> <td>CL</td> <td>99</td> <td>33</td> <td>14</td> <td>0.64</td> <td>100.26</td> <td>50.13</td> <td>1445</td> <td>33</td> <td>260</td>	BH-37	11 ~ 11.5	CL	99	33	14	0.64	100.26	50.13	1445	33	260
BH-44 $7.5 \sim 8$ CL         98         45         20         1.15         123.61         61.8         1838         21         320           BH-44 $3 \sim 3.5$ CH         99         53         24         1.13         135.97         67.98         1795         0         196           BH-44 $1.5 \sim 12$ CL         95         28         10         0.8         104.38         52.19         1316         182         263           BH-48 $12 \sim 12.5$ CL         100         49         25         0.92         182.66         91.33         1915         42         300           BH-48 $5.5 \sim 6$ CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-49 $15 \sim 15.5$ CL         99         38         17         0.94         38.46         19.23         591         122         132           BH-49 $8 \sim 8.5$ CL         99         38         17         0.94         38.46         19.23         591         122         132           BH-50 $7.5 \sim 8$ CL </td <td>BH-40</td> <td>17.5 ~ 18</td> <td>CL</td> <td>98</td> <td>34</td> <td>13</td> <td>0.46</td> <td>98</td> <td>49</td> <td>1546</td> <td>63</td> <td>334</td>	BH-40	17.5 ~ 18	CL	98	34	13	0.46	98	49	1546	63	334
BH-44 $3 \sim 3.5$ CH         99         53         24         1.13         135.97         67.98         1795         0         196           BH-46         11.5 ~ 12         CL         95         28         10         0.8         104.38         52.19         1316         18         263           BH-48         12 ~ 12.5         CL         100         49         25         0.92         182.66         91.33         1915         42         390           BH-48         5.5 ~ 6         CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-49         15 ~ 15.5         CL         99         38         17         0.49         38.46         19.23         591         12         132           BH-49         8 ~ 8.5         CL         99         38         21         0.76         54.94         27.47         800         20         132           BH-50         7.5 ~ 8         CL         99         38         21         0.76         54.94         27.47         800         2.02         131           BH-52         7.5 ~ 8         CL <td< td=""><td>BH-42</td><td>3 ~ 3.5</td><td>CL</td><td>99</td><td>28</td><td>10</td><td>1.2</td><td>111.25</td><td>55.62</td><td>1327</td><td>65</td><td>152</td></td<>	BH-42	3 ~ 3.5	CL	99	28	10	1.2	111.25	55.62	1327	65	152
BH-46         11.5 ~ 12         CL         95         28         10         0.8         104.38         52.19         1316         18         233           BH-48         12 ~ 12.5         CL         100         49         25         0.92         182.66         91.33         1915         42         390           BH-48         5.5 ~ 6         CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-49         15 ~ 15.5         CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-49         8 ~ 8.5         CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50         7.5 ~ 8         CL         99         38         21         0.76         54.94         27.47         800         20         154           BH-50         7.5 ~ 8         CL         100         29         10         0.7         87.94         43.95         1131         322         244           BH-51         12.5 ~ 13         CL	BH-44	7.5 ~ 8	CL	98	45	20	1.15	123.61	61.8	1838	21	320
BH-48         12 ~ 12.5         CL         100         49         25         0.92         182.66         91.33         1915         42         390           BH-48         5.5 ~ 6         CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-48         5.5 ~ 6         CL         99         40         17         1.18         103.01         51.5         1062         34         208           BH-49         15 ~ 15.5         CL         98         34         15         0.73         178.54         89.27         2240         70         442           BH-49         8 ~ 8.5         CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50         7.5 ~ 8         CL         99         38         21         0.76         54.94         27.47         800         20         154           BH-52         7.5 ~ 8         CL         99         28         8         0.63         86.52         43.26         140         24         211           BH-53         12. ~ 12.5         CL         99	BH-44	3 ~ 3.5	СН	99	53	24	1.13	135.97	67.98	1795	0	196
BH-48 $5.5 \sim 6$ CL         99         40         17         1.18         103.01 $51.5$ 1062         34         208           BH-49 $15 \sim 15.5$ CL         98         34         15         0.73         178.54         89.27         2240         70         442           BH-49 $8 \sim 8.5$ CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50 $7.5 \sim 8$ CL         99         38         21         0.76         54.94         27.47         800         20         154           BH-52 $7.5 \sim 8$ CL         100         29         10         0.7         87.9         43.95         1131         32         204           BH-53 $12.5 \sim 13$ CL         990         38         6         0.63         86.52         43.26         1407         24         231           BH-54 $12 \sim 12.5$ CL         990         38         1         1         37.08         18.54         699         16         174           BH-55 $7 \sim 7.5$ CL	BH-46	11.5 ~ 12	CL	95	28	10	0.8	104.38	52.19	1316	18	263
BH-49         15 ~ 15.5         CL         98         34         15         0.73         178.54         89.27         2240         7.0         442           BH-49         8 ~ 8.5         CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50         7.5 ~ 8         CL         99         38         21         0.76         54.94         27.47         800         20         154           BH-52         7.5 ~ 8         CL         100         29         10         0.7         87.9         43.95         113         32         204           BH-53         12.5 ~ 13         CL         99         28         8         0.63         86.52         43.26         1407         24         231           BH-54         12 ~ 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-57         14 ~ 14.5         CL         98	BH-48	12 ~ 12.5	CL	100	49	25	0.92	182.66	91.33	1915	42	390
BH-49         8 ~ 8.5         CL         99         38         17         0.94         38.46         19.23         591         12         132           BH-50         7.5 ~ 8         CL         99         38         21         0.76         54.94         27.47         800         20         154           BH-50         7.5 ~ 8         CL         100         29         10         0.7         87.9         43.95         1131         32         204           BH-51         12.5 ~ 13         CL         99         28         8         0.63         86.52         43.26         1407         24         231           BH-54         12.7 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         1964         104         474           BH-50         7 ~ 7.5         CL         98	BH-48	5.5 ~ 6	CL	99	40	17	1.18	103.01	51.5	1062	34	208
BH-50         7.5 ~ 8         CL         999         38         21         0.76         54.94         27.47         800         20         154           BH-50         7.5 ~ 8         CL         100         29         10         0.76         54.94         27.47         800         20         154           BH-52         7.5 ~ 8         CL         100         29         10         0.7         87.9         43.95         113         32         204           BH-53         12.5 ~ 13         CL         99         28         8         0.63         86.52         43.26         1407         24         231           BH-54         12 ~ 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         164         144         414           BH-70         7 ~ 7.5         CL         98	BH-49	15 ~ 15.5	CL	98	34	15	0.73	178.54	89.27	2240	70	442
BH-52         7.5 ~ 8         CL         100         29         10         0.7         87.9         43.95         1131         32         204           BH-53         12.5 ~ 13         CL         99         28         8         0.63         86.52         43.95         1407         24         231           BH-54         12 ~ 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-57         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         104         14           BH-70         7 ~ 7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         I00         53         28         1.46	BH-49	8 ~ 8.5	CL	99	38	17	0.94	38.46	19.23	591	12	132
BH-53         12.5 ~ 13         CL         99         28         8         0.63         86.52         43.26         1407         24         231           BH-54         12 ~ 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         166         414         474           BH-70         7 ~ 7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         100         53         28         1.46         208.76         104.38         2360         121         488           Min.         78         27         8         0.9         35.71         17.85         90.00         100	BH-50	7.5 ~ 8	CL	99	38	21	0.76	54.94	27.47	800	20	154
BH-54         12 ~ 12.5         CL         99         34         14         1         37.08         18.54         699         16         174           BH-55         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         1964         104         474           BH-70         7 ~ 7.5         CL         98         42         18         0.67         178.54         89.27         1964         104         474           BH-70         7 ~ 7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         100         53         28         1.46         208.76         104.38         2360         121         488           Min.         78         278         8         0.9         35.71         17.85         90.00         100	BH-52	7.5 ~ 8	CL	100	29	10	0.7	87.9	43.95	1131	32	204
BH-55         7 ~ 7.5         CL         100         35         13         1.15         145.58         72.79         1506         41         270           BH-57         14 ~ 14.5         CL         98         42         18         0.67         178.54         89.27         1964         104         474           BH-70         7 ~ 7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         V         100         53         28         1.46         208.76         104.38         230         121         488           Min.         78         278         28         0.9         35.71         17.85         50         0.00         18	BH-53	12.5 ~ 13	CL	99	28	8	0.63	86.52	43.26	1407	24	231
BH-57         14~14.5         CL         98         42         18         0.67         178.54         89.27         1964         104         474           BH-57         7~7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         100         53         28         1.46         208.76         104.38         2360         121         488           Min.         78         25         8         0.19         35.71         17.85         591         0.00         108	BH-54	12 ~ 12.5	CL	99	34	14	1	37.08	18.54	699	16	174
BH-70         7 ~ 7.5         CL         98         35         13         1.46         126         63         1278         46         277           Max.         100         53         28         1.46         208.76         104.38         2360         121         488           Min.         78         25         8         0.19         35.71         17.85         591         0.00         108	BH-55	7 ~ 7.5	CL	100	35	13	1.15	145.58	72.79	1506	41	270
Max.         100         53         28         1.46         208.76         104.38         2360         121         488           Min.         78         25         8         0.19         35.71         17.85         591         0.00         108	BH-57	14 ~ 14.5	CL	98	42	18	0.67	178.54	89.27	1964	104	474
Min. 78 25 8 0.19 35.71 17.85 591 0.00 108	BH-70	7 ~ 7.5	CL	98	35	13	1.46	126	63	1278	46	277
Min. 78 25 8 0.19 35.71 17.85 591 0.00 108												
		Min.		78	25	8	0.19	35.71	17.85	591	0.00	108
Ave. 98 37 16 0.84 114.15 57.07 1489 42 273		Ave.		98	37	16	0.84	114.15	57.07	1489	42	273

As with the classification data, the results span a range at any specific depth and showed a slight increase by depth. Figure 5 shows the distribution consistency of soil in the study areas. The stiffness of the clayey soil ranged from very soft to hard.

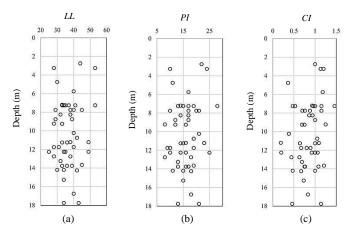


Fig. 3 Values of (a) liquid limit (*LL*); (b) plasticity index (*PI*); and (c) consistency index (*CI*) of samples

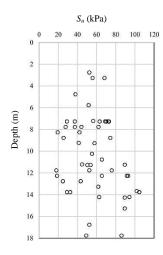


Fig. 4 Values of undrained shear strength  $(S_u)$  obtained from the uniaxial tests

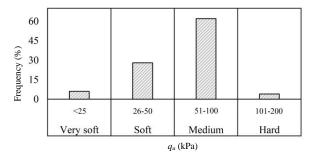


Fig. 5 Distribution consistency of soil in the study area. The stiffness of the clayey soils ranged from very soft to hard

#### 4. CONE PENETRATION TESTING

CPTu was carried out in accordance with ASTM D5778: 2012. In this test, a penetrometer tip with a conical point having a 60° apex angle and cone base area of 10 cm<sup>2</sup> advanced at a constant rate of 20 mm/sec through the soil. The force on the cone required to penetrate the soil is measured as cone resistance ( $q_c$ ).

Sleeve resistance  $(f_s)$  represents the sleeve strength against penetration and is calculated by dividing the measured axial force by the sleeve surface area. The pore water pressure induced during advancement of the cone is measured using a pressure transducer  $(u_2)$ . Total cone resistance  $q_t$  is given as:

$$q_t = q_c + u_2(1 - a) \tag{5}$$

According to the definition offered by Lunne *et al.* (1997), cone area ratio *a*, is approximately equal to the ratio of the cross-sectional area of the load cell or shaft divided by the projected area of the cone. The CPTu equipment used was manufactured by van den Berg, A.P.

Figure 6 shows examples of CPTu profiles of the successive CPTu testing conducted from ground level to the desired depth and the relevant  $q_c$ ,  $f_s$ , and  $u_2$  values are shown in Table 3. Based on the profile, the top soil was followed by a layer of lean clay to a depth of 17.5 m. A silty sand layer about 1 m in thickness (at depths of 11 and 17.5 m) was then observed. Similar profiles for other CPTu tests have been produced and the following steps for comparison of  $S_u$  and CPTu parameters have been performed:

- The borehole nearest to the CPTu is selected according to studies conducted by Ku *et al.* (2010). Because soil variability in this area soil is low, the distance between the selected borehole and the CPTu is less than 3 m.
- A uniaxial test carried out on undisturbed sample is obtained from side-by-side boreholes.
- The average  $q_c$ ,  $q_t$ ,  $f_s$ , and  $u_2$  values were extracted from the CPTu profile at the same depth at which the uniaxial test is done.

Table 3 lists the depths at which uniaxial testing was performed and the average values for  $q_c$ ,  $q_t$ ,  $f_s$ , and  $u_2$  for the same depth are presented as well. Figure 7 shows the average values for  $q_c$ ,  $q_t$ ,  $f_s$ , and  $u_2$  versus depth.

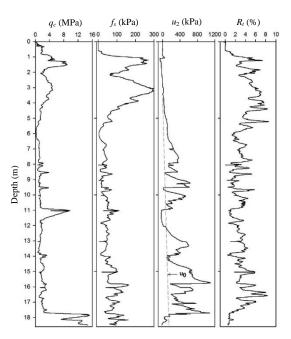


Fig. 6 Examples of CPTu profiles  $(q_c, f_s, u_2, and R_f)$ . After the top soil is a layer of lean clay to depth of 17.5 m with silty sand layer with about 1 m thickness (at a depth of 11 and 17.5 meter)

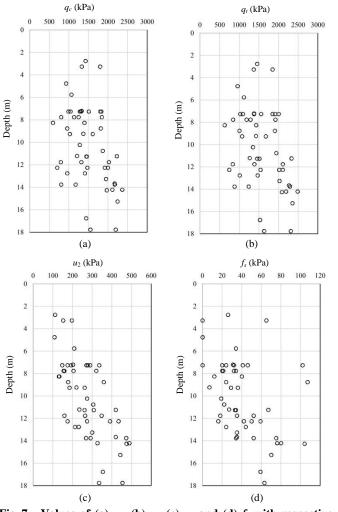


Fig. 7 Values of (a)  $q_c$ , (b)  $q_t$ , (c)  $u_2$  and (d)  $f_s$  with respective depth

# 5. DETERMINATION OF EMPIRICAL CONE FACTORS

Empirical cone factors  $N_k$ ,  $N_{kt}$ ,  $N_{ke}$ , and  $N_{\Delta u}$  were determined from the data listed in Table 3 using the  $S_u$  values from uniaxial testing as a reference.

#### 5.1 Empirical Cone Factor $N_k$

Figure 8 shows the correlations for  $N_k$  using  $S_u$  from uniaxial testing versus  $q_c - \sigma_v$ . As shown, the upper and lower boundaries for  $N_k$  are 29 and 18, respectively. The proposed best value for the soil in the study areas was 22. Equation (6) describes the empirical relationship between these two variables as:

$$S_u = (q_c - \sigma_v) / 22 \quad R^2 = 0.83 \tag{6}$$

#### 5.2 Empirical Cone Factor N<sub>kt</sub>

Figure 9 shows the results of determination of  $N_{kt}$  using  $S_u$  from uniaxial testing versus  $q_t - \sigma_v$ . As shown,  $N_{kt}$  varied from 18 to 31 for the study areas, with the best value equaling 23. Equation (7) describes the empirical relationship between these two variables as:

$$S_{\mu} = (q_t - \sigma_v) / 23 \quad R^2 = 0.84$$
 (7)

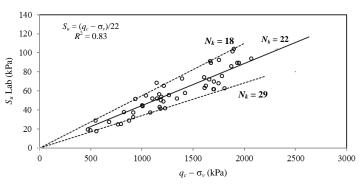


Fig. 8  $S_u$  from uniaxial tests vs.  $(q_c - \sigma_v)$  for determination of  $N_k$ . Based on the upper and lower boundaries max. and min.  $N_k$  are 29 and 18. The best value is 22

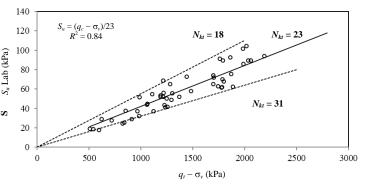


Fig. 9  $S_u$  from uniaxial testing vs.  $(q_t - \sigma_v)$  for determination of  $N_{kt}$ . Based on the upper and lower boundaries max. and min.  $N_{kt}$  are 31 and 18. The best value for  $N_{kt}$  is 23

#### 5.3 Empirical Cone Factor N<sub>ke</sub>

1

Figure 10 plots the shear strength obtained in the laboratory versus the effective cone resistance obtained from CPTu to determine the  $N_{ke}$ . The best value for the factor was 22, which is equivalent to the value for  $N_k$  ( $N_k = N_{ke} = 22$ ). The range of variation of this factor based on the upper and lower boundaries as shown in Fig. 10 is between 17 and 31, which is slightly wider than the range for  $N_k$ . Equation (8) describes the empirical relationship between these two variables as:

$$S_u = (q_E / N_{ke}) = (q_t - u_2) / 22 \quad R^2 = 0.79$$
 (8)

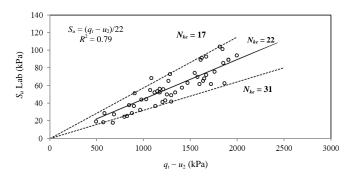


Fig. 10  $S_u$  from uniaxial testing vs.  $(q_t - u_2)$  for determination of  $N_{ke}$ . Based on the upper and lower boundaries max. & min.  $N_{ke}$  are 31 and 17. The best value for the factor is 22

#### 5.4 Empirical Cone Factor $N_{\Delta u}$

Figure 11 plots the shear strength obtained from uniaxial testing versus excess pore water pressure to determine  $N_{\Delta u}$ . The value for  $N_{\Delta u}$  varies from 2.8 to 5.9 and the best value was 3.8. As seen, the amount and the range of variation of this factor is significantly smaller than for the other three factors. Equation (9) describes the empirical relationship between these two variables as:

$$S_u = (\Delta u / N_{\Delta u}) = (u_2 - u_0) / 3.8 \quad R^2 = 0.83$$
(9)

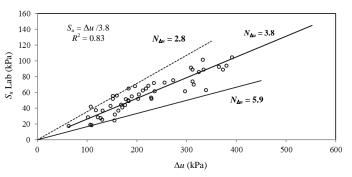


Fig. 11  $S_u$  from uniaxial tests vs.  $\Delta u$  for determination of  $N_{\Delta u}$ . This factor varies from 2.8 to 5.9, and the best value is 3.8

Table 4 shows the best value and the range of the cone factors obtained for the study area in Figs. 8 to 11. In these figures, the upper and lower bounds are plotted to place the majority of the data between two lines, and these lines cross the origin of the coordinate.

 Table 4
 Proposed empirical cone factors using uniaxial test as reference

	$N_k$	N <sub>kt</sub>	$N_{ke}$	$N_{\Delta u}$
Minimum	18	18	17	2.8
Best value	22	23	22	3.8
Maximum	29	31	31	5.9

SPSS software was employed to evaluate the normality of the variable and meaningfulness of the empirical relationships.

(a) (b) 00 0 2 :25  $N_{kt}$ C PI PI(d) (c) °.  $N_{\Delta u}$ <u>008</u>8  $N_{ke}^{a}$ ΡI

Fig. 12 Plasticity index vs. cone factor for the study area: (a)  $N_k - PI$ ; (b)  $N_{kt} - PI$ ; (c)  $N_{ke} - PI$ ; (d)  $N_{\Delta u} - PI$ 

Table 5 shows that the skewness and kurtosis of the variable fall between -2 and 2. The variable can be said to be normally distributed.

	Skev	vness	Kurtosis		
	Statistic Std. Error*		Statistic	Std. Error	
$S_u$	0.206	0.206 0.337		0.662	
$q_c$	0.069	0.337	-0.927	0.662	
$u_2$	0.409	0.337	-0.715	0.662	
$q_t$	0.066	0.337	-0.922	0.662	
$\sigma_v$	-0.075	0.337	-0.936	0.662	
$\Delta u$	0.492	0.337	-0.796	0.662	

The Std. Error or standard error of a statistic is the standard deviation of its sampling distribution or an estimate of that standard deviation.

Table 6 shows the values obtained from the t-test for the empirical relations (Eqs. (6) to (9)). Given that the meaningfulness is less than the amount of error (this test considered an error of 5%), the correlation coefficient was meaningful for the relationships between these parameters.

 Table 6
 Results of t-test to determine meaningfulness of proposed relationships

Model		dardized icients	Standardized coefficients	t	Sig.*
	B*	Std. Error	Beta <sup>*</sup>		
$q_c - \sigma_v$	0.048	0.003	0.916	15.846	.000
$q_t - \sigma_v$	0.048	0.003	0.922	16.450	.000
$q_t - u_2$	0.051	0.004	0.896	13.949	.000
$\Delta u$	0.245	0.016	0.915	15.750	.000

Beta coefficients is the estimates resulting from a regression analysis that have been standardized. B coefficients is the regression carried out on original (unstandardized. Sig. is level of significance. The Sig of .000 means the results are highly significant.

# 6. RELATIONSHIP BETWEEN CONE FACTORS AND PHYSICAL PROPERTIES

Figures 12 and 13 show the plasticity and consistency index

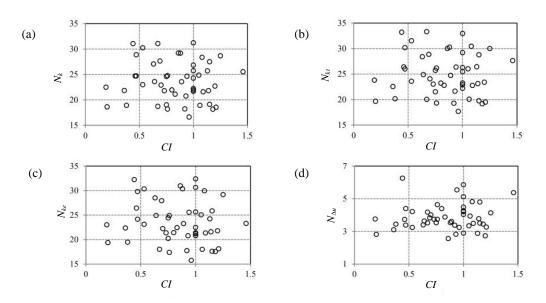


Fig. 13 Consistency index vs. cone factor for study areas: (a)  $N_k - CI$ ; (b)  $N_{kt} - CI$ ; (c)  $N_{ke} - CI$ ; (d)  $N_{\Delta u} - CI$ .

values for different cone factors. There is no empirical relationship with acceptable correlation between plasticity index and the cone factors. It is not possible to offer an empirical relationship with an acceptable correlation between the plasticity index, consistency index and the cone factors. Aas et al. (1986) reported that the empirical cone factor has a direct relationship with the plasticity index, but subsequent studies have not confirmed this relationship (Remai 2013).

# 7. COMPARISON OF RESULTS WITH PREVIOUS RESEARCH

Figures 14(a) ~ 14(d) compare the values determined for the cone factors in the present study with those provided by previous research (Table 1). The values obtained for  $N_k$ ,  $N_{kt}$ , and  $N_{ke}$  from the present study are slightly higher than those determined in previous studies and the value obtained for  $N_{\Delta u}$  is slightly less than those determined in previous studies.

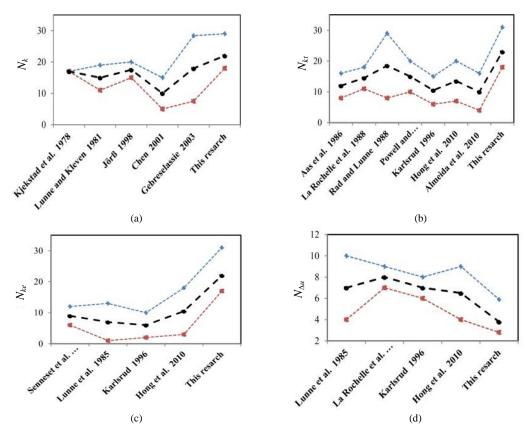


Fig. 14 Cone factors from present study vs. those from previous studies

The reference tests chosen in the earlier studies were the triaxial and field vane shear tests. In the present study, the uniaxial test was used as the reference test. It can be concluded that a major reason for the difference in value is the type of reference test. Other possible reasons are soil disturbance in the process of sampling and preparation of laboratory testing and the material properties of the study area. There are overall similarities between the values obtained in the present study and those form previous studies. There is also a significant and acceptable correlation between the variables.

# 8. CONCLUSIONS

A comparison of the results of 50 uniaxial and cone penetration tests on quaternary fine-grained alluvium (CL and CH) soil with  $q_{\mu}$  values of 35.71 to 208.76 kPa and PI values of 8 to 28 in southern Iran indicates that there is an acceptable and significant correlation between the undrained shear strength of the soil and the cone parameters  $(q_c, q_t, f_s, \text{ and } u_2)$ . The cone factors proposed for the study area were  $N_k = N_{ke} = 22$ ,  $N_{kt} = 23$ , and  $N_{\Delta u} = 3.8$ . The results for these factors were compared with the results for cone factors presented by previous studies and showed only a slight difference, which could be the result of the use of different reference tests or from soil and local site specifications of the areas under study. The reference tests used in the previous studies were the triaxial and field vane shear tests. The present study used the uniaxial test as the reference test, so the test condition and sample disturbance in these tests differed. A comparison of cone factors with physical soil properties, such as the plasticity and consistency indices, did not reveal a reliable correlation.

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