Study of Bored Pile Capacity in Klang Valley Residual Soil based on Field-Performance Data

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ABSTRACT: Bored pile has been gaining its popularity in this recent years due to its ability to carry higher working load and higher lateral force resistance. On top of that, bored pile is suitable to penetrate into shallow rock or hard layer. Many designers in the past would ignore the end bearing contribution in bored pile due to the problem of soft toe at the base. This approach would be too conservative which would result in longer pile length as the geotechnical capacity would only depends on shaft friction. In Malaysia practise, geotechnical capacity of bored pile in residual soil is calculated from SPT-N correlation based on modified Meyerhoff approach. This paper presents the study of relationship between pile capacity obtained from load test results and field performance data in Klang Valley geology. Extrapolation technique using Chin's method has been adopted in obtaining the ultimate shaft friction for non-fail load test. A total of 20 bored piles of diameter varying from 900 mm to 1500 mm were tested on multiple geology formation in Klang Valley. From this research, the relationship between shaft friction and SPT-N blow in three different types of geology such as Granite formation, Limestone formation and Kenny Hill formation are explored. The findings showed that fsu/N ratio in Limestone formation and Kenny Hill formation are quite match and agreeable with studied carried out by other authors. On the other hand, higher fsu/N can be obtained in Granite formation based on the plotted graph. For the base resistance, interpretation of the collected load test results indicated a matching relationship between fbu and Pb/Ptop in soil as well as rock where R-squared of more than 90% are obtained. The study of load test results have enable development of shaft resistance correlation with SPT-N blow as well as correlation between Pb/Ptop and base resistance. This would allow designer to adopt higher bored pile capacity which would result to shorter pile length and cost saving.
Keywords: SPT-N correlation, shaft friction, end bearing, load test and pile length.

1. INTRODUCTION

In Malaysia, the conventional geotechnical practice for pile foundation design is based on working stress method where the derived allowable carrying capacity of pile (working load of pile) shall always be greater than the unfactored column load. The working load of a pile is obtained by applying safety factors (FOS) to the ultimate geotechnical capacity of the pile. Conventionally, different or same FOS will be applied to the shaft and base resistance of the pile. The FOS and the combination of the different FOS are depending on multiple factors such as the experience of the designer to the similar soil or rock conditions, project design brief, client requirement, etc. Technically, the FOS used in foundation is not a factor of safety on the strength of the foundation, but is a factor to limit the settlement at serviceability based on experience of most soils for which relatively stiff and linear behavior will persist if the stress levels are kept below about 30 to 50% of their ultimate capacities (Atkinson, 2007).

Commonly, the unit shaft friction and unit end bearing are obtained from correlation with SPT-N value primarily for residual type of soil. Many studies have been conducted and adopted in today practise where the pile geotechnical capacity is calculated based on SPT-N correlation. Pile design is often verified through pile load tests and is essential to ensure that settlement of the pile would comply with the permissible settlements as per the standards or code requirement.

In today construction, instrumented and working pile load test such as static load test, high strain dynamic load test and even bi-directional load test have been widely carried out. With the huge amount of load test data, study can be undertaken to refine the correlation based on field performance data. Commonly in residual soil, unit end bearing and unit shaft friction are obtained from correlation with field performance data such as SPT-N value.

Considering the different types of soil in Malaysia, different stiffness of residual soil could lead to different unit shaft friction value. With the huge pool of instrumented pile load test data in Klang Valley, Malaysia, there is possibility of developing a realistic unit shaft friction and end bearing correlation to suit with Klang Valley ground condition and further enhance the existing correlation. Study can be carried out to assess the possibility of pile length optimization if higher shaft resistance factor and end bearing factor can be used for different layer of soil (Varies in SPT-N).

This paper studied the relationship between shaft resistance/end bearing and SPT-N blow in different geology formation and discuss the possible correlation which can be developed from load test results.

2. LITERATURE REVIEW

2.1 General Geology of Klang Valley

Klang Valley is defined as an area in Malaysia which centered in Kuala Lumpur and include the surrounding cities of Selangor state. The largely Lower Palaezoic rocks extend southwards along the Western Belt into Selangor and the Federal Territory of Kuala Lumpur. The Kuala Lumpur Limestone is overlain unconformably by the more gently folded Carboniferous to Permian Kenny Hill Formation, estimated to be about 1200 to 1500 m thick, that is exposed in several places notably towards the south of Kuala Lumpur, from Petaling Jaya and Puchong to Kajang and Putrajaya. The Kenny Hill Formation named after Kenny Hill (Bukit Tunku) in Kuala Lumpur is a monotonous clastic sequence of interbedded shale, mudstone and sandstone. The Kenny Hill Formation (Yin, 1976; Foo, 1983) shows both soft-sediment deformation structures and multiple tectonic deformations.

On the other hand, the intrusion of granitic rock, mainly light-grey, coarse-grained biotite granite occupies the hills and the undulating area around Kuala Lumpur except in the south. The granite has intruded into the older sedimentary rocks and has caused tilting and warping of the Kuala Lumpur Limestones and Kenny Hill Formation. The contacts between the granite and sedimentary rocks are generally covered by thick alluvial or superficial deposits during Quaternary period (Komoo, 1989).

2.2 Existing Correlation with Field Data

The current design practice in Malaysia is based on the conventional approach which is the working stress method. The working load acting on the pile shall always be lesser than allowable carrying capacity of pile. Several correlation for calculating fsu and fbu using SPT-N values have been proposed by different authors. Meyerhof

(1976) suggested the ultimate unit end bearing, fb in a homogeneous granular soil for displacement piles as:

$$fb = 40Nb\ (Db/B) < 400Nb \quad (1)$$

where Nb is the average value of SPT-N at the pile base and Db/B is the average depth ratio of the base into bearing stratum.

Other authors suggested a common equation as below.

$$fbu = Kbu \times SPT\text{-}N \quad (2)$$

where Chiu and Perumalswamy (1987) recommended Kbu to be 50 and Toh et al. (1989) proposed Kbu values between 27 and 60.

The relationship for shaft friction in correlation to SPT-N values is generally expressed as below.

$$fsu = Ksu \times SPT\text{-}N \quad (3)$$

Meyerhof (1976) suggested Ksu to be 2.0 while Chiu and Perumalswamy (1987) have adopted 2.5. Toh et al. (1989) recommended Ksu ranges between 2.5 and 2.7 for N values up to 120 and a lower values of Ksu should be used for greater N values.

Established local correlations uses 2.0 as Ksu with fsu limited to 200 kPa for shaft resistance and Kbu = 40 with fbu limited to 4000 kPa for base resistance.

3. METHOD OF STUDY

This research focused on the study of bored pile geotechnical capacity in relation to field performance data such as standard penetration test (SPT-N). This research also study the influence of empirical correlation to the different type of rock formation.

3.1 Data Collection

For the study of bored pile performance, instrumented pile load test results were collected throughout the Klang Valley area. The following data were collected and the summary is indicated in Table 1.

- Data at 14 sites in Klang Valley were gathered.
- 20 numbers of Instrumented Bored Pile were collected with various geological formation.
- Years of testing are from 2012 to 2017.

Table 1 Summary of Data Collection

No	Location	Pile	Year	Formation
1	Site 1	PTP1	2012	Kenny Hill
2	Site 2	PTP1	2013	Granite
3	Site 3	PTP2	2013	Limestone
4	Site 4	RRSN-TP1	2013	Granite
5	Site 4	PTP2	2013	Granite
6	Site 5	TP1	2013	Granite
7	Site 5	TP3	2013	Granite
8	Site 6	PTP1	2013	Granite
9	Site 6	PTP2	2013	Granite
10	Site 6	PTP3	2013	Granite
11	Site 7	BN-122	2013	Limestone
12	Site 7	PTP1	2013	Alluvium
13	Site 8	PTP1	2014	Limestone
14	Site 9	PTP1	2014	Limestone
15	Site 10	P03	2015	Granite
16	Site 11	TP1	2015	Kenny Hill
17	Site 11	TP2	2015	Kenny Hill
18	Site 12	PTP1	2016	Kenny Hill
19	Site 13	PTP1	2016	Granite
20	Site 14	PSLT 01	2017	Granite

The instrumented pile load tests were collected with the following information:

a. Load settlement readings at the pile head.
b. Instrumentation data comprising strain gauges (resistance wire and vibrating wire types) and rod extensometers (tell-tale) along the length of the piles.
c. Soil Investigation data for each pile test.

3.2 Extrapolation of Data

Geotechnical capacity which consist of shaft friction and end bearing can be obtained from the instrumented pile load test. Generally, the ultimate capacity is obtained when the pile is loaded to 3 times of the working load or load to fail which would mobilize the pile. However, non-fail load test would not have mobilized shaft friction and end bearing. Thus, the ultimate capacity would not be able to be determined. Hence, it is important to determine the ultimate or limit load as accurately as possible. Several methods are available to extrapolate the final value to obtain the peak value or resistance of the load test results. Four common extrapolation methods available are Davisson's, Hansen's, Chin's and De Beer's methods.

Davisson's method allow the engineer to extrapolate the maximum value with consideration to the length and size of the pile. On the other hand, Brinch Hansen's method predict the failure based on the assumption that hyperbolic relationships exist between the load and the displacement. For Chin's method, it made assumption that the load-settlement (Q vs Δ) relationship is hyperbolic and hence the inverse slope of a plot of Δ/P (vertical axis) vs P results in the failure value. Lastly in De Beer's method, load settlement values were plotted on double logarithmic chart.

From the 4 methods discussed, Chin's method is deemed to be most suitable for extrapolation of data considering its simplistic approach and independent from any soil condition. Chin's method make it possible to predict the ultimate resistance even if the head settlement did not reach 10% of the pile diameter. However, the extrapolation value become more accurate when the head settlement approaches 10% of pile diameter.

A proposal by Borel et. al (2004) in his research indicated that the Chin method over predicts significantly the shaft resistance when the load is mainly resisted by the toe. The absolute error made can exceed 30% of the ultimate resistance which is independently of the percentage of load carried by the shaft. Therefore, the value extrapolated by Chin method has been reduced by 20% in order to represent the actual ultimate capacity.

3.3 Instrumented Bored Pile Load Test

Instrumented pile load test has been commonly adopted by designer and accepted by most of the client before commencement of actual piling work in the recent years. The awareness of instrumented load test has grown exponentially over the years. Client understand that instrumented load test is able to determine the capacity of pile and to verify the design parameters in relation to shaft and base resistance. Thus, optimization can be explored which would result in economic design.

In the selection of instrumented pile load test, several general rules were observed as below:

- Pile used in the load test shall be constructed similarly with the working pile.
- The test pile could be smaller than the actual working pile but limited to 50% of the working pile diameter.
- Location of the test pile must be similar to the working pile's ground condition.
- Test pile shall be carried out within the same site with the working pile.
- Instrumented pile shall be tested to 3 times working load or failure. Otherwise, extrapolation of data shall be carried out.

All the test pile selected must be installed with instruments where the arrangement generally consist of 4 nos of Vibrating Wire

Strain Gauges (VWSG) and Tell-tale Extensometer at each soil layer. Figure 1 indicated the typical arrangement of the instruments. Photo of instrumented piles and type of load test are indicated in Figure 2, 3, 4 and 5.

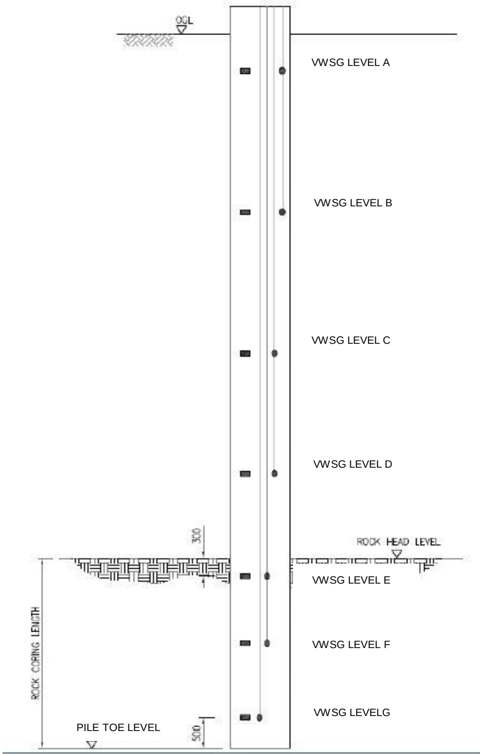

Figure 1 Typical Arrangement of Instruments for Pile Load Test

Figure 2 Vibrating Wire Strain Gauges

Figure 3 Reaction Pile Load Test

Figure 4 Bi-directional Load Test

Figure 5 Kentledge (Static) Load Test

3.3 Correlation between Pile Load Tests and Field Data

From the large pool of load test results, tabulation can be carried out to determine the relationship between shaft resistance and base resistance with field performance data ie. borehole results. In the process of analyzing the result, several assumption have been made.

i. The piles were vertical and no eccentric loading.
ii. All the strains measured in the piles were due to compressive force only.
iii. The cross sectional area and circumference of the test piles were assumed to be constant through the pile length.
iv. Elastic modulus of pile is assumed to be equal to elastic modulus of concrete material of the pile.

The procedures used in the data analysis of the instrumented piles and tabulation of data are as follows:

i. Only ultimate/maximum shaft friction and end bearing values are collected. For load test that have not reach failure state, extrapolation using Chin's method are adopted to obtain the maximum capacity.
ii. Load test selected must be fully instrumented with both strain gauges and extensometers installed along the length of the piles.
iii. The depth of the strain gauges were measured from the top of the pile.
iv. Graphs were plotted for ultimate end bearing against Pb/Ptop, ultimate shaft friction/N against SPT-N and ultimate end bearing/N against SPT-N based on different types of geology.

4. RESULTS AND DISCUSSION

4.1 Relationship between Pile Capacity and Field-Performance Data

From the collected load test results, studies were conducted to correlate the pile geotechnical capacity in term of shaft friction and end bearing with field performance data primarily standard penetration test (SPT-N). Standard penetration test is the most common soil investigation method used in most of the development site. Furthermore, designers in Malaysia have been using SPT-N correlation based on modified Meyerhoff approach to obtain pile capacity for many years.

4.1.1 Shaft Resistance

In this study, correlation of SPT-N with shaft friction, fsu for 3 different geology conditions are looked at to obtain a refinement to current practice. Figure 6, 7 and 8 indicate the relationship between f_{su}/N and SPT-N for granite formation, limestone formation and Kenny Hill formation respectively.

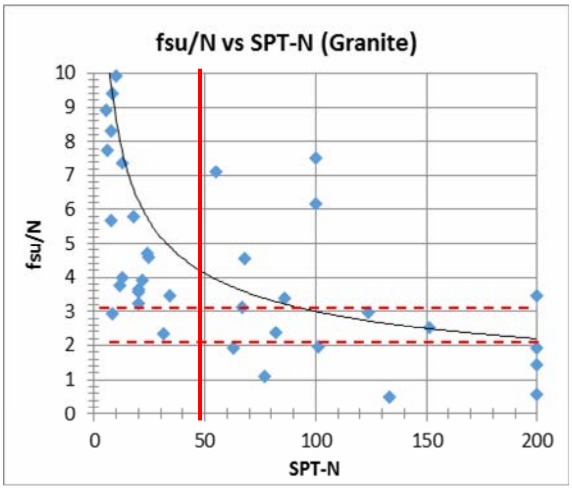

Figure 6 Relationship between fsu/N and SPT-N for Granite formation

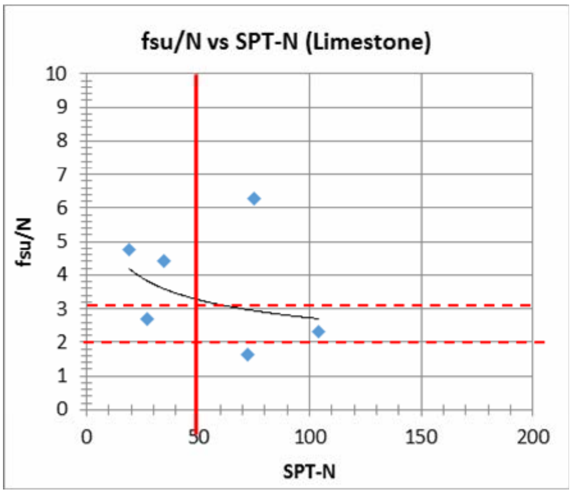

Figure 7 Relationship between fsu/N and SPT-N for Limestone formation

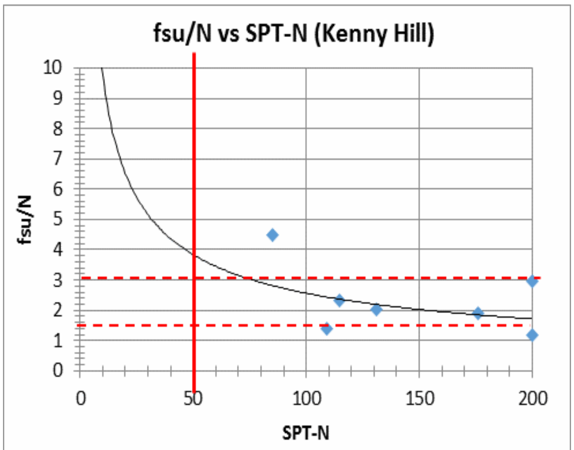

Figure 8 Relationship between fsu/N and SPT-N for Kenny Hill formation

4.1.2 Base Resistance

For end bearing, study has been carried out to obtain correlation of bearing capacity (fbu) for soil and rock with reference to Pb/Ptop. Two (2) graphs which show the relationship between Pb/Ptop and ultimate end bearing are shown in Figure 9 and 10 below.

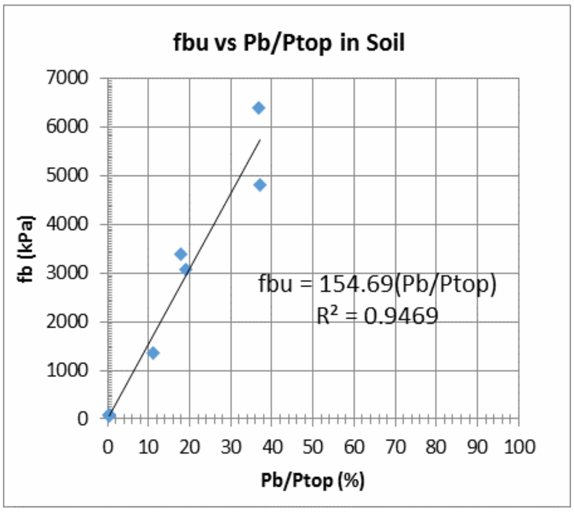

Figure 9 Relationship between fbu and Pb/Ptop in soil

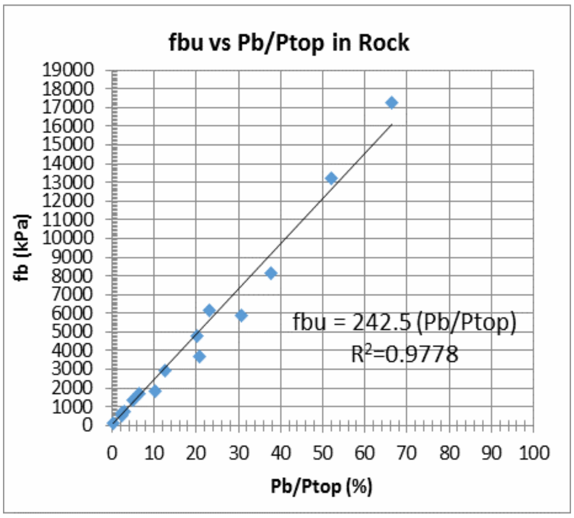

Figure 10 Relationship between fbu and Pb/Ptop in rock

From the plotted graph in Figure 9 and 10, the summary of the developed equation and R^2 percentage are listed in Table 2.

Table 2 Summary of relationship between fbu and Pb/Ptop for soil and rock

Material	Relationship between fbu and Pb/Ptop	R^2 (%)
Soil	fbu = 154.69 (Pb/Ptop)	95
Rock	fbu = 242.5 (Pb/Ptop)	98

For both condition, R-squared of more than 90% are achieved.

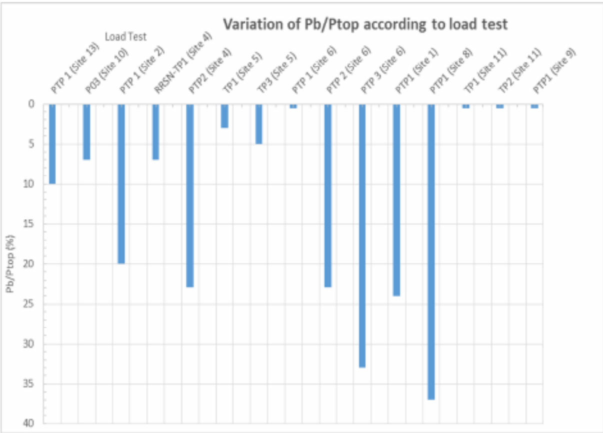

Figure 11 Bar Chart for variation of Pb/Ptop according to load test

From Figure 11, almost half of the collected load tests indicated Pb/Ptop ranges from 20% to 40% at 12.5 mm settlement while the rest of the load tests showed Pb/Ptop less than 10%. An average value of 12% is tabulated from the 20 numbers of load tests carried out.

4.2 Discussion

From the graph plotted between fsu/N and SPT-N for three (3) different types of rock geology as in Figure 6, 7 and 8, a relationship can be derived. All the 3 plotted graphs indicated higher fsu/N can be obtained for SPT-N < 50. Once SPT-N > 50, the fsu/N ratio decreased substantially which shown an almost consistent pattern. This study indicates that fsu/N of more than 3.0 can be adopted in soil with SPT-N < 50. For soil with SPT-N > 50, fsu/N became almost consistent and fall within the range of 2 to 3. Therefore, possibility of using higher fsu/N ratio can be considered for soil with SPT-N < 50. However, load test shall always be carried out to verify the assumption made in design.

In term of base resistance, study has been carried out for two (2) condition which are pile socket into rock and pile socket into hard layer of soil. Relationship between Pb/Ptop and SPT-N blows for all the collected load test results have been plotted. Out of 20 numbers of load test data, 16 number of load tests terminated at rock while the remaining load test terminated in soil. The findings show a good match of data where the R-squared for both condition are above 90%. The equation are as below:

$$fbu = 154.69\ (Pb/Ptop) \text{ for soil} \quad (4)$$

$$fbu = 242.5\ (Pb/Ptop) \text{ for rock} \quad (5)$$

The bar chart as in Figure 11 indicated a variation of Pb/Ptop ratio in between 0.5% and 40%. The average value for all the collected load test data is calculated to be 12%. The average Pb/Ptop value obtained is almost in agreement to the industry practice where the end bearing capacity of bored pile is normally limited to 20% of working load. At Pb/Ptop = 12%, the fbu in soil is calculated to be 1856 kN while fbu in rock is 2910 kN. Fbu of 1856 kN is correlated to be 37N in soil. This correlation is within the range recommended by other authors such as Chiu & Perumalswamy (1987) and Toh et al. (1989). In addition, 37N correlation is also in agreement with the local practise of 40N. Thus, this study validate the existing correlation used for end bearing.

5. CONCLUSION

From the study done on the collected test results, the following conclusion are drawn:

a. The subsoil profile in Klang Valley consist of varies geology mainly Kenny Hill, Granite and Limestone formation. With this varies formation, study has been carried out to determine the influence toward the fsu/N ratio. From the study, Kenny Hill and Limestone formation indicated almost similar value and close to the existing correlation proposed by other authors but granite formation provided a higher fsu/N ratio. As Granite is an igneous type of rock while Kenny Hill and Limestone are sedimentary type of rock, it is believed that different type of rock formation would influence the fsu/N ratio.
b. Some of the load tests have not reach the maximum capacity. Extrapolation using Chin's method deemed to be suitable to obtain the ultimate capacity.
c. Relationship between fsu/N and SPT-N indicated that higher fsu/N can be obtained for SPT-N < 50 while fsu/N ratio drop to a consistent range of 2 and 3 for SPT-N > 50. Therefore, higher fsu/N can be adopted for soil with SPT-N < 50 but verification using instrumented pile load test is highly recommended.
d. For correlation of end bearing, 2 type of conditions are considered which are pile in soil and pile in rock. Based on the plotted graph between fbu and Pb/Ptop, the correlation of end bearing are proposed as in equation 4 and 5. Both of the correlation indicated high value of R-squared of more than 95% which indicate a good fit for all the data.
e. The obtained end bearing correlation with SPT-N blow for soil is within the recommended correlation by other authors. In addition, the finding also validate the existing correlation used in local practise.

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