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Geotechnical Characterization of Soil in Cagayan de Oro Riverbank within Barangay Balulang and Macasandig after the Flashflood Incident Brought by Typhoon Sendong

Vera Karla I. Sabido - Caingles[1*] and Glen A. Lorenzo[2]
[1]College of Engineering and Architecture
Mindanao University of Science and Technology
Cagayan de Oro City, 9000 Philippines
**khaicaingles@yahoo.com.ph*

[2] College of Engineering
Mindanao State University (MSU)
Marawi City. Philippines

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Abstract

The aim of this study is to determine the depth and geotechnical characteristics of new and old soil deposits after typhoon Sendong hit the city. Twenty-nine soil samples from 16 observation sites were taken along the riverbank near Brgy. Balulang and Macasandig, as these areas were seriously damage during typhoon. The results of geotechnical testing shows that for the new deposit, Liquid Limit value ranges from 0% to 35%, Plastic Limit from 0% to 46% and with corresponding Plasticity Index of 0% to 8.8%. Specific Gravity ranges from 2.65 to 2.99 and moisture content from 3.08% to 76.09%. Maximum Dry Density, Optimum Moisture Content and Field Density vary from 10.75kN/m^3 to 16.59kN/m^3, 19.22% to 31.25% and 8.71kN/m^3 to 13.02kN/m^3, respectively. On the other hand, for the old deposit have Liquid Limit ranges from 0% to 46%, Plastic Limit from 0% to 39% and Plasticity Index from 0% to 10.5%. Specific Gravity ranges from 2.65 to 2.98 and Moisture content vary from 4.76% to 46.78%. Maximum Dry Density and Optimum Moisture Content vary from 12.78kN/m^3 to 15.47kN/m^3, 20.38% to 41.0%, respectively. The depth of new deposit ranges from 0.20m - 1.30m. Because of their non-plastic behavior, most of the new deposits as well as the old deposits have low swelling potential but have high collapsibility potential. Therefore, these deposits are expected to lose its strength upon saturation. The compendium will serve as a preliminary forecast and reference guide for the future civil engineering works and construction with respect to the geotechnical characterization of soil along the Cagayan de Oro River.

***Keywords**:* grain sizes, atterberg limits, compaction, field density, collapsibility, soil

1. Introduction

Floods are natural event and considered as the most common and destructive of all natural hazard on earth. Rivers, as it well known, are subject to flood when the volume of water is enormously increased and cannot longer be contained in the ordinary channel but spread out over the level grounds on each side (Scott, 2007). However, in areas largely inhabited by people, there are positive and negative environmental effects of flooding. Although man often seeks to protect himself and his property from the often-damaging effect of floods, man can use them to his advantage.

On December 16, 2011, Typhoon Sendong brought devastation in Cagayan de Oro City and nearby towns when rampage floodwaters engulfed houses along river banks that killed and injured hundreds and displaced thousands of families. It also reshaped the channel of the river. The most affected barangay was Balulang with an estimated affected area of 352,201 hectares, followed by barangay Macasandig with 218,612 hectares. After occurrence of the flashflood, there are changes in the land use and a new layer of soil that was carried out by water. Local government is in the dilemma to look of the new habitat for the affected families to avoid maximizing the unsafe area near the river. It is also their problem to continue the outstanding performance economically where there is a decrease in land use in the city. CBCPNEWS stated that the government made a resolution to stress the need to inform the people on the real situation of the river basin and educate them on the effects of small-scale and large-scale mining, deforestation, and poorly-planned urbanization on the environment and on the communities. It also called for coordination among local government units and the national government in carefully tracing and purposively analyzing the causes, both primary and contributory, of the siltation of the Cagayan and Iponan rivers and the flooding in the surrounding areas.

The study of geotechnical characteristics of the soil near the river would be an ideal initial action to identify the characteristics of the soil in maximizing the available land.

1.1 Statement of the Problem

Soil analysis is very important in construction site. It helps engineers to strategize the foundation of various structures to prevent failure at a later stage. Project delays, failures and cost over-run are the result of inadequate and inappropriate soil investigations. Catastrophic event such as flood, flashflood, earthquake and other similar events causes new formations and structure of the soil which should be considered. Previous studies, before the occurrence of such events, must be updated to present new data and investigations to users of the information.

Cagayan de Oro City is one of the cities experienced changes and acquired new formation of the soil along the river after the typhoon Sendong. The typhoon brought flashflood and carried soil to affected Barangays which creates new layer above the old deposit. In relation to fundamentals of site construction, this study provides information on the geotechnical characteristics of the new and old soil deposits on the two barangays namely, Macasandig and Balulang. This study aims to answer the following questions;

1. How thick is the new fluvial deposit brought by the Sendong flashflood?
2. What are the index properties and types of new and old soil deposits through Atterberg limits and grain sizes?
3. What are the physical properties of soil such as specific gravity, moisture content, and compaction behavior and field density of the new and old deposits?

This study also presents the properties of soil in relation to infrastructure development. It offers an idea on how the stability of the building construction or other form of infrastructures should be done in respect to the general characteristics of the new and old deposits of soil. It is the call of the Civil Engineer in maneuvering the foundation to endow with strong and solid groundwork of the project. High rise buildings and even simple construction ought to confer credits of the soil analysis and should not be taken for granted otherwise the risk of collapsibility is high.

1.2 Theoretical Framework

Soil is a combination of minerals and organic elements that are in solid, gaseous, and aqueous form. Soil consists of particle layers that are different from the original materials in their physical, mineralogical, and chemical properties because of the interactions between the atmosphere and hydrosphere and other reasons. The particles of the soil are created from broken rocks that have been changed due to the chemical and environmental effects, including weather and erosion. Particles of soil are filled loosely, creating a soil formation that consists of pore spaces. Studying soil formation modes is important because it helps in determining properties of soil (Goel, 2011).

This study focuses in determining the geotechnical characteristics of both new and old soil deposits after the flashflood Sendong. Types of soil and its special behavior such as collapsibility and potential to swell depend on the geotechnical study. Ground improvements to be applied depend on the problems that the soil possesses. Geotechnical Engineers should undertake investigations to visually examine and conduct laboratory tests on the soil encountered at a particular site. With this, assessment of the risk to humans, property and the environment from natural hazards such as earthquakes, landslides, sinkholes, soil liquefaction and flood will be identified.

In civil engineering, soils with properties that cannot be safely and economically used for the construction of civil engineering structures without adopting some stabilization measures are known as problem soils. Problem soils are expansive/swelling and collapsing soils (Bolarinwa, 2010). In this study, soil's magnitude to collapse and potential to swell criteria were based on some parameters such as moisture content, plastic limit, plasticity index and liquid limit. Figure 1 illustrates the theoretical framework of this study where the soil classifications, collapsibility, potential to swell and ground improvements depend on the physical and index properties of soils obtained from series of laboratory and field test results.

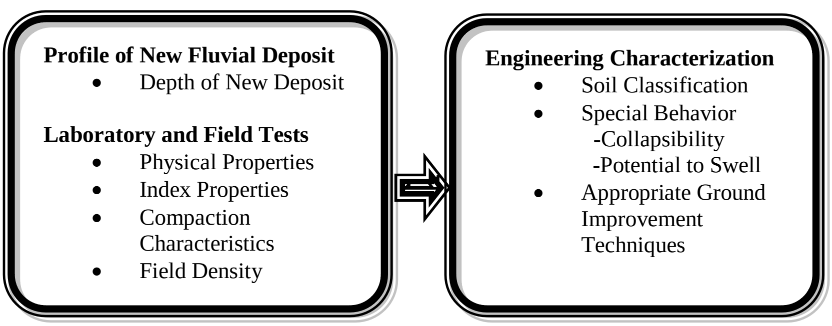

Figure 1. Theoretical framework

This study aims to characterize the geotechnical properties and the associated special soil behavior of the new fluvial deposits along Cagayan de

Oro Riverbank deposited by the flashflood incident brought by Typhoon Sendong.

Specifically, this study aims:

1. to determine the depth of the new fluvial deposit brought by the Sendong flashflood;
2. to determine and compare the Atterberg limits and grain sizes of new and old deposits;
3. to determine and compare the specific gravity, moisture content, compaction behavior and field density of the new and old deposit;
4. to provide reliable data pertaining to the subject area studied as to the geotechnical characteristics of soil.

2. Methodology

2.1 Working Map Preparation

Detailed field mapping preparation was conducted at Labis Surveying Office using Autocad Software. Using transect sampling approach, soil samples were taken along straight lines across the target area with spacing between each sampling points of 500m. There are sixteen (16) observation sites were established, specifically eight (8) sampling points along Barangay Balulang and another eight (8) sampling points along Macasandig. From Labis Surveying record, a reference point and coordinate from generated map was recognized and employed as a starting point to identify the rest 15 observation sites for soil sampling.

2.2 Field Reconnaissance

Pre-survey of the sample points identified in the working map was performed. Together with this, accessibility, conditions of the riverbank, land use and characteristics of the river were observed. From field observation, soil of observation site #8, which is near the public road, was already compacted. Also, observation site #6 is a quarry area owned by a private company. And due to its higher elevation, water from the river during flood did not reach the ground level and no new deposit stored found.

2.3 Collection of Soil Samples for New and Old Deposits

In this stage, Global Positioning System Device was used to identify the actual test point, Labis Surveying Office reference data was served as the starting point. The distance of 500 meters was actually inputted but due to factors encountered (trees, private property areas and inaccessible locations) immaterial variations of distance were experienced. Final sample points on the site were dug using shovels since renting excavation equipment is very expensive and the accessibility of area for this equipment is not possible. Samples were taken for the new and old deposit. Old deposits were determined upon change of textures and color from the new deposits. Soil sample for the old deposit were gathered one meter depth from the end of the new deposit. Distance and elevations of the sample point from the river were defined using measuring tape, markers to mark off points on the map where the soil samples were collected, masking tape for sample labeling and a camera for taking photographs of clay exposures and other observed features that are relevant to the study. The specimen samples were placed in the sack half-filled properly labeled with the observation site number and as to classification of soil. Measurements and details were recorded to the logbook for monitoring. These were immediately delivered to the laboratory for soil analysis.

2.4 Field and Laboratory Test of the Specimen Samples

The laboratory tests were conducted in the LYL Development Corporation. The testing procedures were in accordance with ASTM Standard. The tests include grain size analysis, Liquid Limit, Plastic Limit, Specific Gravity, Moisture Content and Soil Compaction Test. However, Field Density Test was performed on the site to its respective observation points.

3. Results and Discussion

3.1 Profile of the New Fluvial Deposit

The study was conducted along the bank of Cagayan de Oro River. Soil samples were collected from different sixteen (16) observation sites, eight (8) sample points on each side of the river. Table 1 shows the coordinates of each location with respective elevation based on the reference point

Table 1. Coordinates, Length, Elevation and Depth of Observation Sites

Observation Site No.	Coordinates	Length	Elevation	Depth	
				New Deposit (m)	Old Deposit (m)
Reference: Station 08	N03˚ 4'E	0	19m	N/A	1.0
Station 08 to Station 01	N69˚ 12'W	256.14m	18m	1.20	1.0
Station 01 to Station 02	S40˚ 11'W	498.25m	21m	0.90	1.0
Station 02 to Station 03	S22˚ 56'W	503.50m	21m	1.20	1.0
Station 03 to Station 04	S07˚ 06'W	498.37m	22m	1.30	1.0
Station 04 to Station 05	S09˚ 08'W	504.00m	19m	0.90	1.0
Station 05 to Station 06	S53˚ 43'E	504.28m	20m	N/A	1.0
Station 06 to Station 07	S40˚ 10'E	506.01m	22m	0.20	1.0
Station 08 to Station 09	N56˚ 31'W	384.80m	18m	0.20	1.0
Station 09 to Station 10	S52˚ 09'W	500.07m	22m	0.50	1.0
Station 10 to Station 11	S47˚ 04'W	464.12m	20m	0.20	1.0
Station 11 to Station 12	S19˚ 01'E	393.29m	24m	N/A	1.0
Station 12 to Station 13	S02˚ 42'E	510.56m	19m	0.30	1.0
Station 13 to Station 14	S13˚ 57'W	496.86m	18m	1.00	1.0
Station 14 to Station 15	S48˚ 08'E	492.97m	18m	0.50	1.0
Station 15 to Station 16	S48˚ 58'E	505.99m	19m	0.50	1.0

* N/A: No new soil deposit taken

(observation site #8) and its corresponding distance and depth from one observation site to another. Figure 2 is the mapping of the thickness of new deposit along the CDO River.

Considering the map (Figure 2), locations shaded with brown color are stations 8, 12 and 6. Locations fall on blue color are stations 1, 2, 3, 4, 5 and 14 while yellow color are stations 16, 15, 13 and 10. Elevation is one of the factors that affect the flow of flood water during typhoon Sendong. Overflowing of the flood water occurred mostly on the right side of the riverbank with lower elevation. On the other hand, the left side of the river is generally not prone to flooding due to its high elevation. However, the left side of the riverbank is subjected to scouring during flood event which may result to river slide.

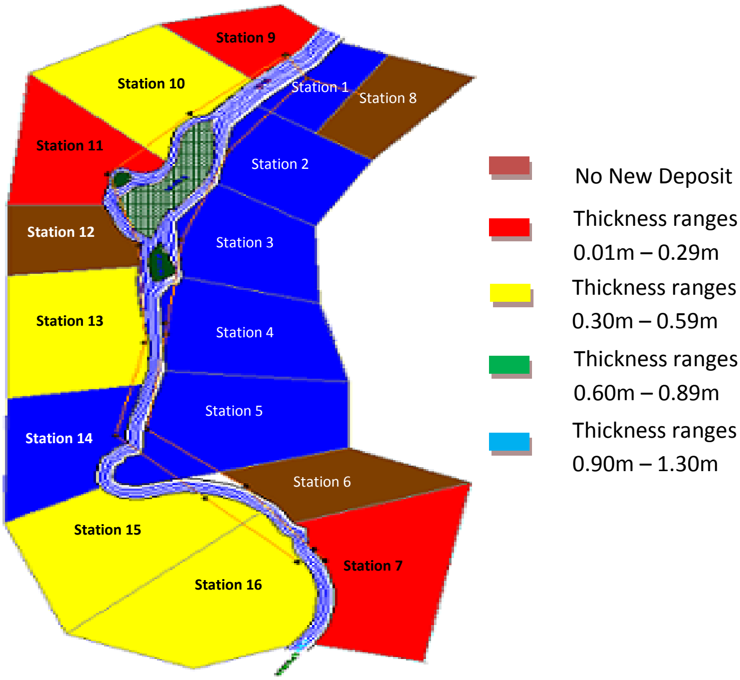

Figure 2. Mapping of the thickness of new deposit

3.2 Physical and Index Properties

Different observation sites had different soil properties. Burmister (1949) classified the plasticity index of soil in a qualitative manner. The plasticity of soil is proportion to its plasticity index. The higher the value of P.I., the higher it's plasticity. From the plasticity index in a qualitative manner of Burmister, the laboratory results of soils were classified as non-plastic (PI = 0), slightly plastic (1 < PI > 5), low plasticity (5 < PI > 10), medium plasticity (10 < PI > 20), high plasticity 2(10 < PI > 40) and very high plasticity (PI > 10). Meanwhile, in the book of Venkatramaiah (2006), compressibility of soil can be classified based on its liquid limit. Soil with less than 30% value of liquid limit fall on low compressibility category, between 30% to 50% fall on medium compressibility while liquid limit greater than 50% fall on high compressibility category. Atterberg limit of new and old deposits is summarized in Table 2 and Table 3.

Table 2. Plasticity and compressibility characteristics of the new soil deposit

Observation Site No.	New Deposit				
	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Plasticity	Compressibility
01	30	26	4	Slightly Plastic	Medium
02	45	38	7	Low Plasticity	Medium
03	0	0	0	Nonplastic	Low
04	0	0	0	Nonplastic	Low
05	0	0	0	Nonplastic	Low
06	N/A	N/A	N/A	N/A	N/A
07	28.5	25.5	3	Slightly Plastic	Low
08	N/A	N/A	N/A	N/A	N/A
09	54.8	46	8.8	Low Plasticity	High
10	0	0	0	Nonplastic	Low
11	34	30	4	Slightly Plastic	Medium
12	N/A	N/A	N/A	N/A	N/A
13	0	0	0	Nonplastic	Low
14	0	0	0	Nonplastic	Low
15	0	0	0	Nonplastic	Low
16	35	33	2	Slightly Plastic	Medium

* N/A: No new soil deposit taken

Table 2 shows that atterberg limit such as liquid limit ranges from 0% to 54.8%, plastic limit from 0% to 46% and plasticity index of 0% to 8.8%. It indicates that seven (7) out of thirteen (13) new deposit soil samples show a non-plastic property and eleven (11) out of thirteen (13) considered as most susceptible in piping for its plasticity index less than 5. Eight (8) out of thirteen (13) observation sites show low compressibility and the rest have medium to high compressibility property.

Table 3. Plasticity and compressibility characteristics of the old soil deposit

Observation Site No.	Old Deposit				
	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Plasticity	Compressibility
01	46	39	7	Low Plasticity	Medium
02	36	30.5	5.5	Low Plasticity	Medium
03	39.5	33.5	6	Low Plasticity	Medium
04	38.5	30	8.5	Low Plasticity	Medium
05	0	0	0	Nonplastic	Low
06	36	30	6	Low Plasticity	Medium
07	30	25	5	Slightly Plastic	Medium
08	29	28	1	Slightly Plastic	Low
09	0	0	0	Nonplastic	Low
10	30	24.5	5.5	Low Plasticity	Medium
11	0	0	0	Nonplastic	Low
12	37	26.5	10.5	Medium Plasticity	Medium
13	0	0	0	Nonplastic	Low
14	0	0	0	Nonplastic	Low
15	31	27.5	3.5	Slightly Plastic	Medium
16	0	0	0	Nonplastic	Low

* N/A: No new soil deposit taken

Old deposit has a liquid limit of between 0% to 46%, plastic limit 0% to 39% and plasticity index 0% to 15% as presented on Table 3. Six (6) out of sixteen (16) old deposits soil samples had non-plastic property and the rest shows plasticity. Seven (7) out of sixteen (16) observation sites show low compressibility and half of the soil samples considered as most susceptible in piping (the degree of internal erosion which takes place when water moves through the pores or cracks of that soil) since it has plasticity index less than 5.

As a whole, level of plasticity and compressibility characteristic of new and old deposit vary on its location. New deposits on observation sites 16, 11 and 9 have higher compressibility level than old deposits while observation sites

15, 10, 7, 4 and 3 of old deposits shows higher compressibility level than new deposits. The rest of the stations for both new and old deposits have the same level of compressibility except stations 6, 8 and 12. New and old deposits on stations 5, 13 and 14 are nonplastic soil while new deposits on stations 16, 11, 9, 7 and 1 have more plastic property compared to old deposits.

The liquid limit of the soil is indicative of its compressibility. The greater the liquid limit, the greater the compressibility of the soil. Based on their atterberg limits, all new deposits have little or no cohesion and will crumble easily when dry. Significantly, these deposits are highly dispersive upon the action of river current and they are also collapsible when fully saturated.

3.3 Grain Size Analysis

Sieve analysis results were tabulated on Table 4 based on the percentage of soil particle such as silt and clay, sand and gravel that passed on different sieve diameter. The dominant soil particle for new and old deposits is sand and considered as coarse grain soil.

Table 4. Percentage of silt and clay, sand and gravel on soil

Observation Site No.	New Deposit			Old Deposit		
	Silt and Clay (%)	Sand (%)	Gravel (%)	Silt and Clay (%)	Sand (%)	Gravel (%)
01	19.49	80.00	0.52	50.00	40.78	9.22
02	14.29	85.71	0.0	47.25	50.55	2.20
03	10.00	89.33	0.67	17.59	63.82	18.59
04	15.28	78.70	6.02	8.19	62.57	29.24
05	9.24	87.82	2.94	18.23	78.91	2.86
06	N/A	N/A	N/A	6.91	63.59	29.49
07	26.93	68.19	4.87	11.17	59.39	29.44
08	N/A	N/A	N/A	22.99	58.76	18.25
09	34.78	51.45	13.77	13.03	86.02	0.96
10	25.12	73.95	0.93	29.96	66.40	3.64
11	31.99	66.75	1.26	36.38	63.42	0.20
12	N/A	N/A	N/A	28.10	62.54	9.37
13	27.93	71.87	0.21	13.75	85.75	0.50
14	17.00	80.98	2.02	26.07	70.63	3.30
15	2.76	96.85	0.39	26.01	71.43	2.56
16	35.84	60.49	3.67	8.81	89.62	1.57

* N/A: No new soil deposit taken

Silt and clay have particle size of less than 0.1mm and passes sieve #200. Sand has particle size ranges from 0.1mm to 2mm while gravel is greater than 2mm. All soil samples for both new and old deposits have higher percentage of sand content followed by silt and clay, and gravel. For the new deposits, the amount of silt and clay, sand and gravel ranges from 2.76% - 35.84%, 51.45% - 96.85% and 0.21% - 13.77%. For the old deposit, silt and clay (6.91% - 50.0%), sand (40.78% - 86.02%) and gravel (0.20% - 29.49%). Soil samples were classified using two different criteria: AASHTO Soil Classification and Unified Soil Classification System. AASHTO classified new deposit as A-2-4, A-2-5, A-3 and A-4 with all have group index of 0. All new deposits are silty or clayey soil and gravel except stations 3, 15 and 16 which were classified as fine sand and silty soil while on old deposit is A-2-4, A-2-6, A-3, A-4, A-7-5 and A-1-b with all have group index of 0 except observation site #1 with G.I. of 2. USCS classified new and old deposits as SM (inorganic silt and organic clay), sand and OL (inorganic silt and inorganic clay).

3.4 Specific Gravity of Soil and Moisture Content of Soil

Laboratory results on specific gravity and moisture content of soil samples are listed in Table 5. Specific gravity indicates how much heavier/lighter a material than water on new and old deposits on each observation sites. Soil moisture is the water that is held in the spaces between soil particles (Arnold, 1999). As moisture content of soil increases, the strength decreases (Das, 2007).

3.5 Compaction Characteristic of Soil

Standard Proctor Compaction Test Method was used to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of each mixture. Corresponding MDD and OMC of each mixture were used in obtaining the field density test results. The moisture content of the soil at which a specified amount of compaction will produce the maximum dry density which is the optimum moisture content and the dry density at the optimum moisture content using specified amount of compaction is the maximum dry density of soil.

The compaction tests results, Table 6, carried out on the 13 observations of new deposit soil samples shows that the maximum dry density vary from 10.75 kN/m3 to a maximum value of about 16.59 kN/m3; the corresponding range of optimum moisture content between 19.92% to 31.25% having a mean value of MDD 13.53kN/m^3 and OMC 21.34%. Since this new deposit are laid blown by water in a saturated state, soil become hard and less compressible with relatively low density as it dry based on its MDD. However, if this deposit is subsequently exposed to water accompanied with or without additional loading, it may collapse and cause large settlement. For the old deposit, out of 16 samples, values of maximum dry density vary from 12.78kn/m^3 to 15.47kn/m^3 with corresponding optimum moisture content of 20.38% to 41% with MDD and OMC mean value of 17.28kN/m^3 and 27.03%.

Table 5. Specific gravity and moisture content of soil

Observation Site No.	Specific Gravity		Moisture Content (%)	
	New Deposit	New Deposit	Old Deposit	Old Deposit
01	2.83	3.08	7.28	2.92
02	2.88	18.43	4.76	2.98
03	2.65	18.00	7.54	2.73
04	2.70	21.76	46.78	2.80
05	2.65	24.79	24.22	2.86
06	N/A	N/A	39.63	2.70
07	2.83	14.09	32.49	2.65
08	N/A	N/A	19.34	2.80
09	2.90	76.09	29.50	2.74
10	2.92	34.88	27.94	2.92
11	2.92	46.85	27.04	2.87
12	N/A	N/A	18.89	2.89
13	2.82	27.93	17.50	2.79
14	2.88	25.36	25.74	2.86
15	2.72	24.41	22.34	2.74
16	2.99	46.03	14.47	2.72

* N/A: No new soil deposit taken

Table 6. Maximum dry density and optimum moisture content of soil

Observation Site No.	New Deposit		Old Deposit	
	Maximum Dry Density (kN/m^3)	Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)	Optimum Moisture Content (%)
01	13.96	22.43	15.27	24.50
02	11.55	30.53	14.12	20.38
03	15.22	19.92	12.91	27.32
04	13.07	30.18	12.98	31.50
05	15.19	21.38	15.39	20.75
06	N/A	N/A	12.86	33.68
07	16.59	24.50	13.04	32.78
08	N/A	N/A	15.47	23.12
09	10.75	24.55	14.21	41.00
10	14.25	24.10	14.58	22.05
11	12.57	31.25	13.69	24.80
12	N/A	N/A	12.78	29.23
13	13.39	27.50	14.98	22.16
14	13.27	28.96	13.87	25.00
15	13.59	26.00	13.87	29.10
16	12.47	30.38	14.62	25.05

* N/A: No new soil deposit taken

3.6 Field Density of Soil

The Sand Cone Method was used to determine the field density of the new deposit. Table 7 below shows the summary of the field density tests conducted in all observation sites. The degree of compaction of the new deposits in its natural condition was determined as the percentage of the field density to the corresponding MDD of the soils.

Table 7. Field density and degree of compaction

Observation Site No.	Field Density (kN/m^3)	Degree of Compaction (%)
01	10.63	76.18
02	9.13	79.09
03	12.26	80.55
04	10.71	81.97
05	12.88	84.81
06	10.25	79.73
07	13.02	78.52
08	12.84	83.01
09	8.71	81.09
10	11.70	82.11
11	10.30	81.94
12	9.62	75.35
13	9.70	72.46
14	9.90	74.64
15	11.04	81.27
16	10.28	82.92

In the most specification for earthworks, there is a certain value on degree of compaction that must be attained in the field. This is referred to as relative density or the degree of compaction, generally range from 90% -95% as compared to the modified proctor and 95% - 100% as compared to the standard proctor. Based on the results presented on Table 7, field density vary from 8.71kN/m^3 to its maximum of 13.02 kN/m^3, with corresponding degree of compaction ranges from 72.46% to 84.81. Hence, the soil deposits in its natural state are not densely compacted since it fails to meet the standard specification. Thus, the new soil deposits must always be compacted at moisture content greater than or less than 2% of its optimum moisture content before any construction begins.

3.7 Special Behavior of New and Old Deposits Collapsibility of the Soil

Priklonski (1952) soil's collapsibility equation is used to identify the level of collapsibility for both new and old deposits. Parameters of this equation are moisture content, plastic limit and plasticity index. Priklonski's soil collapsibility equation is defined in the following formula:

$$K_D = \frac{\text{Natural Moisture Content} - \text{Plastic Limit}}{\text{Plasticity Index}} \tag{1}$$

where:

$K_D < 0$: Highly Collapsible Soil
$K_D > 0.5$: Noncollapsible Soil

Based on the above formula, results are summarized on Table 8. However, Dudley (1970) also reported that most of the collapsing soils have liquid limit of below 45% and Plastic Limit of below 25%.

Collapsible soils exhibit large decrease in strength at moisture content approaching saturation, resulting in a collapse of the soil skeleton and large decreases in soil volume.

3.7 Swelling Soil

Soil swells when it absorbs water and shrinks when water evaporates from it. High swelling pressure develops if the soil has no access to water but is prevented to swelling. Light structure may lift if the swell pressure is excessive (Harishkumar and Muthukkumaran, 2011).

Table 8. Collapsibility of new and old deposits

Observation Site No.	Collapsibility of Soil	
	New Deposit	Old Deposit
01	Highly Collapsible Soil	Highly Collapsible Soil
02	Highly Collapsible Soil	Highly Collapsible Soil
03	Highly Collapsible Soil	Highly Collapsible Soil
04	Highly Collapsible Soil	Noncollapsible
05	Highly Collapsible Soil	Highly Collapsible Soil
06	N/A	Noncollapsible
07	Highly Collapsible Soil	Noncollapsible
08	N/A	Highly Collapsible Soil
09	Noncollapsible	Highly Collapsible Soil
10	Highly Collapsible Soil	Noncollapsible
11	Noncollapsible	Highly Collapsible Soil
12	N/A	Highly Collapsible Soil
13	Highly Collapsible Soil	Highly Collapsible Soil
14	Highly Collapsible Soil	Highly Collapsible Soil
15	Highly Collapsible Soil	Highly Collapsible Soil
16	Noncollapsible	Highly Collapsible Soil

* N/A: No new soil deposit taken

Though the primary design tests for swelling are consolidation swell test (for building) and California Bearing Ratio swell test (for roads), Nayak *et al.,* (1971) reported that plasticity index is the single best factor to predict swelling potential of soil. U.S. Army Waterways Experiment Station classification of potential swell (Table 9) is used to evaluate the swelling degree of the new and old deposit.

Table 9. WES Classification of potential swell

Liquid Limit	Plasticity Index	Classification
>60	>30	High Potential to Swell
50 – 60	25- 35	Moderate Potential to Swell
< 50	< 25	Low Potential to Swell

According to Taboada (2003), rigid or non swelling soils are usually coarse – textured, organic matter – poor, hard to till, low aggregate stability, high modulus of rupture, and low resilience after a given damage. Soils do not change their specific volume, and hence, their bulk density during their water content variation range and considered to have hard-set behavior. In contrast, extensively swelling soils undergo significant bulk density, variations during their water content, variation range. They are usually fine – textured, with smectitic type of clays. It develop desiccation cracks on drying, which confers high resilience, and little tillage requirement. Based on WES criteria, new and old deposits have low potential to swell as presented on Table 10.

Table 10. Swelling potential of new and old deposits

Observation Site No.	Potential to Swell	
	New Deposit	Old Deposit
01	Low	Low
02	Low	Low
03	Low	Low
04	Low	Low
05	Low	Low
06	N/A	Low
07	Low	Low
08	N/A	Low
09	Low	Low
10	Low	Low
11	Low	Low
12	N/A	Low
13	Low	Low
14	Low	Low
15	Low	Low
16	Low	Low

* N/A: No new soil deposit taken

4. Conclusion and Recommendations

Based on the above findings, it is concluded that the thickness of soil that was deposited by the flashflood typhoon Sendong varies with location and it ranges from 0.20 m to 1.30 m. Thicker deposits were generally observed in areas with relatively lower elevation. The new deposits were generally classified as silty sand. They are non-plastic with in-situ dry density of about 70% to 80% of its maximum dry density. Because of its non-plastic behavior, these deposits have low swelling potential but have high collapsibility potential. Hence, these deposits will lose its strength upon saturation.

Based on the results obtained from laboratory investigations, and the formulated conclusions, it is recommended that:

a. Further research on the detailed geotechnical hazard mapping along the Cagayan de Oro River shall be conducted as an additional information in coming up with a more engineered land use map in the area.
b. For a one or two storey building, depth of the foundation should be beyond the depth of new deposit with an additional of at least 1m as possible.
c. Compaction techniques with either conventional impact or vibratory rollers may be used to densify soils at shallow depths up to about 1.5 m. For deeper depths, vibroflotation, stone columns, and displacement piles can be adopted.

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