DEVELOPING A NEW PRECAST CONCRETE DRAINAGE SYSTEM TOWARDS COST SAVINGS

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ABSTRACT

Drainage network systems in some areas of Ghana are not properly planned, designed and constructed. Most drains are constructed in situ with various defects (cracks and leakages). A survey of the drainage network system indicates poor slopes which restrict free flow of liquid. The aim of the research is to develop a covered precast concrete U-drain to improve the environment. An extensive review of drainage network systems was undertaken to establish the gap in literature. In this study, the covered precast concrete U-drain units were developed and tested in the laboratory using silt analysis, sieve test analysis, slump testing and correct batching process, that is, water/cement ration and aggregate/cement ratio. For a ratio of 1:1.5:3, the compressive stress of the U-drain units are 8KN/mm^2, 13KN/mm^2, 18KN/mm^2, 19KN/mm^2 and 20KN/mm^2 for days 3, 7, 21 and 28 respectively. Detailed cost analysis of 600mm x 500mm x 550mm dimensions of two units indicates initial savings of 5-10% in the first year compared to the conventional method expected to increase by 20% in three years after adoption and implementation. Entrepreneurship and technology are demonstrated in this study, likely to curb poor sanitation and provide useful data to government, professional bodies and construction practitioners.

Keywords: *Precast concrete U-drains units, environment, compressive strength, cost analysis, environmental degradation*

1. INTRODUCTION

Drainage systems link the indoor and outdoor waste systems and serve as channels, discharging liquids to storage points. These systems rely extensive on slopes for effective discharge of flow. Yang et al. (2018) evaluated designed slopes with various backfill pressure systems exposed to varying rainfall infiltration to understand the relationship between flows and slopes. Slopes are critical to the free flow of liquid, thereby reducing constant blockages. As drainage systems are designed to withstand pressure, Seyedashraf et al. (2021) optimized the spatial design of a sustainable urban drainage systems by considering five objective functions: minimization flood volume, flood duration, average peak runoff, total suspended solids. The objectives allow the selection of an ensemble of admissible portfolios that best trade-off capital costs and the other important urban drainage services. The research relied on investigating slopes and ineffective flows hindering the performance of drainage systems. In some scenarios, the issues are related to the grate inlet and discharge the capacity of which causes urban flooding due to insufficient drainage size (Dai et al., 2021). Oladunjoye (2019) assessed and developed a cost-benefit analysis model to retrofit of sustainable urban drainage systems towards improved flood-risk mitigation. The model has the potential to support flood risk management policy by helping to increase the resilience of properties, whilst offering other benefits to communities such as improvements in biodiversity and air quality.

Adaptation strategies comprising larger sewer pipes, laissez-faire, local infiltration units, and open drainage system in the urban green infrastructure can reduce the effects associated with poor urban drainage systems. Similarly large sewer concepts and related socioeconomic analyses that correspond to costs and benefits were assessed by Zhou et al. (2013). The study developed a cross-disciplinary framework for assessment of climate change adaptation to increased precipitation extremes considering pluvial flood risk as well as additional environmental services provided by some of the adaptation options. Fraga et al. (2022) evaluated the economic viability of sustainable urban drainage systems, in a simple and easily acceptable way, considering the ecosystem services provided by green roofs and rainwater urban revitalisation and valorisation. The research identified the best-performing scenarios for the rainwater harvesting system with a payback of approximately three years, a benefit-cost ratio of four, and a 45% internal return rate. The ecosystem service benefits represent 36.3% to 50.8% of total benefits.

Shaghaghi et al. (2020) designed and optimised of drainage systems for fractured slopes using the e-Xtended Finite Element Method (XFEM) and Finite Element Method (FEM). The system shows that the immensity of normal flow considerably influences the poor water pressure distribution at the vicinity of the joint. Such influence should be taken into account when designing a drainage system, as the magnitude of normal flow and the performance of the drainage system may affect each other directly. A typical example is precast concrete drainage units as slopes are controlled and measured during construction unlike the conventional in situ approach. Johnson and Geisendorf (2019) presented three scenarios with different combinations of measures and compared their Net Present Values (NPV), Benefit-Cost Ratio (BCR) and benefit and cost efficiencies (BCE). Parameters of the NPV analysis are also analysed in a sensitivity analysis. The study results show positive NPVs and BCRs social benefits yield only slightly improved NPVs and BCRs.

Further, poorly connected drains have been constructed improperly, unplanned, undesigned and created using sub-standard materials (Ahadzie et al., 2011). A lack of adequate slope level often contributes to flooding and related environmental effects. Drainage and flood problems are interconnected, insufficient carrying capacities of the respective drain channels cause flooding. Thus, accumulation and of solid waste dumped into water ways by erosion cause deposits and blockages (Mensah and Ahadzie, 2020).

This study analyses, precast concrete U-drain system with a concept consistent with earlier studies by Johnson and Geisendorf (2019) and Shaghaghi et al. (2020). Over the years, most drainage systems are cast in situ. The problems associated with such systems are numerous as there is a lack of control over the construction, installation and are considered unsustainable. The environmental effects and cost implications are severe. The study seeks to develop a precast U-drain systems and compare the cost implications to the conventional system. Assessing the economic implications provides basis to encourage adoption and implementation to ensure cost savings and reduced environmental effects.

2. MATERIALS AND METHODS

The study relies on experimental theory to address the gaps the research seeks to bridge. The main features of an experimental study, such as laboratory and workshop processes and procedures, were used to as a guide. Kitsikoudis et al. (2021) adopted an experimental approach to develop a dynamic model and quasi-steady for urban drainage. The authors relied on the features of an experimental approach to develop models by considering explicitly local head losses. Similarly, an experimental approach was used to understand the distributed real-time control and modelling of quality of urban drainage systems by Garofalo et al., (2017). The overall approach and method used are presented in Figure1, and 2 indicating the materials used for the production.

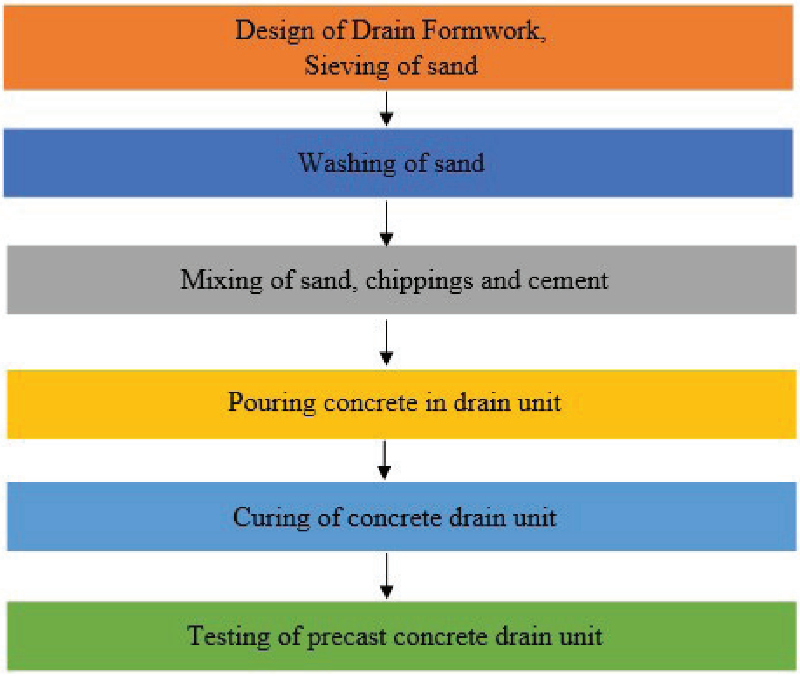

Fig.1.Flow chart depicting overall methodology (Chudley et al. 2020).

Table 1: Materials for precast concrete drain unit formwork preparation

Materials	**Types**	**Condition**	**Remarks**
Wood	Wawa	Fit for work	Brittle because of the dry weather condition
Plywood	25mm	Fit for work	Brittle because of the dry weather condition
Plywood	3mm	Fit for work	Soft and flexible
Nails	50mm	Fit for work	Fastener
Nails	25mm	Fit for work	Fastener

(Chudley et al. 2020)

Table 2: List of Materials used for precast concrete drain unit production work

Materials	**Condition of materials**	**Remarks**
Rapid Hardening Cement (42.5)	Good sound	Fit for purpose
Sand	Well- graded	Fit for purpose
Coarse aggregate	Well graded	Fit for purpose
Wire mesh	In good order not rusted	Fit for purpose
Nails	In good order not rusted	Fit for purpose
5mm sieve	In good order robust	Fit for purpose
PVC Pipe (25mm size)	Strong	Fit for purpose

(Chudley et al. 2020)

2.1 Measuring and Testing Methods

The methodology which is adopted to perform the experimental program has been illustrated with the help of a flow chart in Figure1 and is supported by subsequent description. Silt content testing on sand – Silt is unstable in the presence of water, and often sand with high silt content during bonding reduces the strength and causes rework. Excessive quantity of silt reduces the bonding of cement and fine aggregates and affects the workability, strength and durability of concrete works (Chudley and Greeno, 2008). The percentage of silt content of sand was 6%. A sieve analysis test was performed to determine the suitability of the sand.

The sieve analysis of aggregates is purposely to determine its particle size distribution, uniformity coefficient, fineness modulus and effective size (Chudley and Greeno, 2014). Percentage of fine aggregate passing through sieve = 891g. Also, a consistency/slump test principles were applied to measure the workability of the fresh concrete. The concrete slump test is for the determination of the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work (Chudley and Greeno, 2014). Concrete slump test is carried out from batch to batch to check the uniformity of the quality of concrete during construction. The slump result after measuring was 14mm, consistent with findings established by Li et al. (2022).

2.2 Batching Process and Procedure

The batching work concerns measuring concrete materials to achieve a specific mix design by weight or volume. The aggregate/cement ratio for the precast drain concrete mix was 1: 1.5: 3. During the batching process, one mould full of cement, one and half moulds full of fine aggregate (sand) and three moulds of coarse aggregate (4mm – 6mm aggregate size chippings). These steps were repeated for the other ratios of 1:3:6 and 1:2:4 as presented in Table 3.

2.3 Water - Cement ratio

$2\frac{3}{4}$(2. 75) = Two and three - quarters times of 1 gallon (12 litres of potable water).

The one mould full of fine aggregate was first put on the clean mixing platform. The measured cement was added and mixed uniformly together manually. Then the three moulds full of coarse aggregate were added to the cement with fine aggregate mix and mixed dry to achieve a uniform mix.

2.4 Procedures

The volume of concrete needed for the test was calculated. Based on the mix ratio, the standard mix with the strength of concrete and concrete grade selected was M20. This concrete grade is considered very strong for drainage works, pavement, and other commercial purposes. It has a compressive concrete strength of 20Kn/mm^2 given by the concrete mix ratio, size and nature of the drain.

Table 3: Mixing ratios of the samples

Batching methods	**Mixing ratio for samples**
Aggregate /Cement Ratio	1: 1.5 :3 The batching process is one mould full of cement, one and half moulds full of fine aggregate (sand) and three moulds of coarse aggregate (4mm – 6mm aggregate size chippings) 1:2:4: The batching process is one mould full of cement, two moulds full of fine aggregate (sand) and four moulds of coarse aggregate (4mm – 6mm aggregate size chippings) 1:3:6: The batching process is one mould full of cement, three moulds full of fine aggregate (sand) and six moulds of coarse aggregate (4mm – 6mm aggregate size chippings)
Water/Cement Ratio	$2\frac{3}{4}$(2.75) = Two and three - quarters times of one gallon (12 litres of potable water)
Concrete Mix Design	The standard mix of the strength of concrete and concrete grade selected was M20. It has a compressive concrete strength of 20Kn/mm^2 given by the concrete mix ratio, size and nature of the drain.

Rapid hardening cement (PC 42.5) was used as the binder material. The test specimens were prepared in 600x500x550mm dimensions (Figure 2) and considering the mixture ratios given in Table 1.3, two groups of specimens (precast concrete U-drain with concrete cover) were prepared). The samples were cured in water for three days, seven days, fourteen days, twenty-one days and twenty-eight days as in Figure 3.

PRECAST DRAIN UNIT COVERED WITH CONCRETE COVER AND GRATINGS

Figure 2. Test Samples

Figure 3. Test samples and curing stage

2.5 Curing of precast units

In the water pond, the precast concrete U drain with concrete grating is inserted for curing within three days, seven days, fourteen days, twenty-one days and twenty-eight days. The drains were designed with concrete cover gratings. The precast concrete U-drain with concrete grating was removed from the pond and exposed to the weather and ready for use. At least two samples were used for each parameter, therefore, more precast concrete U-drain must be fixed in the study areas. The drain was properly designed and constructed with quality materials to aid its use within a cluster of residential buildings in isolated urban centres.

3. TEST RESULTS

Table 4: Strength and concrete mix ratios

RATIO	BATCH	STRENGTH	
1:3:6	VOLUME (0.057m3)	3 days	4.75KN/mm^2
Strength at 28 days 10 KN/mm^2		7 days	6.5 KN/mm^2
		14 days	10.78KN/mm^2
		21 days	13.50KN/mm^2
		28 days	16.50KN/mm^2
1:2:4	VOLUME (0.057m3)	3 days	6.5KN/mm^2
Strength at 28 days 15 KN/mm^2		7 days	9.75KN/mm^2
		14 days	13.5KN/mm^2
		21 days	14.25KN/mm^2
		28 days	18.5KN/mm^2
1:1.5:3	VOLUME (0.057m3)	3 days	8KN/mm^2
Strength at 28 days 20KN/mm^2		7 days	13KN/mm^2

		14 days	18KN/mm^2
		21 days	19 KN/mm^2
		28 days	20 KN/mm^2

Table 4 depict the results of the ratios presented with the best and most effective ratio of mix used for the production of the units. The mix ratio used for the precast U-drains was used as indicated in Table 4. For the first three days, a strength of 8KN/mm^2 was realised. This improved over time to a maximum of 20 KN/mm^2 after 28 days consistent with the BS Code. The concrete strength is based on the concrete mix ratio and the duration or number of days for curing the precast concrete unit.

3.1 Cost Analysis of Precast and the Conventional In situ Drainage System

Cost analysis of the samples provides basis for assessing the economic implications and encouraging adoption and implementation. Understanding the cost implications of all scenarios ensures that decisions are taken to match overall gains. Economic gains are expected to drive demand and subsequently contribute to improved supply.

Table 5: Comparative Cost Analysis Between Precast and In situ

Precast Cost Analysis	In situ Cost Analysis
Based on the drain design measurement (600mmx500mmx550mm), the volume of concrete used for the drain was 0.057m3 per for each drain unit costing GH₵ 200.00.	Based on the drain design measurement (600mmx500mmx550mm), the volume of concrete used for the drain was per for each drain unit costing GH₵ 300.00.
The cost of materials for the drain was GH₵ 300.00.	The cost of materials for the drain was GH₵ 400.00.
Artistry for constructing the drain unit = GH₵ 100.00.	Artistry for constructing the drain unit = GH₵ 100.00.
Total cost for constructing the drain = GH₵ 400.00.	Total cost for constructing the drain = GH₵ 500.00.

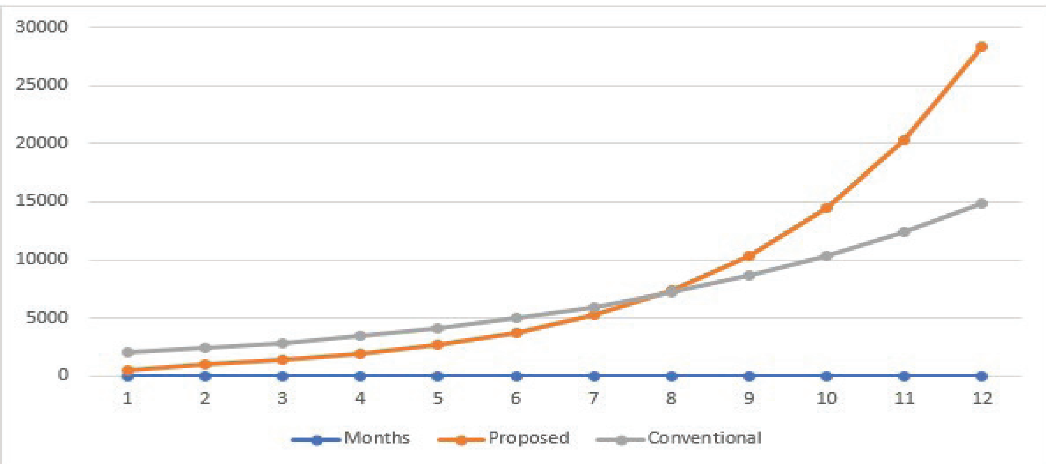

Figure 4: Cost savings project – first - year analysis

Figure 4 shows the precast units monthly cost saving analysis compared to the conventional approach. The basis of the analysis is tied to a minimum of 5 units per month. Initial savings of GH₵ 500.00 were established for the five units as compared in length to the conventional approach. The first few months show minimal gains as the precast units are expensive to install. Given the high cost of installation, a few months before the 8th month. Thereafter, the cost savings as presented increased throughout the period. The first - year cost - saving analysis shows between 5-10% of the overall cost per meter length. This projection is expected to increase in the long term as many more precast U-drains are installed instead of the traditional system.

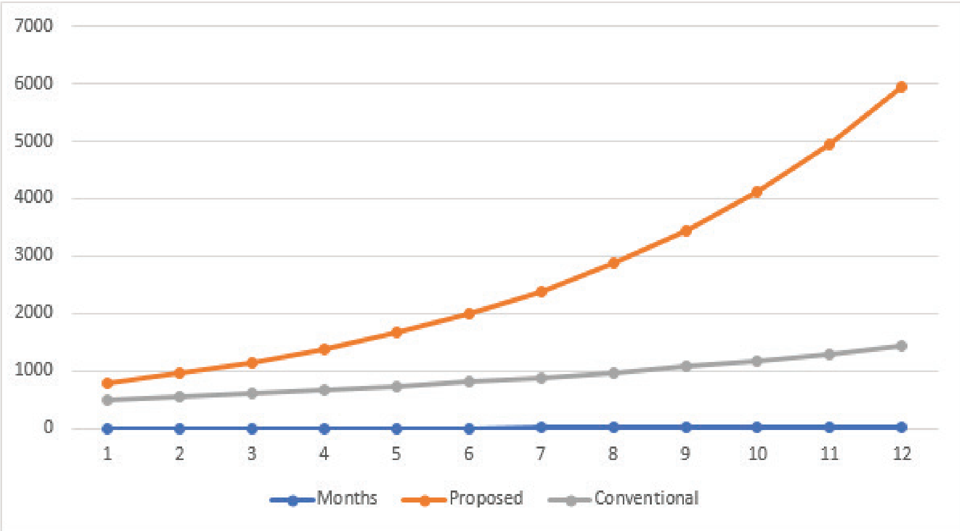

Figure 5: Cost savings – first three years analysis

Figure 5 shows the precast units' monthly cost – saving analysis compared to the conventional approach. In the first year, the gains were between 5-10%, expected to increase over time. Figure. 5 presents analysis of likely cost savings if more precast U-drain units are installed. As indicated, a projection of 20% was established using current prices for construction and installation. It is expected that, as many units are installed, the projections may increase. The cost of maintenance is likely to push the overall cost of the traditional cast insitu higher, thereby increasing the cost savings of the precast units.

4. DISCUSSION

The study aims to develop a precast drain unit and complete a cost analysis. To achieve the first objective different ratios were mixed and tested. Thus, a ratio of 1:1.5:3 was used to mould the precast units. For a ratio of 1:1.5:3, the compressive stress of the precast concrete U-drain units; 8KN/mm^2, 13KN/mm^2, 18KN/mm^2, 19KN/mm^2 and 20KN/mm^2 for days 3, 7, 14, 21 and 28 respectively. Also, for a ratio of 1:2:4, the compressive stress of the U-drain units includes 6.5KN/mm^2, 9.75KN/mm^2, 13.5KN/mm^2, 14.25KN/mm^2 and 18.5 KN/mm^2 for day 3, 7, 14, 21 and 28 respectively. Also, for a ratio of 1:3:6, the compressive stress of the U-drain units; 4.75KN/mm^2, 6.5KN/mm^2, 10.78KN/mm^2, 13.50KN/mm^2 and 16.50 KN/mm^2 for day 3, 7, 14, 21 and 28 respectively. The authors of similar studies relied on the features of an experimental approach to develop models that consider local head losses. Similarly, an experimental approach was used to understand the distributed real-time modelling of quality urban drainage system by Garofalo et al. (2017).

5. CONCLUSIONS

The study aims to develop a precast drain unit and complete a cost - saving analysis. The cost -saving analysis shows that 5-10% savings is achievable for the first year. This is expected to increase to 20% after three years of installation. Also, based on the ratio of 1:1.5:3 used for the precast drain design; the compressive strength gained after 28days of curing is 20KN/mm^2. This presents an interesting concept for assemblies, construction professionals and other government institutions.

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