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RESEARCH ARTICLE OPEN ACCESS

Proposed Design of Underground Duct Bank and Pipelines as Alternatives for Conventional Overhead Lines and Drainage Systems on Guagua, Pampanga

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Abstract:

Overhead lines are the common electric and telecommunication distribution system in most countries including the Philippines. This distribution line is exposed to atmosphere and susceptible to weather conditions such as heavy rains and strong winds. In addition, they are less attractive and prone to damage causing disruptions and inconvenience to people. Undergrounding cables can prevent distribution outages and hazards to people and improve the reliability of the electric power supply.

Urban drainage systems have been in place as an important component of city infrastructure to collect and drain wastewater and stormwater. However, the drainage system in most places of the Philippines is usually an open channel hidden beneath concrete slabs on sidewalks. This drainage is easily exposed to waste materials and poses danger to pedestrians. An effective, functional underground pipeline drainage system can be designed to drain wastewater, decreasing the chances of water contamination and flooding, and giving the property a finished, clean appearance.

The study area, Guagua, Pampanga, a commercial flood prone local area, even more need an efficient and reliable drainage and cabling system. The researchers proposed a design of underground pipeline and duct bank to help alleviate flooding and deliver more dependable utility distribution.

Keywords **—Drainage, Duct Bank, Overhead Lines, Pipelines, Underground**

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I. INTRODUCTION

Surface drainages and overhead powerlines have always been two huge consumers of space on local road facilities. Commercial local zones, such as public markets with high electricity demand and wastewater volume, are most likely to have these unaesthetically pleasing overhead powerlines and overflowing surface drainages. Moreover, both of these are most likely to trigger economic losses, risk public safety, and pose damages to properties, when inevitably exposed to disastrous natural events or dilapidated. At present, flood occurrence has become one of the most damaging natural disasters primarily due to its growing scope and frequency over time.[7]According to Zhou et al. [8], mitigating this problem in a commercial location can vary significantly on how well its drainage system performs. On the other hand, overhead wiring systems are naturally prone to environmental interventions. As stated in a news article by Sun Star[5], the electric power lines, posts, and other electrical system components are among those most impacted when typhoon comes, bringing forth some safety hazards and power supply issues.

In many locations in the Philippines, the drainage system is usually hidden beneath the sidewalks with concrete slabs that conceal the drainage channel. This does not only mean easy access for waste materials to enter but also poses danger to pedestrians walking. One project by the local government of the city of Iloilo was a drainage system whose main idea was to get wastewater to nearby bodies of water such as streams or rivers.[3] With this objective adding the concept of an underground drainage system betterment will arise in the disposal of wastewater, the safety of sidewalks, and the landscaping of local roads.

The majority of the electric power distribution in the world is through the use of overhead lines. These are structures of poles, posts, and steel towers carrying power lines that transmit electricity over long distances. However, overhead power lines can be easily affected by weather as they are exposed to the atmosphere, which also makes them an unpleasant addition to a location's landscaping. In 2014, Davao City made a huge leap in its cabling system with its Ordinance No. 0177-14 Series of 2014.[4] It is an ordinance relocating all electrical and telecommunication wires underground on some roads around its City Hall façade as part of a beautification initiative. Another purpose of this ordinance is to enhance the safety and security of the affected vicinities while attaining and ensuring sustainable development.[1]

Guagua is one of the municipalities of Pampanga, a commercial area at the same time, a flood-prone one as it is only one meter above sea level.[2] The Guagua river basin is vulnerable to flooding primarily due to its low elevation and flat terrain, its proximity to Manila Bay where tides impede the river and creek flow several kilometers upstream, and the narrow and slow waterways brought on largely by the severe Mount Pinatubo eruption. A possible contributory cause is the reported slow sinking making the area very vulnerable to instant flooding. Some of the recent typhoons which caused knee length flooding in the town of Guagua were typhoon Paeng and Karding, which made the town not passable to light vehicles and residents were unable to go back to their house.[1] In addition, these floodings and some other unexpected adversities are also causing interruptions to the power and telecommunication distribution of the town. According to PELCO II [6], even small, unexpected events are causing these interruptions such as broken poles, grass fire, hanged objects on wires, and damaged transformers. Structures of underground drainages and underground cabling around the roads of Plaza Burgos in Guagua, Pampanga, and some of its surrounding vicinities are to be established as a research proposal that aimed to alleviate the recurring flooding in the municipality and improve its cabling system. This also aimed to transform the location into a more visually appealing and reliable commercial town.

II. METHODOLOGY

A.Data Gathering Procedure

TABLE I
Data Gathering Procedures

Date	Agenda
February 17, 2023	Compose letters of request to be signed by the engineer adviser of the study. The letters are to be sent to PELCO II to request the overhead electric line map of the study area, and to the LGU of Guagua to request the rainfall data (if available) needed for the study and the plan of the existing drainage system of the study.
February 20, 2023	Hand in the letters to the respective offices.
February 20 - April,2023	Acquire the data requested from PELCO II and LGU of Guagua, Pampanga.
February 25 - March 20,2023	Design the duct bank and underground pipeline layouts based on the standards acquired from different books of provisions.
March 21 - April 23, 2023	Structural specifications of the designs finalizing through manual computations.
April 24 – April 30, 2023	Create the structural plans for the designs using AutoCAD.
April 30, 2023	Create the route of the underground cables and pipelines utilizing the layout map that will be provided by PELCO II and Guagua LGU.

B.Design Parameters

This part of the chapter contains the materials and dimensions gathered from the different books of standards that will be the main guidelines for designing the underground structures. The chapter will also contain the codes and provisions that will be used for the analysis of the designs.

1) Underground Drainage

Dimensions

The general dimensions in the design were based on various sources but mostly from ASTM Standards and AASHTO LRFD Bridge Design Specifications.

1.Depth – The minimum cover from the top of the rigid pavement must be greater than the ½ of the inside diameter of pipe or at least 24 inches or 650mm.

2.Length – The pipe must have a laying length of at least 10 ft ¼ in or 3 m.

3.Pipe Diameter – The diameter of the pipe will be determined based on the accumulated average rainfall data of the location.

4.Wall Thickness – The thickness will be based on the diameter of the pipe used.

5.Minimum Trench Width – It shall not be less than the greater of either the outside diameter of the pipe plus 16 inches (400 mm) or 1.25 times the outer diameter of the pipe plus 12 inches (300 mm).

6.Slope - A drain should have a slope 1/4 inch for every foot of the pipe. This means that the pipe should dip by 1/4 inch for every foot it runs horizontally. If the path of the drain is overly flat, it won't be able to exert the force required to move the waste out.

Materials

The materials used in the design of underground pipelines were from the specification of ASTM requirements.

1.Pipe- the pipe to be used is polyvinyl chloride (PVC) or Corrugated Flexible Pipe.

2.Final Backfill - natural soil refills the trench to the original ground level.

3.Embedment - The bedding used is Class II well-graded sand, in which the excavation of the rigid material should be beneath the reservoir's bottom of the pipe and pipe bell, at least 150 mm deep. And to fit the bottom of the line, the conduit is laid on a proper earth shape.

•Foundation - Install and compact in layers no greater than 6 inches or 150mm.

•Bedding - Install and compact in layers no greater than 6 inches or 150mm and no less than 4 inches or 100mm.

•Haunch Zone - Install and compact in layers no greater than 6 inches or 150mm.

•Initial Backfill - Install and compact in layers between 6 inches or 150 mm to 12 inches or 300 mm over the top of the pipe.

2) Underground Duct Bank

Dimensions

The dimensions used in the design were based on different standards set by various books of manual designs and specifications for underground duct banks and cabling.

1.Depth – Duct bank outside building premises should be minimum 36 inches or 900 mm deep below finished grade line.

2.Clearances - Power and telecommunications duct banks must be separated vertically and/or horizontally by at least 12 inches of soil or concrete. The electricity ducts must be above the telecommunications ducts if the services must be vertically stacked on top of one another. Place duct banks and conduits at least 12 inches away from other utilities such as steam, sewerage, chilled water, etc.

3.Concrete Encasement - A minimum of 3 inches of concrete must surround the sides of the duct bank.

4.Pipe Diameter – The pipe should conform to the size of the cables to be encased and should have a minimum diameter of four inches for primary feeder conductors, and four inches for telecom services.

5.Pipe Spacer – A minimum spacing of 1.5 inches from the outer diameter should separate each pipe.

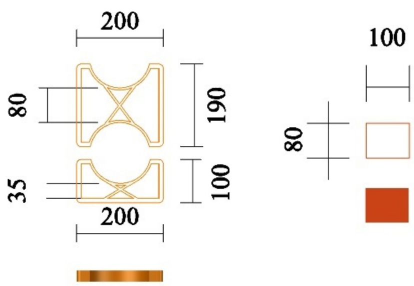

Fig. 1. Pipe Spacer

6. Reinforcing Bars - The longitudinal rebars must be size four or greater and tied with stirrups size three. The corners of the encasement envelope are where the first four rebars should be positioned. At the top and bottom centers, the following two rebars should go. Following that, all rebars must be evenly placed apart from the corner rebars.

Materials

The materials used in the design were based on manual designs and specifications listed in Research Instrument: Underground Duct Bank.

1.Concrete – Encasement concrete shall have 3000 psi at 28 days strength. When necessary, red pigment must be properly mixed into the concrete to have a red concrete encasement for the duct bank containing electrical cables.

2.Reinforcing Bars - The specified longitudinal main bars used must be at least grade 60 with 60,000 psi or 420MPa yield strength. Stirrup bars must be at least grade 40 with 40,000 psi or 280MPA yield strength.

3.Conduit – Use galvanized rigid steel (GRS) for the duct bank containing power lines and PVC schedule 40 for the duct bank containing telecommunication lines. For underground installations, the minimum conduit/duct size requirements are one inch for branch circuits, four inches for primary feeder conductors, and four inches for telecom services.

4.PVC Spacers and Mount- Prefabricated rigid PVC connecting spacers, sized for the specific types and sizes of ducts being used, and chosen to offer the minimum duct spacings required when supporting ducts while backfilling or concreting.

5.Warning Tape - Place warning tape approximately 18 inches (450 mm) above the duct banks. Place the tape 3 inches (75 mm) parallel from the midsection of the duct bank. Warning tape must be made of plastic, vinyl, or Mylar, and be either red for electrical power or orange for telecommunications.

B.Design Analysis

After the gathering of dimensions, materials, and specific data, the underground drainage and cables were subjected to theoretical analysis using the abovementioned elements.

1) Underground Drainage

Stresses in underground drainage were brought on by external loads. The stresses were of the highest significance and the sole factor considered during design. The external loads can be divided into two categories: superimposed loads and loads imposed by backfill material.

1.Storm Runoff Estimation

Storm runoff is the amount of precipitation that drains onto the ground. There are other methods for calculating drainage, but the rational approach is the most generally employed.

$$Q = 10CIA$$

- Q - runoff in m³/hr
- C - dimensionless runoff coefficient
- i - intensity of rainfall in mm/hr
- A - area of drainage district in hectares

2.Manning's Formula for Gravity Flow

The drainages shall not run entirely; otherwise, the pressure will rise above or below the atmospheric pressure, and the condition of gravitational channel flow will cease to exist. Formulas can be used to verify the following:

a. the flow rate and slope of a chosen drainage size and velocity.

$$Q = \frac{1}{n}(3.118x10^{-3})D^{2.67}S^{1/2}$$

- Q - discharge in l/s
- S - slope of the hydraulic gradient
- D - internal diameter of pipeline in inches
- n - Manning's coefficient of roughness

3.Superimposed Loads on Conduit

Concentrated and distributed loads are the two forms of superimposed loads that are typically found in underground pipelines.

•Soil Compaction and Bedding (NSCP 2015)

In every location, the soil has different characteristics. Some ground can have a poor bearing capacity that can cause settlement. The NSCP (2015) section 304 design solves these soil weaknesses.

•Design Vehicular Load (AASHTO 2014)

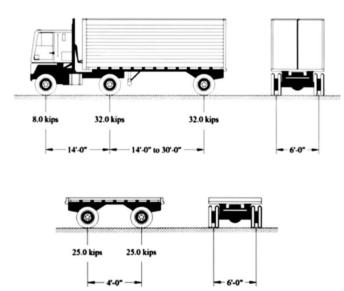

Fig. 2. Truck Wheel Load

The maximum feasible live load that will use for the analysis is HL-93. The tire contact area will be a rectangle 20 inches broad and 10 inches long.

For Truck and Tandem, the design contact area of tire is assumed to be a single rectangle of width 20 inches (510mm) and length 10 inches (250mm). The tire pressure is assumed to be uniform over the contact area. Generally, the center of truck wheels must be at least 600mm from the edge of a design lane and 300mm from the overhanging deck. The minimum tail to nose distance between two successive trucks in a lane is 5 feet (1.5m). The minimum distance between the tandem wheels in a lane is 4 feet (1.2m).

•Stress Distribution in Soil (Subsurface Stresses)

The soil stress distribution determines the amount of stress transmitted to the duct bank to transfer the force from the acting load above. A 60-degree approximation is used to determine the underground stresses in this situation.

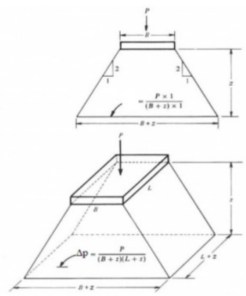

Fig. 3. Stress Distribution

Stress at Depth h: $\sigma = \frac{P}{(B+h)(W+h)}$

•Transverse Application of Live Load (AASHTO 2014)

To evaluate the maximum load distribution for the design, the overall position of the design vehicle is 4 feet from center to center of the loading condition.

2) Underground Duct Bank

The study is in accordance with the provisions of the specified code mostly from the NSCP 2015 and AASHTO LRFD Design 2014.

1. Soil Compaction and Gravel Bedding (NSCP 2015)

2. Design Vehicular Load (AASHTO 2014)

3. Stress Distribution in Soil (Subsurface Stresses)

4. Transverse Application of Live Load (AASHTO 2014)

5. Structural Analysis (NSCP 2015)

The duct bank was designed using the concrete and steel designs from NSCP 2015 sections 409 and 413.

A.Shear and Moment Diagram

The analysis of shear and moments was used to identify the value of shear and moment acting on the structure.

B.Ductile Failure Test

A ductile failure test was used to assess whether the reinforcement steel will yield before the concrete.

- $0.85f'cA_c = A_sF_y$
- $a = \frac{A_c}{b}$
- $c = \frac{a}{\beta_1}$
- $\varepsilon_s = \frac{0.003(d-a)}{a}$
- $\varepsilon_s > \varepsilon_y$

C.Ultimate Moment Capacity

For solving ultimate moment capacity, the NSCP 2015 codes were followed:

Where:

- $M_u = \Phi \, M_n$

where: $\Phi = 0.90$

- $M_n = R_n bd^2$
- $M_{u(cap)} = \varphi 0.85f'cA_c(d - \frac{a}{2})$
- $\rho = \frac{0.85\,f'c}{fy}(1 - \sqrt{1 - \frac{2R_n}{0.85f'c}})$
- $\rho_{min} = \frac{\sqrt{f'c}}{4fy} \geq \frac{1.4}{fy}$
- $A_s = \rho bd$

D. Minimum Spacing of Shear Reinforcement

To achieve the required spacing of shear reinforcements, the code allows the least of the following:

- $S_{max} = \frac{Av_{min}fyt}{0.062\sqrt{f'c}b_w}$
- $S_{max} = \frac{Av_{min}fyt}{0.35b_w}$
- $S_{max} = \frac{d}{2}$ $or\ 600mm$

E. Allowable Area to Soil Bearing Capacity

To determine the area of the duct bank, the allowable soil bearing capacity was based on the ratio of loads.

- $A_{ftg} = \frac{P_{DL}+P_{LL}}{Qa}$

F. Ultimate Soil Bearing Capacity

For solving shear and moment, the effects of soil on the load and structure were considered.

- $Q_u = \frac{1.2\ DL + 1.6\ LL}{Area\ of\ Duct\ Bank}$

G. Notation and Terminologies

- a – Effective Compression Block
- Ac – Area of Concrete
- Aftg – Area of Footing

- As – Area of Tension Steel at Nominal Strength
- Av – Area of Shear Reinforcement within Spacing
- b – Breadth of the Structure
- bf - – Breadth of Flange
- c – Distance of Extreme Compression Fiber to Neutral Axis
- d – Depth of the Structure
- f'c – Compressive Strength of Concrete
- fy – Yield Strength of Non-Prestressed Reinforcement
- fyt – Yield Strength of Non-Prestressed Reinforcement
-
- Mn – Nominal Moment
- Mu – Ultimate Moment
- Mucap – Ultimate Moment Capacity
- qa – Allowable Soil Bearing Capacity
- qu – Ultimate Soil Bearing Capacity
- Rn – Nominal Resistance
- Smax – Maximum Spacing of Transverse Shear Bars
- tf – Thickness of flange
- ε_s – Tensile Strength in Extreme Longitudinal Tension Reinforcement
- β_1 – Factor Relating Depth of Equivalent Rectangular Compressive Stress Block to Depth of Neutral Axis
- ε_y – Yielding Tensile Strength in Extreme Longitudinal Tension Reinforcement at Nominal Strength
- ρ – Ratio of Area of steel to Area of concrete
- ρ_min – Minimum Ratio of Area of steel to Area of concrete
- Φ – Strength Reduction Factor

III. RESULTS AND DISCUSSION

This part of the chapter will show the results and discussion of the final design and calculations for the structural analysis of the underground duct bank and underground drainage.

A. Design of Duct Bank

1) Dimension of the Design

The dimension used in the design was drafted upon the application of the specifications taken from the Northwestern University - Underground Ducts and Raceways for Electrical Systems SECTION 26 0543, The University of Arizona Manual of Design and Specification Standards, and University of Michigan - Underground Services for Electrical Systems Design Guideline 260543.

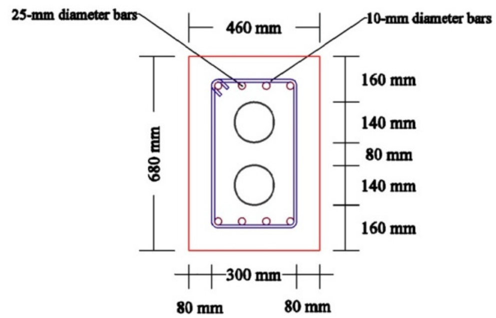

Fig. 4. Cross-sectional Dimension of the Duct Bank

The duct bank has a width of 460-mm and a height of 680-mm. The duct bank consists of 2 pipes with a diameter of 140-mm. The longitudinal reinforcements used were Grade 60, 2-25mm diameter bars were positioned 90-mm from the extreme fiber on both the top and bottom, and 2-25mm diameter bars were positioned on centers of the two outermost bars spaced equally on both top and bottom.

2) Materials of the Design

The design and specifications for the materials utilized in the design were discussed in Design Parameters for Underground Cables

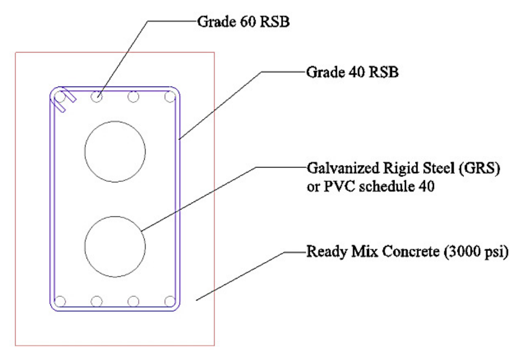

Fig. 5. Designation of material (Cross-Section View)

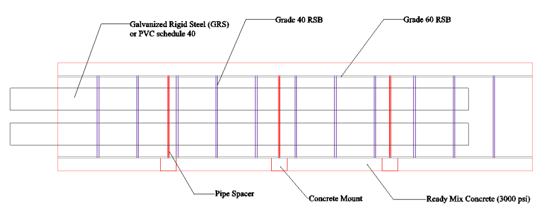

Fig. 6. Designation of material (Lateral View)

3) Analysis of the Design

The duct bank was applied with loads specifically from the HL-93 Truck (AASHTO 2014) at critical points to test the theoretical application of the design in Plaza, Burgoz, Guagua, Pampanga.

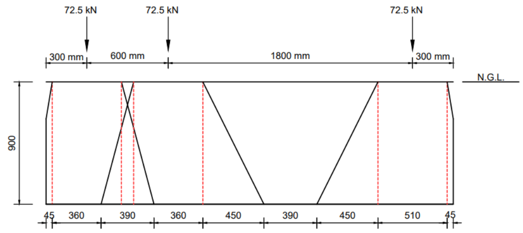

Fig. 7. HL93 Live Load Application

Based on the design parameter, the proposed duct bank should be buried 900 mm below the natural grade line.

A. Stress Distribution of Soil

TABLE II
Stress Distribution of Soil (Duct Bank)

HL93 Loadings	1	2	3
Live Loads (kN)	72.5	72.5	72.5
Stress at 900-mm Depth (kN/m)	20.568	20.568	20.568
Factored Value (kN/m)	32.9088	32.9088	32.9088
Distribution Length	1.605	0.390	1.005

The three loads applied by the wheels of HL93 Truck Design were all 72.5 kN. The first two were spaced 1.8m apart and positioned 300mm from the edge of the design, and the farthest one was positioned 600mm from the second wheel. By uniformly distributing the loads, the stress at depth 900-mm from the wheels is 20.568 kN/m with factored value of 32.9088 kN/m.

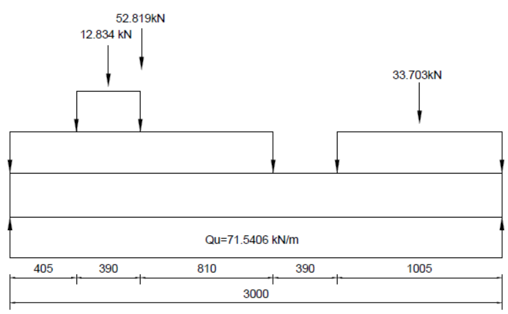

Fig. 8. Stress Distribution on the Structure (Duct Bank)

TABLE III
Required Ultimate Soil Bearing Capacity (Duct Bank)

Factored Loadings (kN)			Dimension of the Design (m)		Required Ultimate Soil Bearing Capacity (kPa)
52.819	12.834	33.073	0.46	3.0	71.5406
Total	98.726		Area (m^2)	1.38	

The computed uniformly distributed loads were converted into concentrated loads to obtain the value of the required ultimate soil bearing capacity of *71.5406 kPa* that was used on computing for the shear and moment.

B. Maximum Moment Applied

•Shear and Moment

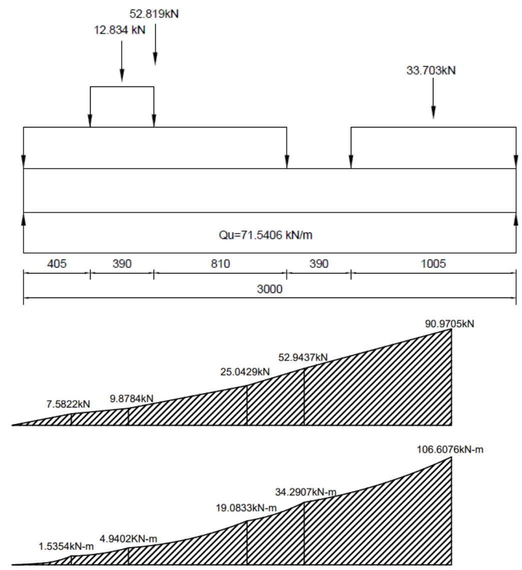

Fig. 9. Shear and Moment Diagram

TABLE IV
Shear and Moment Results

Shear (kN)	7.5822	9.8784	25.0429	52.9437	90.9705
Moment (kN-m)	1.5354	4.9402	19.0833	34.2907	106.6076

The maximum moment that the duct bank will experience, which would be used for the ultimate design, is determined to be *106.6076 kN-m*.

C. Analysis of Dimension and Design

I. Allowable Area of Duct Bank

The duct bank area must meet the specifications for the standard or altered soil load bearing capacity.

TABLE V
Analysis of the Design (Duct Bank)

Bedding Material	Excavated Material (Guagua, Pampanga)	Compacted Gravel Bedding
Allowable Soil Bearing Capacity (kPa)	24	100
Design Length (m)	3	3
Applied Loads (kN)	61.7038	61.7038
Required Width (mm)	856.997	205.679
Adequacy of the Design Width, $w_{(min)} \leq w_{(des)}$	$w_{(min)}>w_{(des)}$	$w_{(min)}<w_{(des)}$
Remarks	Adjustment in the soil bearing capacity is needed.	The design width satisfies the requirement.

Upon computing for the analysis of the design width, it was found that adjustment is needed in the soil bearing capacity of Guagua, Pampanga which is only 24 kPa. The required minimum width of 856.997 mm that satisfies the soil bearing capacity of the location was not met by the design width of 460mm. Therefore, the design of the bedding covers 300 mm of G3/4 gravel and compacted to raise its soil bearing capacity from 24 kPa to 100 kPa as stated in Section 304 of NSCP 2015. The design adjustment yields to a lower required minimum width of 205.679 mm which is lower than the design width of the structure.

II. Irregular Beam Reinforcement Design Analysis

The pressure at the bottom of the duct was evaluated to determine whether the duct bank can withstand the force created by the crucial point of the factored live loads.

The maximum moment applied to the structure is 106.6076 kN-m and the maximum shear is 90.9705 kN.The compressive strength of concrete is 20.68 MPa, while the yield strength of 25 mm diameter steel reinforcement main bars is 420 MPa. The duct bank has a width of 460 mm and its effective depth is 600 mm. This data value was used for the analysis of the design.

•Check if the Duct Bank is Wide Rectangular Design

TABLE VI
Checking for Wide Rectangular Design

Compressive Force	Tensile Force	Checking	Remarks
1293.741 kN	824.66 8 kN	$C_f>T$	The structure is Wide Rectangular Design

To check if the structure is a wide rectangular design, compare the value of the compressive force to the tension force. The compressive and tensile force results showed that the compressive force is greater than the tensile force.

Therefore, the structure is Wide Rectangular Design.

•Check if the Duct Bank will have Ductile Failure

TABLE VII
Ductile Failure Test

Tensile Strain	Yielding tensile strain	Checking	Remarks
0.01200	0.00207	$\varepsilon_s>\varepsilon_y$	The structure will yield at tension steel first.

To check if the structure will yield at tension steel first, the structure underwent ductile failure. To depth of the compression block, the compressive force was equated to the tensile force. Then, to acquire the distance of extreme compression fiber to neutral axis by dividing the depth of the compression block to a factor β_1, which is taken as 0.85 for concrete compressive strength less than or equal to 4000 psi or 27.58 MPa. The distance of extreme compression fiber was then used to calculate the tensile strength of the duct bank, which resulted in 0.01200. The yielding tensile strength of the steel was obtained from its theoretical formula, using the yield strength of 60 ksi and Young's Modulus of Elasticity equal to 29000 ksi. The tensile strain is greater than the yielding tensile strain.

Therefore, the structure yieldsattension steel first.

•Solve for the Moment Capacity of the Design

TABLE VIII
Maximum Moment Capacity

Maximum Moment Capacity of the Design	Maximum Moment of the Design	Checking	Remarks
407.473 kN-m	106.6076 kN-m	$M_{u(cap)} > M_{u(des)}$	The structure can withstand the given critical forces from the HL-93 Truck.

Upon solving for the ultimate design moment capacity of the duct bank with the capacity reduction factor of 0.9, it shows that the moment capacity is greater than the actual maximum moment of the design. It means that the design of the structure is adequate to support the loads induced on the surface.

Therefore, the structure can withstand the given critical forces from the HL-93 Truck.

III. Shear Reinforcement Design Analysis

•Number of Shear Reinforcement: The diameter of shear reinforcement bars used is 10 mm diameter bars with yield strength of 280 MPa. Upon solving for the maximum spacing that can be used for the analysis of the design, 270mm produced the least value out of the maximum spacing from the codes. The length of the design lane is divided by the least spacing acquired, producing 11 shear reinforcement bars.
•Final Reinforcement Spacing: The final spacing of the reinforcement bars was calculated based on the number of reinforcement bars used. The spacing of the bars in the 3000 mm design length is 250 mm on center.

Therefore adopt 11-10mm Shear Reinforcement bars at 250mm on center.

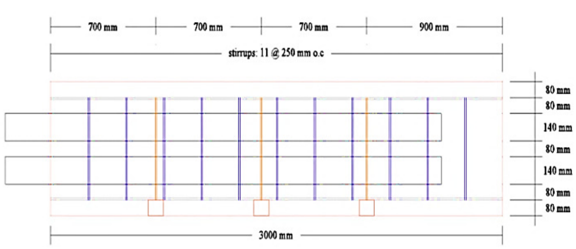

Fig. 10. Lateral Dimension of the Duct Bank

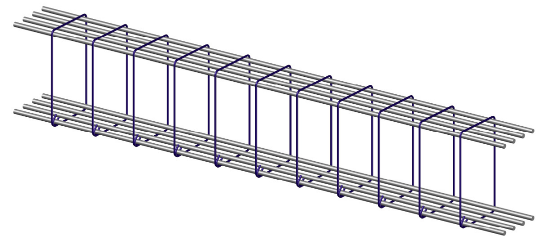
Fig. 11. Model of the Reinforcement Bars

D. Model of the Design

The rendered visualization of the final design of the duct bank with the warning tapes are shown below. The warning tapes are placed 450mm above the top of the duct banks. Red is used for power lines and orange is used for telecommunications lines.

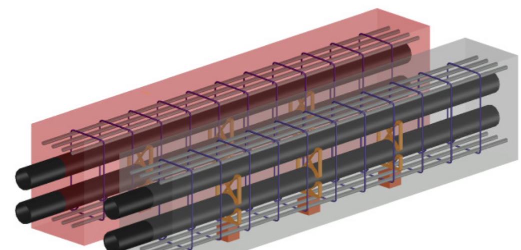
Fig. 12. Three-Dimensional Model of the Duct Bank

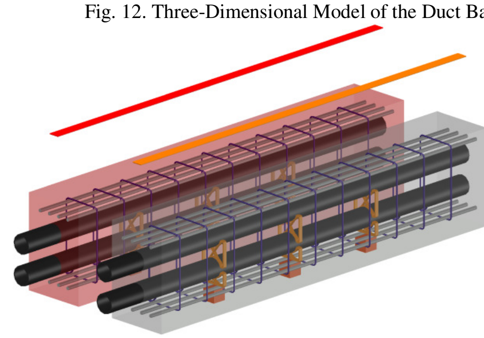
Fig. 13. Three-Dimensional Model of the Duct Bank with Warning Tapes

A.Design of Drainage

1) Solving for the Pipe Diameter

TABLE IX
Discharge Value

Dimensionless Runoff Coefficient	10-year Average Rainfall Intensity in/hr (mm/hr)	Area of Drainage District m^2 (hectare)	Discharge m^3/hr(L/s)
0.89 (commercial area)	19.591 (497.606)	13100 (1.31)	5801.59 (1611.5538)

The discharge value, 5801.59 m^3/hr, was computed using the rational formula of discharge. The runoff coefficient used was 0.89 for the commercial area which is 1.31 hectares. The 10-year average rainfall density from MDRRMO was used to complete the computation.

TABLE X
Design Diameter

Discharg e	Manning' s Coefficient	Slo pe of the Pipe	Diamet er of the Pipe	Diamet er Based on ASTM
1611.553 8 L/s	0.013 (plastic pipe)	0.2 5	35.172 inches	38.3 inches (973-mm)

Manning's formula for discharge was used to calculate the required diameter of the pipe for the design using the coefficient of roughness for smooth pipes, 0.013. The calculated value for the diameter of the pipe is 35.172 inches.

TABLE XI
Design Pipe Stiffness

Outside Diameter	Thickness	Pipe Stiffness
973 mm	29.5 mm	320 kPa

Using the table for pipe stiffness from ASTM (Table 1), the outside diameter and thickness of the pipe were finalized to be 38.3 inches (973-mm) and 29.5 mm, respectively.

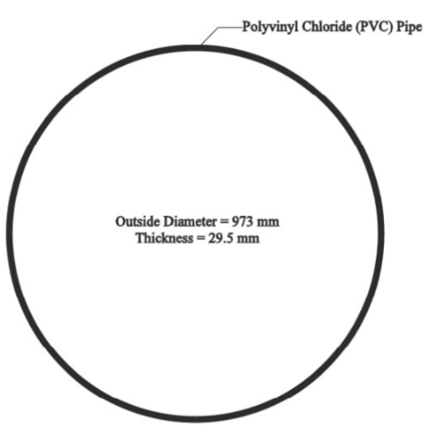

Fig. 14. Dimensions of the Pipe

2) Stress Distribution of Soil

The design and materials from the specification were applied to the general requirements of the structure. The pipe was applied with loads specifically from the HL-93 Truck (AASHTO 2014) at critical points to test the theoretical application of the design in Plaza, Burgoz, Guagua, Pampanga.

TABLE XII
HL93 Truck Load Types (Pipe)

HL93 Truck Load Type	Ultimate Bearing Capacity	Remarks
Design Truck	41.397 kPa	Use Design Tandem on Live Load Application
Design Tandem	50.574 kPa	

The HL93 Design Tandem yields a higher value of ultimate soil bearing capacity of 50.574-kPa compared to the Design Truck with 41.397 kPa. Therefore, the HL93 Truck Design Tandem was used on the computation of load application on pipe.

TABLE XIII
Stress Distribution of Soil (Pipe)

HL93 Loadings	1	2
Live Loads	55 kN	55 kN
Stress at 650-mm Depth	51.260 kN/m	51.260 kN/m
Factored Value	82.015 kN/m	82.015 kN/m
Distribution Length	0.9 m	0.9 m

The two loads applied by the wheels of HL93 Truck Design Tandem were both 55kN based on AASHTO. They were spaced 1.2m apart and positioned 600mm from the edge of the design. By uniformly distributing the loads, the stress at depth 650mm from both wheels is 51.260 kN/m with factored value of 82.015 kN/m.

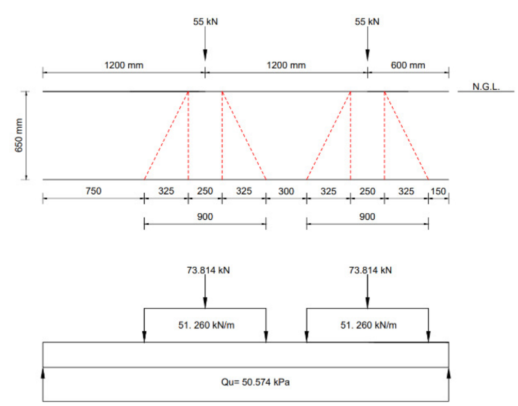

Fig. 15. Maximum Transfer of load (Pipe)

TABLE XIV
Required Soil Bearing Capacity (Pipe)

Factored Concentrated Loadings		Dimension of the Design		Required Ultimate Soil Bearing Capacity
73.814 kN	73.814 kN	0.973 m	3.0 m	50.574 kPa
Total	147.628 kN	Area	2.919 m^2	

The computed uniformly distributed loads were converted into concentrated loads to obtain the value of the design ultimate bearing capacity of 50.574 kPa that was used on computing for the shear and moment.

TABLE XV
Design Requirement (Pipe)

Required Ultimate Soil Bearing Capacity for the Pipe	Pipe Stiffness	Remarks
50.574 kPa	320 kPa	The pipe stiffness satisfies the design requirement.

Considering the required ultimate soil bearing capacity of 50.574 kPa as the maximum loadings that the pipe will experience, the pipe stiffness of 320 kPa satisfies the design requirement.

3) Analysis of Dimension and Design

TABLE XVI
Analysis of the Design (Pipe)

Bedding Material	Excavated Material (Guagua, Pampanga)	Compacted Well-graded Sand Bedding
Allowable Soil Bearing Capacity	24 kPa	75 kPa
Design Length	3 m	3 m
Applied Loads	92.268 kN	92.268 kN
Required Width	1.281 m	0.410 m
Adequacy of the Design Width, $w_{(min)} \leq w_{(des)}$	$w_{(min)} > w_{(des)}$	$w_{(min)} < w_{(des)}$
Remarks	Adjustment in the soil bearing capacity is needed.	The design width satisfies the requirement.

Upon computing for the analysis of the design contact width of the pipe, it was found that adjustment is needed in the soil bearing capacity of Guagua, Pampanga which is only 24 kPa. The required minimum width of 1.281m of the soil bearing capacity of the location was not met by the design width of 0.973m. Therefore, the bedding was adjusted to satisfy the design. The design of the bedding covers 300 mm of well-graded sand and should be compacted to raise its soil bearing capacity from 24 kPa to 75 kPa as stated in Section 304 of NSCP 2015. The design adjustment yields to a lower required minimum width of 0.410m which is lower than the design width of the structure.

Model of the Design

This part shows the final drawing of the design after a series of calculations accumulated to satisfy various code requirements.

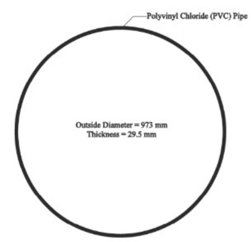

Fig. 16. Final Dimensions of Drainage Pipe

Based on the results calculated using the 10-year rainfall data of Guagua, Pampanga, the drainage pipe is buried 650 mm below the natural grade line. It has an outside diameter of 973 mm with a thickness of 29.5 mm.

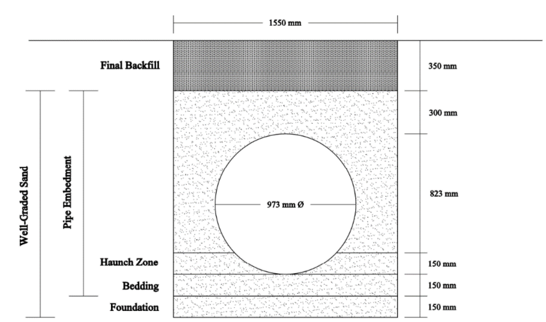

Fig. 17. Trench Design of Drainage Pipe

The material of the bedding of the pipe is well-graded sand, and it is compacted to raise its soil bearing capacity from 24 kPa to 75 kPa as stated in Section 304 of NSCP 2015. It consists of 150 mm foundation and 150 mm pipe bedding. The pipe embedment extends up to 300 mm from the top of the pipe. The PVC pipe will be produced to withstand the load from HL-93 directly by the manufacturer.

Fig. 18. Three-Dimensional Rendering of the Drainage Pipe

C. Route Layout of the Underground Structures

The data provided by PELCO II which is the overhead powerline map and Guagua LGU which is the drainage line map were used to verify the points where the underground structures can be located. After analyzing the data, Figure 30 shows the final layout mapping of the structures on Plaza Burgos, Guagua, Pampanga.

The red lines represent the underground cables, while the blue lines represent the underground drainage.

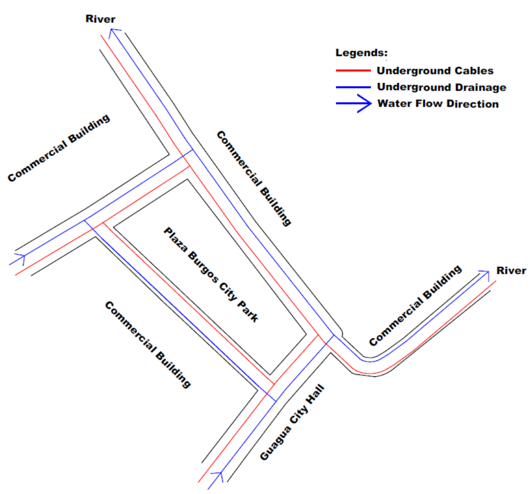

Fig. 19. Route Layout of the Underground Structures

IV. CONCLUSIONS

Guagua is one of the municipalities of Pampanga, a commercial area at the same time, a flood-prone one as it is only one meter above sea level with deficient drainage system. In addition to that, it has high demand of electricity and telecommunication utilities leading to overcrowded and tangled overhead lines. These situations may eventually lead to multiple issues, either environmentally or economically, and may pose danger to its residents. Considering those, this study was proposed to design underground structures to alleviate and relieve risks concerning the safety and wellness of the area. The study proposed to create designs of underground duct bank and underground drainage based on the accumulated specific design codes and provisions. Moreover, it will provide a route layout draft for the duct bank and drainage utilizing both the plan layouts of Guagua drainage line and PELCO overhead powerlines.

The proposed designs were analyzed with series of analytical calculation based on various codes and provisions. Data gathered from Guagua, Pampanga were incorporated in the calculations to establish the desired design of underground structures for the area. The following dimensions and designs are the concluded results of the study:

A. Underground Drainage

• The underground pipeline should be buried 650-mm below the natural grade line and should sit on a 300-mm compacted well-graded sand to produce a safe soil bearing capacity for the design.

• The outside diameter of the pipe must be 973-mm with thickness of 29.5- mm. Conforming to ASTM standards, the pipe must have a minimum pipe stiffness of 320 kPa.

B. Underground Duct Bank

• The underground duct bank should be buried 900-mm below the natural grade line and should sit on a 300-mm compacted G3/4 gravel bedding to produce a safe soil bearing capacity for the design.

• The dimensions of the duct bank must have a width of 460-mm and a height of 680-mm. The duct bank must have 2 pipes with diameter of 140-mm and length 3-m placed 160-mm from both ends. The design must have 3 pipe spacers and concrete mounts placed at 700mm on center. The concrete to be use must have 3000 psi at 28 days strength, making the design safe with shear and flexure.

• The longitudinal reinforcements must be Grade 60, 4-25mm diameter bars and positioned 80-mm from the extreme fiber on both the top and bottom. The shear reinforcement bars must be Grade 40, 11-10mm diameter bars spaced at 250-mm on center.

• The duct bank containing electrical cables must have its concrete be dyed red with red warning tape 450-mm above its topmost end. The duct bank containing telecommunication cables must have an orange warning tape 450-mm above its topmost end.

C.Route Layout

• The route of the duct banks must follow the direction where the electrical post and overhead powerlines are originally located.

• The route of the drainage should start from the farthest ends of the study area and should have open ends on the river.

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