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Characterization of Index Properties of Low Plasticity Clay for Permeability Test

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Abstract: *This study investigates the index properties of low plasticity clay to better understand the geotechnical behavior of the soil. The soil samples used for this research were collected from Harrison Plaza, Manila. All tests were performed following the ASTM standards, including Atterberg limits, specific gravity, compaction, particle size distribution, and relative density. The results gathered from the tests showed that the soil has a specific gravity of 2.52, a plasticity index of 6.09%, and a void ratio of 1.12, indicating the soil's dense state and moderate compaction potential. These findings suggest that low plasticity clay has low compressibility, fair water-holding capacity, and suitable strength characteristics for engineering applications. The study aims to contribute to providing predictive models that can help reduce reliance on repetitive index testing.*

Keywords: Low plasticity clay; index properties; permeability; relative density; Atterberg limits

1. INTRODUCTION

Determining the different index properties of soils is a fundamental aspect in geotechnical engineering. This is because identifying the index properties of soils would provide essential insights into how the soil would behave under varying environmental and loading conditions. Index properties of the soil are used for project design, land development, slope stability, disaster risk mitigation, stabilization, and other relevant utilization. In the case of fine-grained soils like clay, index properties are highly important since these characteristics significantly influence the permeability, strength, compressibility, and overall stability of the soil. Particularly, low plasticity clay is known to have intermediate plasticity, relatively low compressibility, and has a reduced range of moisture content. With its index properties, low plasticity clays can retain less water, and are less prone to swelling and shrinking compared to high-plasticity clays. In engineering applications, the rate at which water can flow through clay can determine the success or failure of a project. Low plasticity clay usually exhibits lower permeability than sandy soils but is higher than high plasticity clays, which makes its behavior unique depending on its mineralogical composition and in-situ conditions. [8]

While low plasticity clay is commonly encountered in many regions of the Philippines, it remains under-characterized in terms of its geotechnical behavior. The Philippines is a part of the Southeast region of Asia where countries typically experience warm temperatures, high humidity, and abundant rainfall. Notably, the Philippines, being on the Pacific Ring of Fire, commonly encounter heavy rainfall and fluctuating groundwater levels. [1 & 5] With this, it is vital to understand the index properties of locally available low plasticity clays in order for engineers to understand its soil mechanics and utilize the soil for project use. In tropical climates, these areas experience climates that constantly alternate between wet and dry seasons which can lead to significant changes in soil moisture content. This would then affect the soil's strength, volume stability, and shear resistance. With the warm and humid conditions of these areas, it causes intense weathering of parent rock material, often leading to the formation of residual soils. These residual low plasticity clays, though commonly used in construction, are often overlooked in detailed geotechnical investigations as compared to other types of soil. [2 & 7]

This research focuses on the evaluation of the index properties of low plasticity clay. Laboratory tests such as specific gravity, Atterberg limits, hydrometer analysis, sieve analysis, and relative density tests will be conducted to provide an overview of the characteristics of the sample. The study aims to lessen the need to conduct index tests by providing a general idea of the soil properties of low plasticity clays that can be used to create a predictive framework for assessing soil performance. Such correlations can aid in preliminary site assessments, soil classification efforts, and can also be used in other tests

By examining the geotechnical characteristics of low plasticity clays, the study can help contribute by providing a better understanding on how the said soil would behave under local environmental conditions. The results from this study can be utilized for the enhancement of soil suitability assessments, creating civil engineering designs, and support the development of standards for earthwork projects. Moreover, the findings from this study may be applicable to other areas that have similar geological and climatic conditions. This is especially important for regions that are also prone to flooding, erosion, or slope instability, since improper soil characterization can lead to structural failures or environmental degradation.

2. MATERIALS

2.1 Low Plasticity Clay

The low plasticity clay samples that will be used in this research were sourced from the construction site located in Harrison Plaza, Manila, Philippines.

The acquired soil sample is not uniformly clay all throughout and has sands, silts, and debris mixed to the overall sample. Hence, to acquire clay materials finer than No. 200 (75-µm) sieve, the soil sample must undergo sieve washing following the standards provided by the American Society for Testing and Materials (ASTM) D1140. The practice will start by collecting about 500 g of low plasticity clay and will then be saturated with hot water to help break it down, any debris found in the soil will be removed. The soil will be washed through a No. 200 sieve using gentle agitation, to prevent breaking the wire mesh in the sieve, to separate the fine clay from any sand or debris found in the soil. The retained clay will then be left to settle so that the excess water can be removed. The samples will then be placed in an oven to dry any remaining water. Once dry, the clay will be grinded for use in laboratory experiments.

3. METHODOLOGY

This study will use a quantitative experimental method approach by relying on the data gathered from laboratory experiments to interpret the results. The sampling and testing procedures will follow the ASTM standards to ensure accuracy and consistency of the results, refer to Fig. 1. All laboratory experiments will be conducted at the Geotechnical Engineering Laboratory in the St. Miguel Building of De La Salle University - Manila.

3.1 Specific Gravity Tests (ASTM D584)

The specific gravity of soils is defined as the ratio of the density of soil solids to the density of water at a standard temperature. Other factors, such as relative density, are dependent on the values attained through this test. The test procedure begins by getting the weight of an empty flask and pan container. 500 mL of distilled water is then added into the flask and then recording the combined weight, the water is cooled to room temperature to ensure uniformity in mass and volume. After that, approximately half of the water should be removed from the flask, and 150 grams of low-plastic clay soil is then added into the flask. Agitate the flask continuously until the mixture inside becomes homogeneous. During agitation, air bubbles may form and must be removed using a vacuum system for 10 minutes. Once de-aired, refill with water to the 500 mL mark in the flask, and record the new weight. Transfer the soil mixture into a pan and place into a drying oven. Once the soil mixture has dried, record the final weight of the soil.

3.2 Atterberg Limits Test (ASTM D4318)

The Atterberg Limits aim to determine the moisture content of fine-grained soils through its Plastic Limit, Liquid Limit, and Plasticity Index. These limits would define the behavior of the low plasticity clay under various moisture contents that can be used in determining the soil's compressibility, permeability, compactibility, shrink-swell, and shear strength.

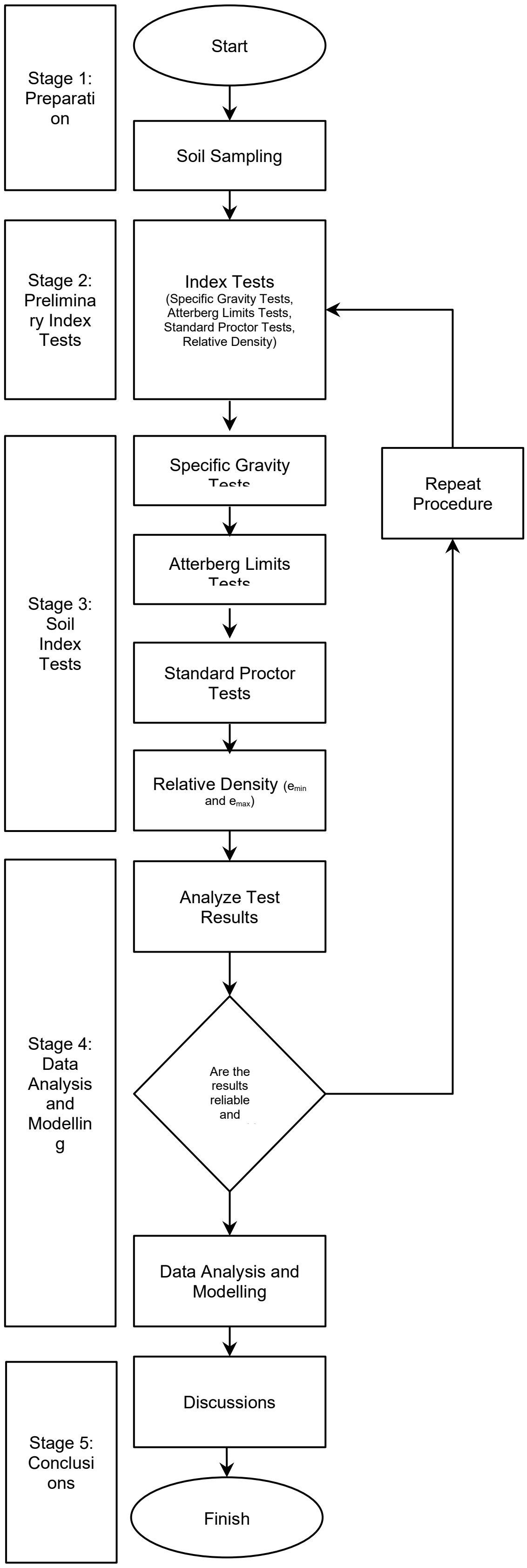

Fig. 1 Flowchart of Experiment

3.2.1 Liquid Limit

Liquid limit is defined as the limit where the fine-grained soil contains enough water content to behave like a liquid. The test starts by mixing oven-dried clay with water until it reaches a dough-like consistency. The soil is then placed into a brass cup to a depth of around 10 mm, and a groove is made in the center using the beveled edge of a standard grooving tool. The cup is then mounted onto the device and dropped repeatedly by turning the crank at a rate of two drops per second until the groove closes over a length of 0.5 inch. Once this happens, about 50 grams of soil, preferably from the center, is collected, and weighed. Place the collected sample into an oven and record the weight once the sample is done drying to calculate its moisture content and liquid limit.

3.2.2 Plastic Limit

Plastic Limit is the moisture content at which a fine-grained soil changes from a plastic state to a semi-solid state. The procedure starts by mixing clay with water until it reaches a dough-like consistency. A small portion of the mixture (about 1.5 to 2.0 grams) is hand-rolled on a glass plate into a thread, roughly 2.2 mm in diameter, then repeat the process until the thread starts to break apart. Gather at least 6 grams of the crumbled pieces into a moisture can then measure its weight. Place the collected sample into an oven and record the weight once the sample is done drying to determine the plastic limit.

3.2.3 Plasticity Index

The plasticity index is a numerical value representing the range of water content over which a soil remains in a plastic state. To get the plasticity index, get the difference between the computed liquid limit from the experiment and the computed plastic limit from the experiment.

3.3 Standard Proctor Test (ASTM D698)

The Standard Proctor Test is used to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil by generating a compaction curve from the results. The procedure begins by weighing the containers and mold to be used. Other than weighing the mold, record the dimensions of the mold as well. Prepare around 3 kg of soil, that was sieved through sieve No. 4, and moisten it gradually. Compact it into the mold in three layers, then deliver 25 blows from a standard rammer per layer. After the mold is filled, a soil sample per layer is collected. Weigh the soil sample added per layer and place the soil sample into a drying oven. Record the weight of the dried soil that will be used for moisture content analysis. This process is repeated in three trials with progressively higher moisture content in order to determine the MDD and OMC of the soil.

3.4 Particle Size Distribution

Particle Size Distribution, or also known as the Grain-Size Distribution Curve, refers to the range of particle sizes present in a soil sample. In usual situations soil mass consists of particles of many different sizes, particles' size range may vary from coarse to fine in just one sample. It can be conducted through different tests such as sieving, laser diffraction, microscopy, etc. The texture measurement in a soil characterization is only an approximate measure of the amount of each particle size group in a soil sample. By performing the Particle Size Distribution test, these estimates can be checked by measuring quantitatively the amount of each of the particle sizes in a sample. Sand is the largest soil particle size (2.0 mm - 0.05 mm), silt is intermediate in size (0.05 mm - 0.002 mm), and clay is the smallest (less than 0.002 mm). Since the soil sample used for this experiment is clay, it is expected that the size of the soil would be less than 0.002 mm and would pass the No. 200 sieve. For this research, hydrometer analysis and sieve analysis were used to determine the particle size distribution of low plasticity clay.

3.4.1 Hydrometer Analysis (ASTM D7928)

Hydrometer analysis is a method used to determine the particle size distribution of fine-grained soils (silt and clay) by measuring the rate at which they settle out of suspension in a liquid. To perform the procedure, start by obtaining at most 200 grams of low plasticity clay that have passed sieve No. 4, and place it in a beaker filled with 250 mL of distilled water. Mix the clay-water mixture for 10 minutes using a blender or by hand. After mixing, transfer the mixture into a sedimentation cylinder and fill it with distilled water until it reaches the 900 to 950 mL mark. After doing so, seal the cylinder with a rubber stopper and alternately turn the cylinder upside down and back upright for one minute. Once done, fill the cylinder with distilled water until it reaches the 1000 mL mark, and immediately place the cylinder in a water bath. Insert the hydrometer into the cylinder and record the readings and temperature. Ensure to record the readings in time intervals of: 2, 5, 15, 30, 60, 120, 240, and 1,400 (in minutes).

3.4.2 Sieve Analysis (ASTM D6913)

Sieve analysis is used to determine the grain size distribution of soils which have a diameter that is greater than 0.075 mm. To perform the test, weigh each empty sieve that will be used. After that, obtain 500 grams of soil and prepare the sieve stack chronologically with a pan at the bottom to collect soil particles that would pass through the No. 200 sieve. Pour the soil into the top sieve and securely cover it with the lid to ensure that no soil would be spilled when placed in the machine. Place the sieve stack in a mechanical sieve shaker and run the shaker for 5 minutes. Once done, weigh each sieve individually to record the amount of soil retained on each sieve.

3.5 Relative Density Test

The relative density test measures the compactness of soils, in comparison to their loosest and densest possible states. This method is used by comparing its in-situ density to its maximum index density (e_{max}) and the minimum index density (e_{min}) to get the computed void ratio ($e_{computed}$) of the soil. By getting the void ratio, this would determine the density of the soil that would show the compressibility and load bearing capacity of the soil sample.

3.5.1 e_{max} (ASTM D4253)

ASTM D4253 focuses on acquiring the maximum index density of the soil. To perform the experiment, begin by weighing the mold and recording its dimensions. Fill the mold with low plasticity clay and position the surcharge weight on top to replicate overburden pressure. Place the mold on the vibrating table and vibrate it at 60 Hz for 8 minutes. Afterward, weigh the mold with the compacted soil and calculate the e_{max} based on the results gathered from data.

3.5.2 e_{min} (ASTM D4254)

ASTM D4254 focuses on acquiring the minimum index density of the soil. To perform the experiment, begin by weighing the mold and recording its dimensions. Fill the mold with low plasticity clay from a height of an inch (approx. 25 mm), make sure to avoid any vibration, tamping, or compaction, and then use a straightedge to level the soil surface. Place the mold on the vibrating table and vibrate it at 60 Hz for 8 minutes. Afterward, weigh the mold with the compacted soil and calculate the e_{min} based on the results gathered from data.

4. DISCUSSION

4.1 Specific Gravity

The specific gravity for low plasticity clays ranges from 2.6 to 2.7 according to the American Association of Highway and Transportation Officials (AASHTO). Through conducting numerous tests, a specific gravity of 2.52 for low plasticity clay is attained. Since the value is slightly lower than the average value for low plasticity clays, this indicates that the soil particles may have lower compressibility, density, and shear strength. The lower value for specific gravity may be due to the presence of organic materials found in the soil. Another factor that may have also affected these results is the tropical or alluvial environment where the soil was sourced from which can be affected by weathering or mixed grain composition.

Table. 1 Summary of Results of Specific Gravity Test of Low Plasticity Clay

Specific Gravity Test Results			
	Trial 1	Trial 2	Trial 3
Specific Gravity	2.65	2.53	2.38
Average		2.52	

4.2 Atterberg Limits

The average percentage value for liquid limits for low plasticity clays ranges from 15% to 25%, meanwhile for plastic limit, the percentage ranges from 25% to 35%. [6] In this study, the soil sample exhibited a liquid limit of 29.84%, a plastic limit of 23.75%, and a plasticity index of 6.09%. The computed values had a slight deviation from the expected range, with the liquid limit being slightly higher and the plastic limit slightly lower, while the plasticity index remains within the low plasticity category. This suggests that the soil has limited plastic behavior and has relatively low compressibility. This makes it suitable for applications where volume stability is important, such as subgrade layers or structural fills in areas, since the soil exhibits moderate moisture fluctuations.

The plastic limit value of 23.75% suggests that the soil can be molded without cracking at moderate moisture levels, indicating good workability and a fair water-holding capacity. These characteristics are consistent with fine-grained soils like silts and clays, which tend to exhibit cohesive behavior and moderate permeability. The low plasticity index also implies that the soil will not undergo any significant changes in consistency when slight variations are applied in the soil's moisture content.

Table. 2 Summary of Results of Atterberg Limits Test of Low Plasticity Clay

Atterberg Limits Test Results	
Liquid Limit	29.84%
Plastic Limit	23.75%
Plasticity Index	6.09%

4.3 Standard Proctor Test

As seen in the plotted compaction curve found in figure 2, the Standard Proctor Test results for low plasticity clay indicates that there is a clear relationship between the moisture content and dry unit weight of the soil. Results showed that the soil sample had an average water content value that ranges from 32.80% to 50.03%, showing an increasing trend across trials. For the computation, the value for specific gravity used is the same with the one acquired in section 4.1, which was 2.52. Correspondingly, the dry unit weight initially increased with moisture content, peaking at 11.8339 kN/m³, which is the MDD of the soil, at approximately 42.17% moisture content, which is identified as the soil's OMC. Beyond this point, further increases in water content led to a decline in dry unit weight, confirming the typical bell-shaped curve of compaction behavior. Since low plasticity clay is considered as a cohesive soil it can be seen in the graph that excessive moisture reduces compaction efficiency due to water occupying space between soil particles. [3]

Low plasticity clay typically has an average MDD of 13 to 17 kN/m³ and an average OMC of 15% to 25%. [10] The test results showed that the values gathered were not within the average range for low plasticity clay. This may affect the soil's load bearing capacity and resistance to settlement. Factors that could have affected this are the weathering the soil is exposed to, high natural water retention of the soil, and the mineral composition of the soil.

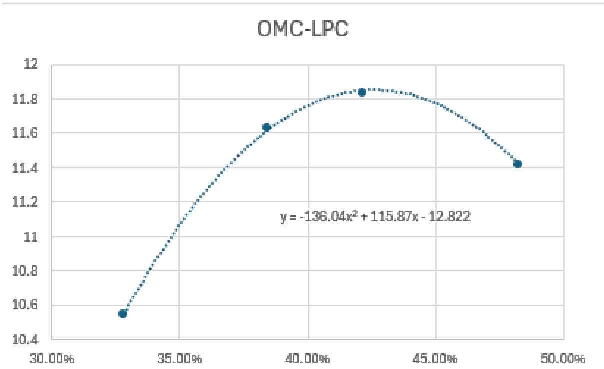

Fig. 2 Compaction Curve for Low Plasticity Clay

4.4 Particle Size Distribution

By conducting both sieve analysis and hydrometer analysis, the summary of the results for particle size distribution can be seen on Figure 3. The graph shows the grain size distribution curve (GSDC) for the soil sample. After conducting the tests, the sieve analysis shows that a majority of the particles found in the sample are finer than 0.075 mm, with 67.32% passing this size, indicating that it is a fine-grained soil.

Meanwhile, the hydrometer analysis further refines the distribution for smaller particles, extending the curve to sizes as small as 0.00136 mm. As seen in the graph, there is a steep increase in the percent finer curve at finer particle sizes, confirming that the soil has dominant clay and silt fractions. The distribution suggests that the soil has poor gradation, which is typical for low plasticity clay, [8] and the negative values at the lowest diameters in the hydrometer analysis may indicate either measurement anomalies or the limit of the testing method's sensitivity.

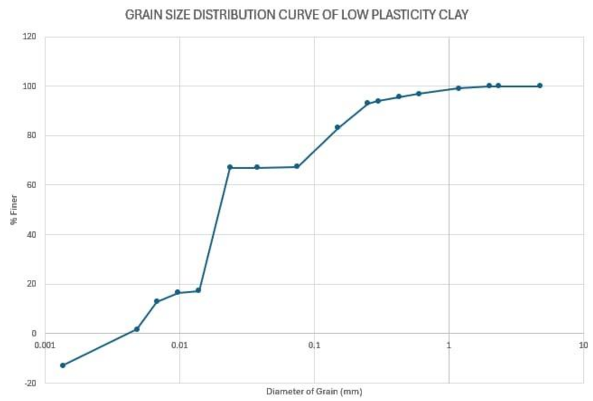

Fig. 3 Grain Size Distribution Curve for Low Plasticity Clay

4.5 Relative Density

The results gathered from the experiment showed that the soil had a void ratio ($e_{computed}$) of 1.12, maximum dry unit weight (γd_{max}) of 11.83 kN/m³, while the minimum dry unit weight (γd_{min}) was 10.30 kN/m³. Other than these values, the average maximum and minimum void ratios were also calculated which had values of 1.40 and 1.09, respectively. These values indicate that the soil has a relatively narrow range of density variation, which is typical for cohesive soils like low plasticity clays. The computed relative density (Dr) of 0.90 suggests that the soil sample was in a very dense state relative to its loosest and densest possible conditions. This implies that the soil has low compressibility, similar with previous tests, and good load-bearing capacity when compacted appropriately. [9]

Table. 3 Summary of Results of Relative Density Test of Low Plasticity Clay

Relative Density Test Results at 90%		
	emin	*emax*
Trial 1	1.095231241	1.453437722
Trial 2	1.078175329	1.378495458
Trial 3	1.102128181	1.373740844
Average	1.091844917	1.401891341
$e_{computed}$	1.122849559	

5. CONCLUSION

Based on the findings and analysis done for this study, it can be concluded that the low plasticity clay sourced from Harrison Plaza, Manila, exhibits geotechnical characteristics that align with its typical classification under the Unified Soil Classification System (USCS), but also has differing values which may be due to local influences. Based on the test results, the soil had a specific gravity of 2.52, which is slightly below the typical range, which may suggest that the soil has a presence of organic matter or the effects of prolonged weathering in a tropical climate.

The Atterberg limit results had a plasticity index of 6.09%, which falls within the low plasticity range, supporting its classification and indicates a limited range of moisture content over which the soil remains plastic. This implies that the soil exhibits low compressibility and a moderate capacity to retain moisture. This means that the soil can be used in subgrade layers and as backfill material where excessive deformation or water sensitivity compromises the structural performance. For areas with fluctuating humidity, a soil having low plasticity index would be favorable since it would have minimal shrink-swell potential.

The Standard Proctor Test identified an optimum moisture content of 42.17% and a maximum dry density of 11.83 kN/m³. The values were slightly outside typical range values, suggesting that this specific clay may require specialized handling in compaction processes. The high OMC indicates that more water is required to achieve the soil's densest configuration, possibly due to the fine particle size and the presence of hydrophilic clay minerals. The relatively low dry density suggests that the soil may be lightweight or porous in nature.

Additionally, the particle size distribution analysis confirmed the soil's fine-grained nature, containing prominent clay and silt fractions. The poor gradation observed, characterized by a lack of coarser particles and a uniform particle size, is typical for low plasticity clays and contributes to the soil's reduced permeability and cohesiveness.

The relative density test produced a void ratio of 1.12 and a high relative density of 0.90, indicating a densely packed soil structure. These results demonstrate the dense state of the soil and the potential of the soil for good load-bearing capacity when properly compacted, making it suitable for applications that requires stable and durable subgrades.

In regions that experience challenging environmental conditions, particularly those in tropical climates characterized by intense rainfall, fluctuating temperatures, and seasonal drying, these findings emphasize the necessity of localized soil characterization. If future research rely solely on general soil classification can lead to oversight of unique soil behaviors influenced by climate, vegetation, and anthropogenic activities.

The study shows that the index properties of soils may diverge from the expected average range values which may be affected by local environmental factors. In countries like the Philippines, where climatic factors such as high temperatures, seasonal rainfall, and varying humidity levels prevail, these influences can alter the behavior and engineering performance of native soils.

Overall, this study aims to contribute valuable baseline data on low plasticity clay, sourced from areas that experience similar tropical conditions. This data can be used for creating a predictive framework and reducing the dependence on repetitive and costs on soil testing for the use of future research and engineering design.

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