SUSTAINABLE & COST-EFFECTIVE DRAINAGE DESIGN SOLUTION FOR AN URBAN ROAD SCENARIO USING HYDRAULIC SOFTWARE APPLICATION

Snehal Kamuni [1], Sanjeev Yendamuri [2], Prof. Nitin Sawalkar[3]

[1] M. Tech Student, Department of Civil Engineering, Vishwakarma Institute of Information Technology, Pune Maharashtra, India
[2] Principal Engineer - Storm Water Drainage, Civil & Infrastructure Sector, AECOM GDC, Bengaluru, India
[3] Assistant Professor, Department of Civil Engineering, Pune, Maharashtra, India

---

Abstract - *This paper presents an overview of sustainable and cost-effective drainage design solutions for an urban road scenario by evaluating the design based on Modified Rational Method against several parameters. It discusses the objectives and benefits of sustainable and cost-effective drainage design, including effective management of surface runoff, attenuation of the flow to combat against flash discharge, ease of installation of drainage assets and finally meeting the regulations of Environment Agency, UK. It also examines the importance of optimizing the drainage assets there by reducing carbon footprint, cutting down on construction costs by optimizing the drainage assets, achieving long-term cost savings, meeting regulatory requirements, and engaging stakeholders. The use of hydraulic software applications is explored as an effective tool for designing, modelling, analysing drainage systems for storage requirements, helping to identify the most efficient and cost-effective drainage design solution.*

The study includes development of three drainage design alternatives which would best suit the new urban road site selected for the study and then comparing these three designs against several parameters to arrive at an optimized and cost-effective solution. Various combinations of available Surface and Subsurface drainage solutions are analysed in industry standard hydraulic software application, MicroDrainage and the most sustainable and Cost-effective Option is suggested which would best suit the site.

***Key Words*: Stormwater Drainage Design, Urban Road Scenario, Cost-effective Drainage Design, Microdrainage.**

1.INTRODUCTION

Sustainable and cost-effective drainage design solutions are essential for managing urban stormwater runoff and to prevent flooding in cities. With the increasing urbanization and climate change impacts, there is a growing need for innovative drainage solutions that can efficiently handle the increasing volume of stormwater runoff due to newly developed impervious surfaces in urban areas. Hydraulic software applications are becoming a popular tool for designing and analysing drainage systems. Climate change and urbanization are significant challenges that require effective strategies to mitigate their impacts on the environment, society, and economy [5].

The use of hydraulic software applications can aid in the design and analysis of drainage systems and help identify the most efficient and cost-effective solution for the specific requirements of urban road scenarios. Hydraulic software applications are computer programs that can simulate the hydraulic performance of drainage systems. These applications use various mathematical models to predict the flow of water in drainage systems and evaluate their efficiency.

The objectives of a sustainable drainage design may include:

- Managing surface runoff by accounting for the climate change factor
- Efficient use of resources which in turn reduce the carbon footprint
- Reducing construction costs and time
- Meeting the attenuation requirements
- Finally liaising with regulatory standards.

2.STUDY AREA

The site chosen for comparative study of suitable drainage designs lies in UK along a strategic road. It is assumed that the new carriageway improvements would be proposed within the existing public highway boundary and that involves a minor realignment of the existing highway to accommodate the proposed new access roundabout and the creation of a 3 m wide multi-use pedestrian and cycling route as it is generally the case in case of improvisation of existing road infrastructure. The Proposed Development is located within a Metropolitan Council that acts as administrative & Local Planning Authority. The council also acts as Lead Local Flood Authority (LLFA), responsible for managing local flood risks and ensuring co-operation between the Risk Management Authorities in the area. So, to

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 05 | May 2023 www.irjet.net p-ISSN: 2395-0072

meet the objective of comparing the three suitable drainage designs for the site and to arrive at a better optimised option, the above new proposal is assumed to be carried out.

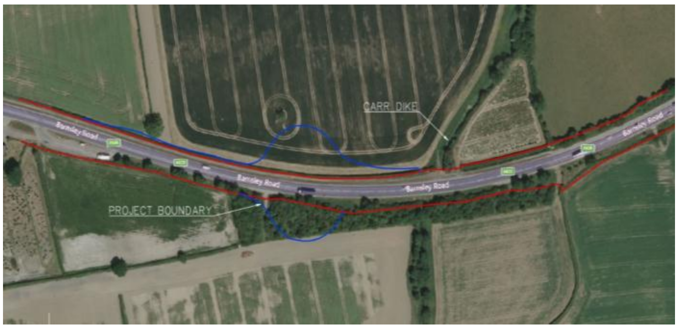


Fig -1: Study Area

In short, it is assumed that the development proposal would involve the construction of the following:

- New access roundabout and accompanying embankment earthworks for connecting the future road coming from south direction
- Carriageway improvements which include a new 3 m wide pedestrian and cycle access route
- 2m wide grass verge spanning alongside south of the carriageway
- Surface water drainage network capable of attenuating up to and including the 1 in 100-year rainfall event plus 40% CC factor with discharge control to limit the runoff rate to existing or pre-development scenario.

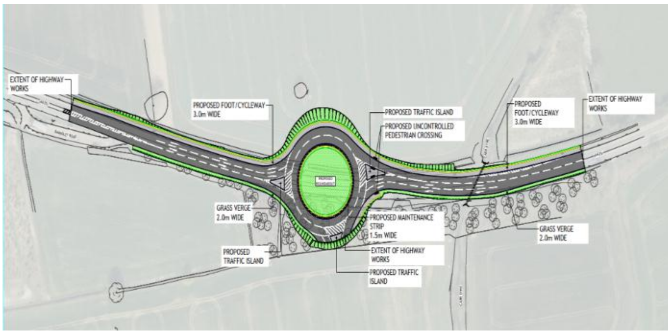
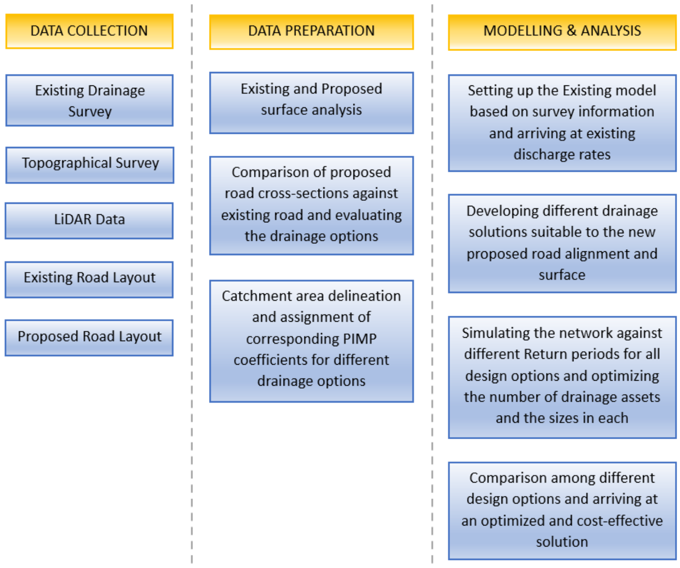


Fig -2: Proposed Improvisation to Existing Road Scenario

3.DESIGN METHODOLOGY



4.EXISTING HYDRAULIC MODEL DEVELOPMENT

To liaise with the Environment Agency regulation of meeting the pre-development flow rate for any of the new developments, an existing flowrate need to be arrived. This can be achieved by building an existing model and then simulating it against different rainfall return periods. Using the Existing drainage survey and Topographical information, the existing network was simulated using hydraulic software called Microdrainage. By assigning catchment areas and the corresponding PIMP coefficients, the model was analyzed, and the existing flow rates were determined for respective storm return periods.

Table -1: Design Parameters considered while constructing and simulating the hydraulic model:

1. FSR (Flood Studies Report) Rainfall data
2. Time of Entry – 5 minutes
3. Grid Reference: 444510,403913
4. M5-60 (mm): 19
5. Ratio M5-60/M5-2Day (R): 0.375
6. PIMP for Carriageway / Footpath - 100%
7. PIMP for Verge / Cutting / Embankment - 20%
8. Volumetric Runoff Coefficient C_v – 0.75

5.PROPOSED DRAINAGE DESIGN

The proposed site is studied in detail by performing the catchment analysis to check if there was any effect of overland flow that would intercept the road embankments. The proposed road cross-sections are then compared against the existing road surface to identify if there is any section of road that remained unchanged and to choose drainage collection system suitable for those road slopes. Since the proposal included the provision of Roundabout that in turn would encroach the existing ditch, a need for realigning of existing ditch is identified. This ditch will cutoff the overland flow and will divert the runoff to the existing culvert downstream thus safeguarding the proposed road earthworks.

The Environment Agency in UK will normally require that, for the range of annual flow rate probabilities, up to and including the 1% annual probability (1 in 100-year event) the developed rate of runoff into a watercourse should be no greater than the undeveloped rate of runoff for the same event based on the calculation of Mean Annual Flood (QBAR) or Median Annual Flood (QMED) and the use of FSSR growth curves [5].

The purpose of this is to retain a natural flow regime in the receiving watercourse and not increase peak rates of flow for events of an annual probability greater than 1%. Three annual probabilities are used to define discharge compliance limits though the critical criteria are for the lowest and highest frequency events: 100% (1 year), 3.33% (30 year) and 1% (100 year). Thus, any storm water drainage system that is to be designed for a new development should collect runoff originating from site, store or attenuate it and then release only at Green Field or Pre-Development Runoff discharge rate to the receiving water body after satisfying the water quality criteria.

5.1 Contributing Catchment Areas of Existing and Proposed Model

To identify the attenuation volume requirement, the catchment plans of both existing and new proposals are studied and the Gross Impervious Area is evaluated. The figures below depict the area contribution in existing and proposed scenario.

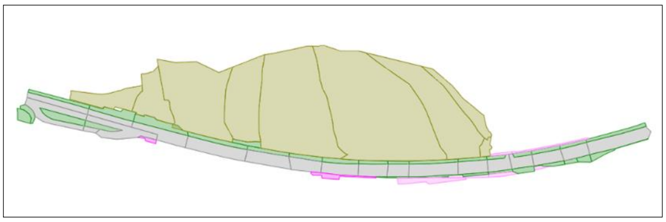


Fig -3: Contributing Catchment areas in Existing scenario. Gross Impervious Area: 0.609ha

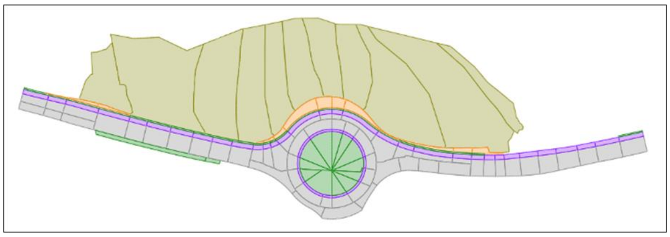


Fig -4: Contributing Catchment areas in Proposed Design scenario. Gross Impervious Area: 1.130ha

5.2 Design Options Arrived

Upon analyzing the existing and proposed road surfaces, three design alternatives were identified which best suit the site. These include:

- **Option-1: Gullies and Pipe System along with Filter Drains at toe of cutting earthwork slopes.**

Since Road Gullies form the conventional road drainage collection system that is adopted by many councils across UK. This option was chosen as one of the drainage options after meeting the Gully/Inlet spacing requirements as per the UK's DMRB standard (CD526) by satisfying the Flow width criteria. The gullies are proposed with optimal spacing to collect the highway runoff and then convey through the carrier drains up to outfall. The online attenuation is provided in carrier drains with the help of orifice plates to meet the existing discharge rates at outfall. The network is optimised further by simulating it against respective rainfall events and the quantities are extracted to compare against other drainage options.

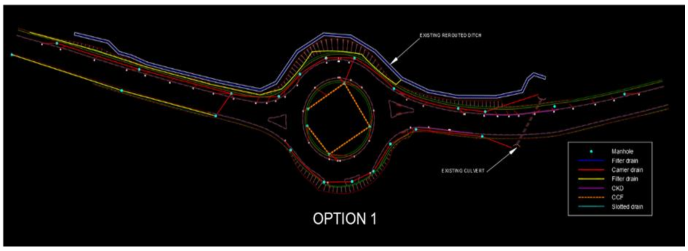


Fig -5: Drainage 2D layout - Option 1

- **Option-2: Slotted Drains and CKDs along with Filter drains at toe of cutting earthwork slopes**

The Slotted Drains (SD), Combined Kerb Drains (CKD) offer more benefits than the Gully system as it not only collects the runoff but convey the flow through the same conduits. This eliminates the need for number of pipe connections and make the drainage system clutter free. This system can be adopted at the edge of the road, thereby eliminating all potential clashes with underground utilities in the verge. The system comes with prefabricated units of specific length and is easy to install which reduces the installation time to a greater extent. A combination of Slotted Drain and CKD integrates the advantages of both the systems to provide a more efficient and effective drainage solution.

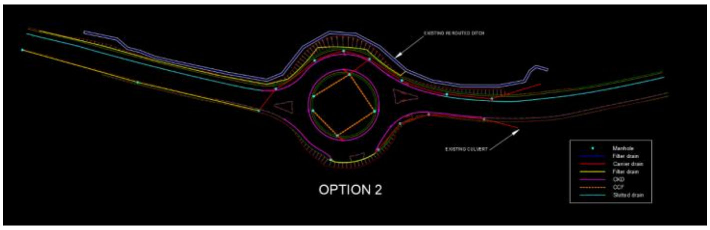


Fig -6: Drainage 2D layout - Option 2

- **Option-3: Combination of Existing drainage and Proposed CKDs with pipe system**

Incorporating part of the existing storm drainage network into a proposed network where it can be retained has several advantages such as savings in time and cost, environmental benefits and minimizes disruption. In this option, the existing network with Gullies and Pipe system is retained where the road width and slopes are unchanged. Where the road alignment changes particularly at roundabout portion, the proposed CKD system is connected to the new pipe network and is used for attenuation to meet the discharge regulations. The network is optimised further by simulating it against respective rainfall events and the quantities are extracted to compare against other drainage options.

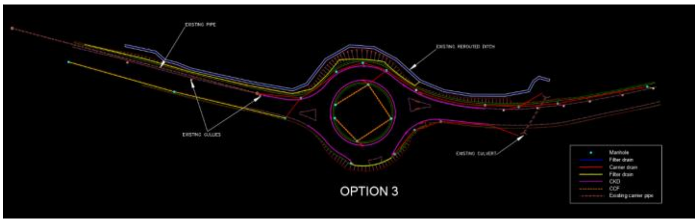


Fig -7: Drainage 2D layout - Option 3

6. COMPARATIVE STUDY OF DESIGN OPTIONS

After ensuring that each design is meeting the primary objectives of runoff collection, conveyance, and attenuation requirements as per the UK DMRB standards and Environment Agency guidelines, a detailed analysis is carried out to check if it is feasible for construction. The optimization process is performed on each design option to ascertain the minimal quantity of drainage assets are obtained for respective option, with the goal of reducing carbon footprint, maximizing efficiency and effectiveness. The network quantities are exported separately to compare the lengths, diameters of similar pipe & chamber types, total cost of assets in each option against all three design options. Below is the graphical representation of total lengths of pipe types in each option. These can now be evaluated to arrive at total cost of construction by looking at the breakdown of Capital, Installation and Maintenance costs.

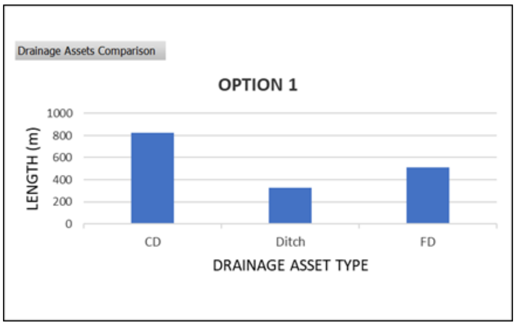


Chart -1: Lengths of different liner assets - Option 1

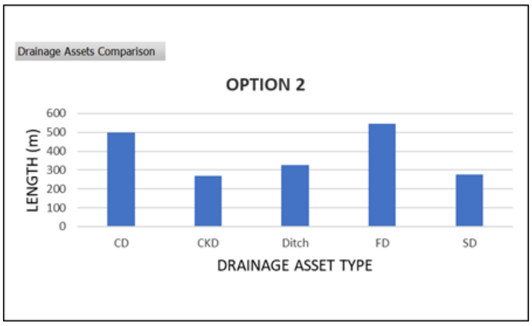


Chart -2: Lengths of different liner assets - Option 2

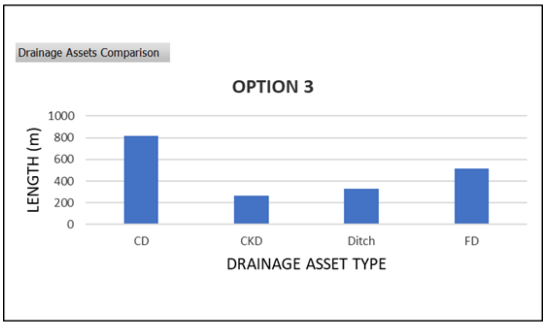


Chart -3: Lengths of different liner assets - Option 3

6.1. Cost Comparison of Drainage Options Chosen

Although one particular drainage solution offers few advantages as well as disadvantages over other, to strike a right balance, a more efficient and cost-effective solution will be widely adopted. Hence, the cost of drainage network on the whole is often the deciding factor in addition to its efficient functioning. This cost can mainly be divided into Capital Cost, Installation Cost and Maintenance Cost. The maintenance cost is a recurring cost and is added throughout the life of the network for its seamless functioning.

- **6.1.1: Capital Cost.**

The capital cost in storm drainage typically includes the cost of physical assets such as pipes, manholes, catch basins, gullies, grates, channels, slot drains, combined kerb drains, pollution control chambers and other components that make up the drainage system. These costs can vary depending on the materials used, size of the assets, number of assets required for the project and the local suppliers. In the present study an approximate cost of the drainage assets in UK is considered at the time of writing this report [9] [12]. These costs vary with time and can also vary in different countries. However, the variation in cost of different drainage assets would still be equivalent in other geographical locations. The capital cost is arrived at by doing the literature review, browsing through the list of suppliers and their official websites, and then making some realistic assumptions to suit for the product types applied on this study. The same is tabulated below for easy reference.

Table -2: Drainage Asset Cost per meter/unit in (£)

S No.	Drainage Asset Type	Size (mm)	Cost per meter/unit in (£)
1	Carrier Drain	150	13
		225	35
		300	54
		375	54
		450	54
		525	138
		600	52
2	Filter Drain	100	10
		150	17
		225	28
3	Gullies	450x750	105
	Gully Grating	450x450	130
4	Slot Drain	225	23
5	Slot Drain Access Unit	Nominal	13
6	CKD	Base 155	95
7	CKD Access Unit	Nominal	160
8	Manhole	1200	485
	Manhole Cover	1200	65
	Orifice chamber	1500	1100
9	Junction Y-Type	Varies	8

The bar chart below presents the comparison of capital cost of the selected three drainage design options for the present study.

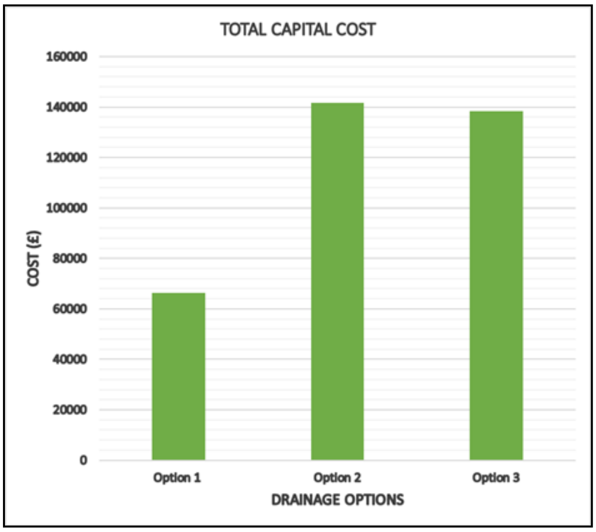


Chart -4: Capital Cost Comparison for three Drainage Design options

- **6.1.2: Installation Cost.**

Installation cost often makes out to be the most significant component in drainage network construction. The installation cost of storm drainage systems can vary greatly depending on the size of the system i.e., number of assets, the materials used, the complexity of the design, and the location of the project, type and significance of road and the quantum of traffic the road handles etc. Typically, installation cost of storm drainage systems includes the equipment rental, cost of human resources to conduct the job, excavation of earth and any necessary permits or inspections. Again, this installation cost varies in different countries however the activities performed in the installation may remain same.

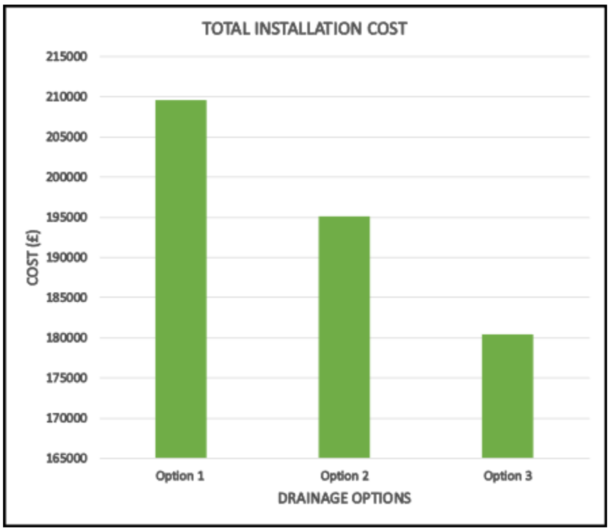


Chart -5: Installation Cost Comparison for three Drainage Design options

- **6.1.3: Maintenance Cost:**

An efficient working of a good drainage system lies in proper maintenance of the whole network. The assets should be free from debris, clogging due to sediments, moreover it is to be ensured that the structural integrity is taken care of, to avoid cracks, collapse of pipes due to protrusion of tree roots. This maintenance cost of a storm drainage system can vary depending on factors such as the type of drainage assets installed, number of assets, the frequency and intensity of rainfall occurrences, the level of debris and sedimentation, and the condition of the system [13]. Generally, maintenance activities for a storm drainage system may include:

- Regular cleaning of gullies, slot drains, and other drainage assets to prevent blockages and ensure proper functioning
- Inspection and repair of damaged pipes, chambers, and other structural components
- Clearing of debris, litter, and sedimentation from catchpits, manholes, and other drainage structures
- Removal of invasive vegetation, such as tree roots, that can compromise the integrity of the system
- Regular monitoring of water quality to ensure compliance with environmental regulations.

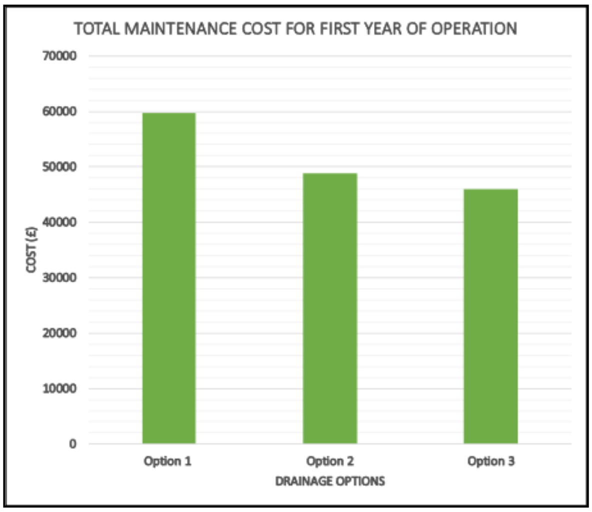


Chart -6: Maintenance Cost Comparison for three Drainage Design options

6.2. Summary of Overall Cost

The following chart summarizes the cost of all three best suited design options for this study area. The individual cost categories of each design option are presented to quickly arrive at the significant cost component in each. The comparative study of these design options is also carried out for the first 1 year of its operation and also throughout the life of the drainage system by assuming a design life of 40 years. This will guide us with the importance of maintenance cost for the efficient functioning of whole drainage system.

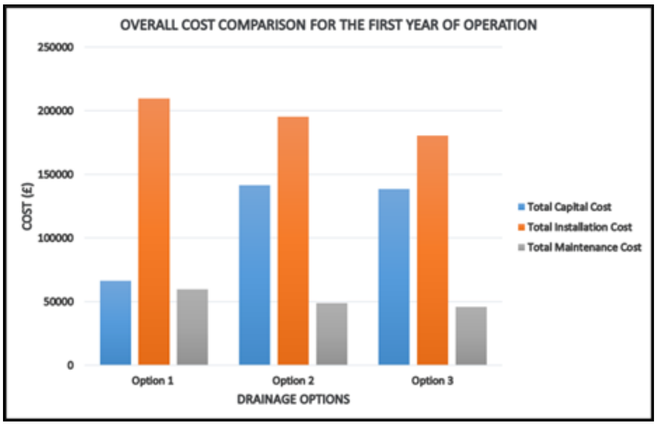


Chart -7: Graphical Representation of Overall Cost Comparison for 3 Design Options for the First Year of Operation

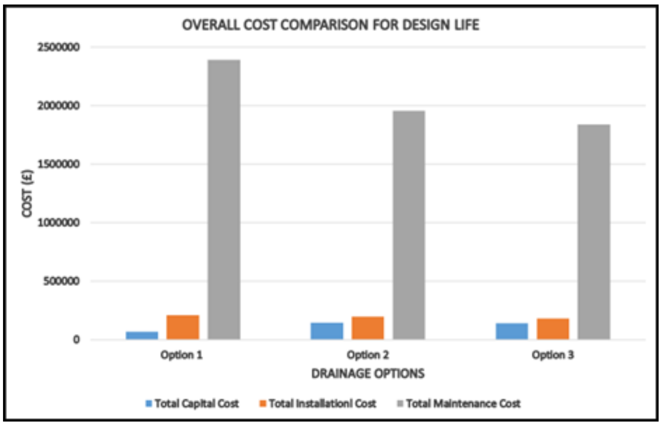


Chart -8: Graphical Representation of Overall Cost Comparison for 3 Design Options over its Design Life

7. CONCLUSIONS

Based on the results presented in the Overall Cost Comparison graph, the following conclusions are drawn:

The installation cost makes out to be the most in any design option during the construction as most of the cost will be accounted for traffic management, safety measures taken on site, hiring human resources to carry out the work, equipment rental, transportation of assets and corresponding equipment for their installation and necessary permits. Option 1 is having higher installation cost compared to other design options as there are a greater number of assets and their corresponding network connections. In contrast, Option 3 utilizes the existing drainage network, making it a cost-effective choice for installation compared to the other options.

The capital cost of option 1 with Gullies and Pipe system is lower compared to other options though the assets are more in the design. This is due to the fact that gullies are cheaper compared to more recent drainage systems such as slot drain and CKDs. The Slot and CKD conduits have been evolving over the years through a high level of research to suit for different road and kerb configurations thus have become more costlier compared to Gullies.

The maintenance cost of option 3 comprising of existing and proposed assets offers better cost savings during the first year of its operation and subsequently over its lifetime as the assets are fewer and most of the network comprise of a proposed linear kerb system which is relatively easier to maintain. It is assumed that the maintenance of the drainage system is done on a yearly basis and that it may differ from region to region and the frequency of rainfall, clogging and sedimentation etc. However, a proper and regular maintenance is key for proper functioning of a system to meet its objectives.

Among all three options, Option 1 with Gullies and Pipe system provides better cost savings when looked at the overall cost for the first one year of operation, but Option 3 with a mix of Existing Gullies & Pipe system and Proposed CKD network proves to be economical when looked at the full design life of the system. Thus, maintenance cost plays a vital role in overall cost of a drainage system when looked at its full design life.

REFERENCES

[1] Construction Industry Research and Information Association (CIRIA), Flood risk management and surface water drainage https://www.ciria.org/CIRIA/Topic_overviews/Flood_risk_management_and_surface_water_drainage.aspx?hkey=e2db6bec-aa41-41a4-bff8-bdb313739491

[2] DMRB Drainage Standards, UK https://www.standardsforhighways.co.uk/search?discipline=DRAINAGE&suite=DMRB

[3] Duffy, A., Jefferies, C., Waddell, G., et al. (2008). A cost comparison of traditional drainage and SUDS in Scotland. Water Science and Technology, 57(9), 1451–1459.

[4] Cely-Calixto, N. J., Carrillo-Soto, G. A., and Bonilla-Granados, C. A. (2020). Optimization of a storm drainage network using the storm water management model software in different scenarios. Journal of Physics: Conference Series, 1708(1), 012030.

[5] Environment Agency, UK https://www.gov.uk/government/organisations/environment-agency

[6] ACO Drainage Design Solutions https://www.aco.co.uk/drainage-design

[7] Drainage Supplies from Marshalls https://www.marshalls.co.uk/commercial/civils-and-drainage/drainage-supplies

[8] JDP. (n.d.). Surface Water Drainage Systems - JDP. Retrieved from

https://store.jdpipes.co.uk/surface-water-drainage.

[9] The Complete Price Guide. (n.d.). The Average Drainage Costs. Retrieved from https://www.homehow.co.uk/costs/drainage.

[10] D. Store. (n.d.). Drainstore | Drainage and Pumping Supplies - Drainstore. Retrieved from https://drainstore.com/.

[11] George Lines. (n.d.). Gully Pots - Gullies - Drainage. Retrieved from https://www.georgelines.co.uk/drainage/gullies/gully-pots/.

[12] cmostores.com limited. (n.d.). ACO TotalFlow Nickel Bronze Height Adjustable Gully | Drainage Superstore®. Retrieved from https://www.drainagesuperstore.co.uk/product/aco-totalflow-nickel-bronze-height-adjustable-gully.html.

[13] Checkatrade. (n.d.). Drain Unblocking Cost. Retrieved from https://www.checkatrade.com/blog/cost-guides/drain-unblocking-cost/.