INVESTIGATION OF IGUORHIAKHI SOIL AS POTENTIAL COMPACTED SOIL LINER FOR SANITARY LANDFILL

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Abstract
Consideration for the establishment of sanitary landfill, include amongst other things, copious availability of clay Compacted Liner materials, used to prevent the pollution of underground water and soil conditions. The soil at Iguorhiakhi was examined to determine its suitability as a candidate liner material in its natural state and when cement, lime and a combination of cement and lime were added as stabilizing agentsRecast this phrase.. Investigations revealed that the natural soil is sufficiently adequate as a barrier material, and the stabilising agents, irrespective of their quantities, did little to improve the barrier characteristics of the soil. Some correlation and predictability were however recorded especially for the moisture content and the liquid limit when a combination of cement and lime was used as the stabilizing agent than when cement and lime were used separately.

Keyword: *Landfill, Stabilizing Agents, Soil, Cement, Lime, Liquid Limit and Moisture Content.*

Introduction

The prevention of contamination of underground water storage arising from leachate of landfills is one of the cardinal considerations in the sitting of sanitary landfills. Other considerations such as the protection of the barrier layer from burrow animals, wind and water erosion are also factored into the planning phase of the choice of barrier material that can be used for a particular landfill . Barrier layers in landfill must have low hydraulic conductivity and high compactibility to minimised fluid flow. Compacted soil layers (CSL) and manufactured geo-synthetic clay layer (GCL) are often used as barrier materials due to their low hydraulic conductivity. GSL attains a low permeability by compacting fine grain soils at their optimum moisture content .

Clay, being relatively impermeable to water, is used where natural seal are needed such as in the cores of dam and as barrier material in landfill against toxic seepage . The use of clay soil materials as barrier below waste disposal sites has been a contentious issue following experimental and field evidence of failure due to clay-leachate incompatibility .However information abound that clay has successfully been employed in the design of contaminated landfill with some measure of success .

Clay properties are somewhat altered when additives such as cement and lime are added to it as stabilising agents. The popular stabilizers used in civil engineering works include, cement, lime and geosynthetic materials. Typical characteristic clay liner materials as presented in include the following:

(a) Coefficient of permeability (hydraulic conductivity) of 1×10^{-9} m/s or less
(b) Minimum clay content of 10%
(c) Minimum Fines (clay & silt) content 30%
(d) Plasticity index > 10% and < 65%
(e) Liquid limit < 90%
(f) Maximum particle size of 75mm.

This study seeks to assess the possibility of using Iguorhiakhi top soil as candidate material for landfill barrier in its natural form or after stabilisation using varying amount of cement, lime and a mixture of cement and lime. The focal point of analysis shall be the optimum moisture content and the liquid limit of the soil samples.

Compacted soil Liners configurations

Available arrangement of the compacted soil liner include the single compacted soil liner and the double compacted liner which are presented in Figure 1. The system comprises of a geomembrane which heavily restrict the movement of fluid from the top of the landfill and reinforced by the compacted clay liner. The clay liner plays the dual of providing support to the geomembrane as well as minimizes leakage arising from the likelydefects in the geomembrane . (Katsumi *et al.,* 2001)

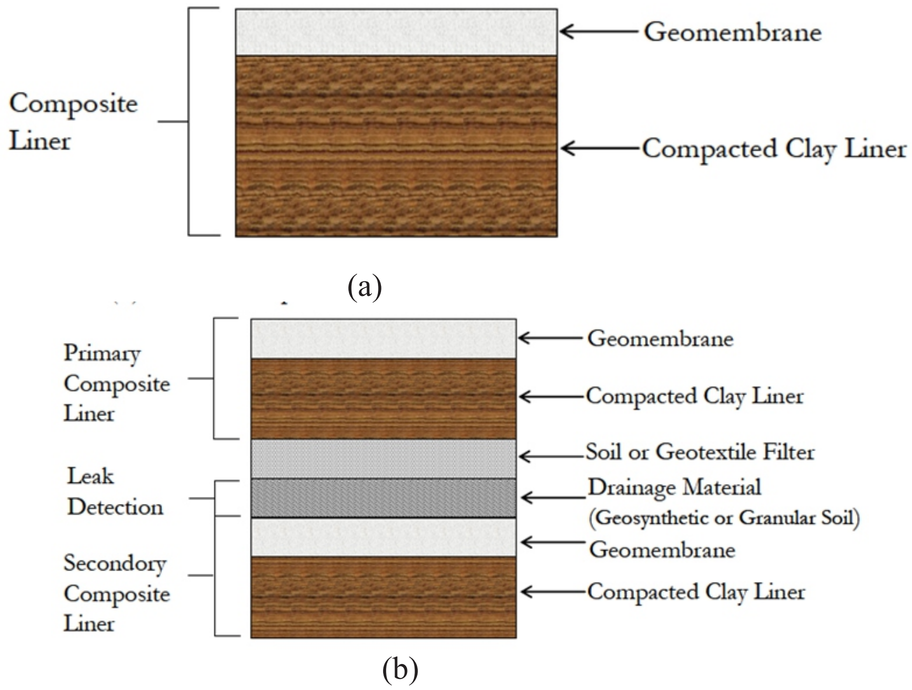

Figure 1: Variant of Compacted Clay Liner used in Sanitary Landfill. Where (a) Single Compacted Liner and (b): double compacted Liners. Source: (Koerne and Daniel, 1997)

1.2 Location Description

Iguoriakhi is a community in Iguobazua town in Ovia South West Local Government Area of Edo state. It is subdivided into two (2) sub-communities: Iguorhiakhi upland and Iguorhiakhi water side. Soil samples were collected from Iguorhiakhi waterside where visual inspection indicated that the soil is sufficiently clayey and possess some barrier properties. The major language spoken in the area is Bini and the dominant means of livelihood is agriculture. The major soil type in the location is the red lateritic soils, which is typical of the Benin Formation. The location lies around latitude 6°33'22.47”N and longitude 5°21'33.80”E. The location map of the study area is shown in Figure 2 below.

Figure 2: Location map showing Iguorhiakhi and environs. (http//maps.googleearth.ca/maps).

MATERIALS AND METHODS

Index Tests on Soils Samples

Index tests were carried out on the soils samples obtained from the project location. The index tests include Specific Gravity tests, Hydrometer tests, Atterberg limits tests, Modified Proctor compaction tests, Triaxial test, consolidation tests and California Bearing Ratio tests. All tests were carried out according to procedure prescribed in (BS EN 1997:2:2007 Eurocode 7, 2007). . One of the suitability criteria considered to place the soil for used as landfill liner is based on the Cassangrade chart as shown in Figure 3. Brief description and computation for the specified tests are presented below:

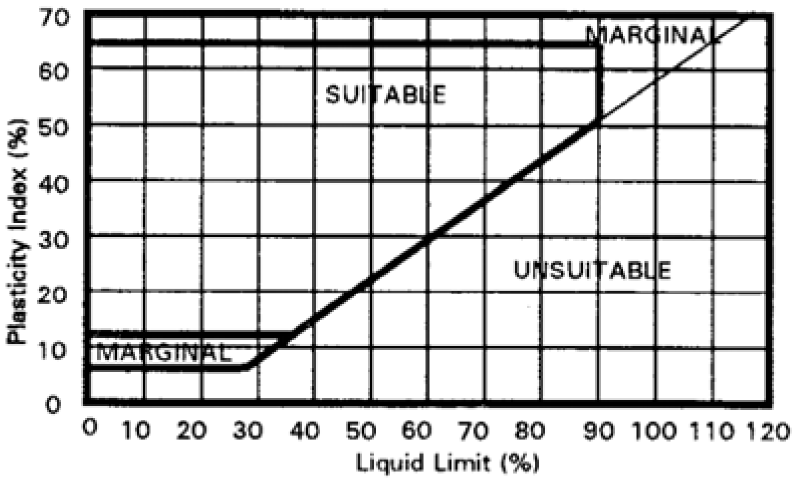

Figure 3: Plasticity and Suitability Criteria of Material for Landfill Liners. Source: (Jones et al., 1995)

Specific gravity Test.

The specific gravity of a soil is the reciprocal of the soil unit weight. It gives an indication of the level of hardness of the soil grain. A measured quantity of the specimen soil is poured in to 50ml density bottle. The quantity of soil should be between 1/4th and 1/2th of the volume of the density bottle. Water is then poured on the bottle with its soil content until it is full. Preferably distilled water is used in this instance. Weight measurement of the bottle with water as the only content and full is noted. The expression for the determination of the specific gravity from these instances is given as

$$G_S = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \text{------------------} (1)$$

Where Gs is specific gravity; M1 is the weight of the empty density bottle; M2 is the weight of the density bottle with the dry soil alone; M3 is the weight of the density bottle containing the specimen soil and water; ; M4 is the weight of the density bottle with water alone (Garg, 2005; Punmia et al., 2005).

2.1.2. Hydrometer Tests

The hydrometer tests is carried out to determine the extremity of the particle sizes in a soil sample. In this test, a 1000ml suspension of soil and dispersing agent is vigorously shaken to ensure proper mixing of the soil and water, leading to escape of air. The procedures for the calibration of the hydrometer bulb and the identification of the effective depth (He) in the sedimentation jar are presented in literature (Punmia et al., 2005; BS EN 1997:2:2007 Eurocode 7, 2007). The hydrometer bulb is inserted into the suspension and allowed to stabilise before readings are taken. Readings are usually taken at intervals of 30sec, 1, 2, 4, 8, 15, 30 minutes and 1, 2, 4 hours. Preferable readings are obtained when the water is at a temperature of 20oc.The fall of soil particles is governed by Stoke's law and is presented in equation (2)

$$D = \sqrt{\frac{18\eta}{\gamma_m (G_s - 1)} \cdot \left(\frac{H_e}{t}\right)} \text{--------------------} (3)$$

Where D is the depth of fall, η, γ_m, H_e and G_s represent the viscosity, unit weight of water at the operating temperature, effective depth and soil specific gravity respectively. t is the time interval of measurement of the fall of the hydrometer bulb in the suspension.

For each computed depth of fall, the percentage of fine (N) in the soil mix is given by:

$$N = \frac{\frac{R}{1000}\left[\frac{G_S}{(G_S - 1)}\right]}{\frac{M}{V}} \text{--------------------} (4)$$

Where *M,* V and R represent the total mass of dry soil sample, volume of suspension and corrected hydrometer reading respectively.

Atterberg Limit Test
The Atterberg limits test is a test that gives the water content in a soil for which it will behave like a liquid or material that can be moulded. The test comprises liquid limit, plastic limit and shrinkage limit tests. The soil used for the test is the soil passing through the 425 μm sieve. The experimental setup and detailed procedures for carrying the liquid limit, plastic limit and shrinkage limit tests are presented in literature (Garg, 2005; Punmia et al., 2005; BS EN 1997:2:2007 Eurocode 7, 2007). The results of the tests are used to plot a flow curve from which the moisture content at 25 blows is taken as the liquid limit of the soil. The difference between the liquid limit and the plastic limit will constitute the plasticity index. The slope of the flow curve, flow index I_f is computed as

$$I_f = \frac{w_2 - w_1}{\log N_1 - \log N_2} \text{------------------} (5)$$

Where N_1 and N_2 are the lowest and highest number of blows corresponding to the moisture contents w_1 and w_2 respectively.

Compaction Tests
The compaction test is used to determine the most adequate amount of water that can be added to a soil to attain its maximum density. The method adopted in this study for the determination of the optimum moisture content and the maximum dry density was the standard Proctor compaction tests. Detailed description of the procedures involved in the standard proctor compaction is presented in (BS EN 1997:2:2007 Eurocode 7, 2007). The output of the standard Proctor compaction is plotted on a compaction curve where the ordinate is the dry density in g/cm^3 and the abscissa is the moisture content in percentage. The compaction curve usually follow a parabolic path where the moisture content and the dry density of the highest crest point is recorded as the optimum moisture content and maximum dry density respectively. The relationship between the optimum moisture content (w) and the maximum dry density Υ_d from which other parameters such as the degree of saturation (S), specific gravity (G_S) and void ratio (e) can be are presented in equations 6 and 7: (Garg, 2005; Punmia et al., 2005)

$$\Upsilon_d = \frac{9.81 G_s}{1 + \frac{wG_s}{S}} \text{----------------------} (6)$$

$$\text{Where } e = \frac{wG_s}{S} \text{--------------------} (7)$$

Consolidation tests
Consolidation of soil involves every process where a decrease in the water content of a saturated soil occurs without replacement of the water by air as a result of an imposed long term static load. The Oedometer is used in carrying the tests for the determination of consolidation parameters such as the coefficient of volume change, the coefficient of compressibility and the coefficient of permeability among others. The procedures and sampling activities for conducting consolidation tests using the Oedometer is as spelt in (Punmia et al., 2005; BS EN 1997:2:2007 Eurocode 7, 2007). The coefficient of volume change (m_v) as computed from the void ratio method is given as

$$m_v = -\frac{\Delta e}{1 + e_0} . \frac{1}{\Delta\sigma'} \text{--------------------} (8)$$

Where Δe and e_o represent change in void ratio and initial void ratio of the soil sample respectively; $\Delta\sigma'$ represent the initial bearing stress based on the imposed load.

The coefficient of consolidation was obtained using the square root of time fitting method with the time-consolidation curve used to obtain the time (t_{90}) of 90% consolidation of the soil. The mathematical expressions for the determination of the coefficient of consolidation (C_v) and the coefficient of permeability (k) are as presented in equation 9 and 10.

$$c_v = \frac{(T_v)_{90}.d^2}{t_{90}} \left(m^2 / \sec\right) ----------------------(9)$$

$$k = 9.81.c_v m_v (\quad / \sec) ----------------------(10)$$

Where $(T_V)_{90}$= Time factor for a 90% degree of saturation considering a single drainage system; d= depth of soil layer; t_{90} = time for the soil to attain a 90% degree of consolidation

X-ray Identification Diffraction Test

The X-Ray diffraction test is used to identify the various structural groups and structural varieties present in a clayey soil sample. It involves subjecting the clay mineral to X-ray radiation using Geiger counter Spectrometer for recording the radiation. Detailed description of the procedures for the identification of minerals in clay soil sample is as presented in (Brindley, 1955).

Stabilisation of Samples

Stabilisation of the soils using substances such as Lime, Cement and 1:1 combination of Cement and Lime were used as stabilizing agents to determine their effects on the soil strength and their likelihood of improving the barrier properties of the soil. These stabilizing agents constituted 3%, 5%, 7%, 9% and 12% of the tested soil samples (Garg, 2005).

Statistical Analysis

Statistical analysis of the liquid limit and the moisture content test results for the soil samples in its natural state as well as when some stabilising agents were added was carried out. Two-way ANOVA analyses were performed with the aid of MATLAB software (Hahn and Valentine, 2002) to determine the level of influence of the specified tests vis-à-vis the variation in the percentage of the stabilizing agents on the strength characteristics of the soil. Correlation computation was also carried out to determine the relationship between the Atterberg liquid limit tests and the moisture content tests. The formula used for the computation of the coefficient of correlation is given as:

$$r = \frac{n\sum x_{si}y_{si} - \left(\sum x_{si}\right)\left(\sum y_{si}\right)}{\left[\sqrt{n\left(\sum x_{si}^2\right) - \left(\sum x_{si}\right)^2}\right].\left[\sqrt{n\left(\sum y_{si}^2\right) - \left(\sum y_{si}\right)^2}\right]} -----------(11)$$

Where r is the coefficient of correlation, s_i is stabilisation (s) with the material *i;* x and y are the two components for correlation determination, i.e. liquid limit and moisture content. n is the number of correlation parameters (Daniel and Eelco Van, 2005).

Results and Discussion

Natural Soil Geotechnical Properties

The existing soil in Iguorhiakhi location of Edo state was found to be high plasticity clayey soil with critical swell-shrinkage characteristics based on the Unified System of Soil Classification. It was shown from (Punmia et al., 2005) that the specific gravity result indicate a soil with sufficient amount of serpentine, which triggers the swell shrinkages characteristics of the soil. The percentage of soil passing the 0.075mm sieve indicated that the soil is sufficiently fine. The coefficient of permeability was lower than those specified in (Jones et al., 1995) for suitable materials that can be used as barrier material for sanitary landfills. Mineral identified by x-ray analysis include Phlogopite, Chrysotile, Osumilite, Hematite, Kaolinite, Illite, Muscorite, Lizardirite, Montmorillorite etc. Table 1 is a summary of the test results.

Table 1: Summary of Geotechnical Properties of Iguorhiakhi Soil in its Natural State.

Test Parameters	Critical Results	Units
Specific Gravity	2.21	%
B.S Wet Sieve 0.075mm size	96.27	%
Hydrometer Analysis No. 618.4 (0.001µm)	**31.414***	%
Average Bulk Density	1.650	g/ cm³
Optimum Moisture Content	28	%
Maximum Dry Density	1.450	g/ cm³
Atterberg Liquid Limit	69.58	%
Plastic Index	45.80	%
Linear Shrinkage	14.29	%
Coefficient of compressibility, a_v	9.542×10^{4}	m²/kN
Coefficient of consolidation, C_v	6.14×10^{-4}	cm²/sec
Coefficient of permeability, K	3.658×10^{10}	m/sec
Stress-strain modulus of the soil, Es	636.36	N/m²
Mineral identification by using X-ray	Phlogopite, Chrysotile, Osumilite, Hematite, Kaolinite, Illite, Muscorite, Dickite, Lizardirite, Montmorillorite, Quartz	

***The minimum size of particle was 0.001µm**

ANOVA Tests on Tests Results

ANOVA Tests for Liquid Limits Results

The liquid limit results after stabilisation are presented in table 2. It can be seen that the liquid limit ranged from 50.40% to 56.00% when cement was used as the stabilizing agent; 51.00% to 54% with lime and 51.70% to 54.50% where a combination of cement and lime is used as the stabilising agent. The critical percentage of cement, lime and their combination were 3%, 5% and 3% respectively. The critical liquid limit value is that liquid limit that tends to move the soil towards the extreme of the fine soil classification. The summary of computation of the two-way analysis of variance of the stabilized liquid limit results are shown in the Figure 4. Figure 5 is a plot of the liquid limit with the stabilization agents, aimed to the show trends of the stabilisation agents.

Table 2: Liquid Limit Results for the Different Additives used As Stabilizer

Percentage additives	Stabilizing Agents (%)		
	Cement only	Lime only	Cement and lime combination
0%	54.00	54.00	54.00
3%	56.00	51.00	54.50
5%	50.20	55.00	53.20
7%	51.50	51.80	51.80
9%	52.00	51.80	52.00
12%	51.00	51.40	51.70

Figure 4: Results of Two-Way ANOVA Tests on Analysis

Source	SS	df	MS	F	Prob>F
Columns	0.6211	2	0.3106	0.14	0.8748
Rows	15.8672	1	15.8672	6.91	0.022
Interaction	0.1211	2	0.0606	0.03	0.974
Error	27.54	12	2.295		
Total	44.1494	17			

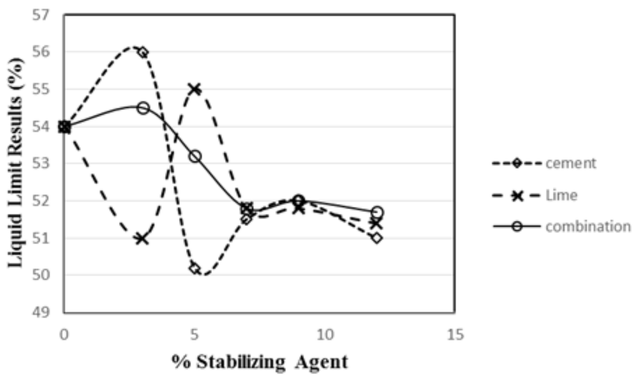

Figure 5: Plot of Liquid Limit against Percentage of Stabilizing Agents

From the Figure 3, it is evident that the there is no significant difference in the liquid limit of the soil when either of cement, lime or a combination of cement and lime was used as additives. There was however noticeable difference by varying the amount of additives that was added on the soil to improve their barrier properties. The highest liquid limit was obtained when 3% of cement was used to stabilise the soil (see table 2). The interaction parameters indicated no sharp difference between the type of stabilizing agents and varying the amount of the stabilizing agents. Figure 5 showed that only the combination of cement and lime gave a defined regression plot relating the liquid limit with the quantity of stabilizing agent.

ANOVA Tests for Moisture Content Results

The moisture content results after stabilisation are presented in table 3. From the table, it is evident that only cement additive gave comparative increase in moisture content which was highest at 5% cement content with a value of 38.49%. The other additives gave reduced moisture content with the addition of the stabilizing agents. The summary of computation of the two-way analysis of variance of the stabilized moisture content results is shown in the Figure 6. Figure 7 is a plot of the moisture contents with the stabilization agents, aimed at showing the trends of impact of the stabilising agents.

Percentage additives	Stabilizing Agents (%)		
	Cement only	Lime only	Cement and lime combination
0%	27.53	27.53	27.53
3%	29.74	20.41	18.00
5%	38.49	18.54	18.40
7%	31.09	13.33	19.20
9%	30.44	14.24	20.00
12%	24.93	14.70	20.80

Table 3: Optimum Moisture Content Results for the Different Additives Used as Stabilizer

Source	SS	df	MS	F	Prob>F
Columns	501.444	2	250.722	15.39	0.0005
Rows	77.875	1	77.875	4.78	0.0493
Interaction	36.801	2	18.401	1.13	0.3552
Error	195.467	12	16.289		
Total	811.588	17			

Figure 6: Results of Two-Way ANOVA Tests on Analysis

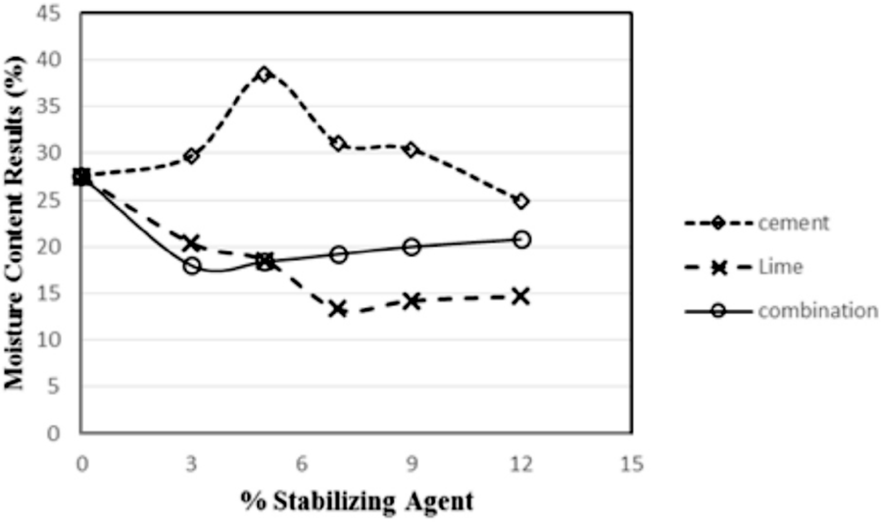

Figure 7: Plot of Optimum Moisture Content against Percentage of Stabilizing Agents

The correlation results showed that there is a fundamental difference in the moisture content when cement, lime and a mixture of cement and lime were used as the stabilizing agents. However, the difference was slightly significant for the different percentages of additives that was added to the soil samples. Generally, it can be inferred from the interaction parameter that there is a fairly significant difference between the various stabilizing agents and the amount of additives used per time. The highest moisture content generally occurred when cement was used as the stabilising agent for which 5% gave a moisture content of 38.49%. Lime stabilisation gave the lowest moisture content at 7% with a value of 13.33%. The plot showing the relationship between the moisture content and the quantity of stabilising agent gave a define plot for a combination of cement and lime than where the other stabilising agents were used separately.

Correlation Analysis output

Results of correlation analysis showed that cement, lime and a combination of cement and lime have correlation coefficient of -0.36, 0.5 and 0.219 respectively. The highest positive correlation was obtained when lime was used as the stabilizing agent while cement stabilisation gave a negative correlation.

Conclusion

The natural soils obtained from Iguorhiakhi were found to be sufficiently suitable for use as compacted clay liner for sanitary landfill. The introduction of stabilizers such as cement, lime and a combination of cement lime did not make a marked difference in improving the barrier characteristics of the soil. It was also observed that an obvious difference in the optimum moisture content occurred when cement was used as the stabilizing agent. The combine

Checkuse of cement and lime as the stabilising agent in respect of the moisture content and liquid gave the most predictable trend with a coefficient of determination of 0.219 than where the other stabilizing agents were used separately.

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