Climate Resilient Concrete Structures in Marine Environment of Bangladesh

Cost Analysis Report

Mott MacDonald Ltd.

Mott MacDonald

AsCAP Project Reference Number BAN2077A

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Cover Photo: Photo showing construction of deck slab of bridge in Gopalganj district

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Project Summary

Bangladesh has a vast coastal infrastructure seriously affected by climate change and associated extreme environmental conditions. Reinforced concrete structures in the coastal regions can deteriorate rapidly (within 5-10 years of construction) due to exposure to aggressive marine environment, issues related to poor workmanship, limited availability of good quality materials and lack of awareness on good construction practices.
LGED maintains around 380,000 linear metres of concrete bridges/culverts in the rural coastal areas and are planning to build more than 200,000 linear metres during the next ten years. In order to construct durable concrete structures to withstand the aggressive coastal environment for the intended design life, there is a need to study the local factors that influence the durability of reinforced concrete structures. The first and main part of the project examined the major factors that contribute to premature deterioration of concrete structures, recommended cost effective concrete mix design to enhance the durability of future structures and suggested improvements in construction practice and workmanship necessary to enhance service life. Following the success of the main project, further works were awarded to study the whole life costing of the recommended concrete mixes, review and modification of LGED schedule of rates standard to incorporate recommendations for durable concrete mix and provide training to LGED engineers on best concreting practices.

This report compares the life-cycle cost analysis for three different concrete mixes, viz, LGED nominal mix 1:1.5:3 with stone aggregates, brick aggregates and recommended durable concrete mix containing 30% flyash. The cost analysis study for a sample structural element (deck slab of bridge/culvert) concludes that the recommended durable concrete mix fulfils the 75-year design life with no major repair costs. On the other hand, the current LGED specified concrete mixes incur repair costs, which is therefore not a cost-effective design for concrete structures in coastal regions of Bangladesh.

Key words

Cost analysis, Life-cycle costing, service-life, Concrete durability, Corrosion, Bangladesh, Coastal infrastructure, Life-365

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Acronyms, Units and Currencies

£	British Pound
RECAP	Research for Community Access Partnership
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
LGED	Local Government Engineering Department
DFID	Department of International Development
MML	Mott MacDonald Ltd.
BDT	Bangladesh Taka
BNBC	Bangladesh National Building Code
SCM	Supplementary Cementitious Material
CI	Corrosion Inhibitor
SSD	Saturated Surface Dry
W/C	Water/Cement or Water/Cementitious ratio

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Contents

1 Introduction

1.1 Background

Following the successful completion of the main project on "Climate Resilient Reinforced Concrete Structures in the Marine Environment of Bangladesh", an extension contract was awarded to execute uptake and embedment activities based on the final recommendations of the main project. This report deals with the first deliverable of the extension project on the life cycle cost analysis of concrete mixes comparing existing specifications in LGED standards with recommended durable concrete mix.

1.2 Scope

This report presents preliminary cost analysis of concrete mixes for a sample structure such as road culvert or concrete pavement. Benefit of whole lifecycle costing analyses will be demonstrated based on literature review, focussing on comparison between a) concrete mixes in existing guidelines and b) the recommended concrete mix identified under this research project

2 Cost analysis of concrete mix

The durability study on various concrete mixes with different proportions of mineral admixtures as presented in the final report concludes that 30% Fly ash addition in the concrete with minimum cementitious content of 500 kg/m3 is the optimum composition to produce durable concrete exposed to marine environmental conditions experienced in the coastal districts of Bangladesh. In this section the cost effectiveness and life cycle costing of this durable concrete mix is compared with standard concrete currently specified in LGED standards.

Table 2-1 Mix proportions for nominal mix and durable concrete mix

	LGED Standard	New Durable Concrete
Concrete mix	Nominal mix 1:1.5:3	Mix design at Laboratory
Water/Cement ratio	0.4	0.4
Cement content (kg)	410	500
Cement type	CEM I	CEM I + 30% Fly ash
Coarse Aggregate	= 0.818 m^3*1550 kg/m^3 = 1268 kg (stone aggregate) = 0.818 m^3*1200 kg/m^3 = 981.6 kg (brick aggregate)	= 990 kg Stone aggregates
Sand	= 0.409 m^3 * 1500 kg/m^3 = 614 kg	= 660 kg
Water	164 Litres	200 Litres
High range water reducer	Appropriate amount to get target slump of 75-100mm = 4 kg (assumed 1% of cement content)	Appropriate amount to get target slump of 75-100mm = 5 kg (assumed 1% of cement content)

2.1 Cost of concrete mix (materials)

The approximate mix proportions for nominal concrete mix and durable concrete mix is presented in Table 2-1. The unit cost of materials (2017 rates) available at Dhaka is presented in Table 2-2. The cost comparison per cubic metre of concrete mix based on nominal mix and durable design mix is presented in Table 2-3. The cost comparison does not consider the transportation cost of materials to a construction site at coastal regions, production/mixing costs and the cost of good quality water to produce concrete at site. However, these costs will be similar for both nominal mix and durable concrete mix.

Based on the cost comparison of total materials cost provided in Table 2-3, the unit cost of durable concrete mix is observed to be lower than the nominal mix concrete when stone aggregates are used in the mix. The cost of brick aggregate nominal mix concrete is lower than the durable concrete mix, but the strength and durability of designed concrete mix will be far better than the brick aggregate nominal concrete mix. It should be noted that, in the case of durable concrete mix, there will be additional capital costs in performing the trial mixes and associated durability testing in the laboratory.

Table 2-2 Unit cost of materials

Sl. No.	Item	Unit Cost (BDT)	Unit
1	Cement (CEM I)	420	per bag (50 kg)
2	Fly ash	140	per bag (50 kg)
3	Slag	200	per bag (50 kg)
4	Stone Coarse Aggregate	6356	per m^3
5	Brick Aggregate (Machine broken)	3531	per m^3
6	Sylhet Sand	2825	per m^3
7	High range water reducer (HRWR)	150	Per kg

Table 2-3 Total material cost comparison between Nominal concrete mix and Durable concrete mix

	Nominal mix 1:1.5:3 (Stone aggregates)		Nominal mix 1:1.5:3 (Brick aggregates)		Durable concrete mix (Stone aggregate)	
Materials	Quantity (kg per m^3)	Cost (BDT)	Quantity (kg per m^3)	Cost (BDT)	Quantity (kg per m^3)	Cost (BDT)
Cement	400	3360	400	3360	350	2940
Fly ash	0	0	0	0	150	420
Water	164	Free	164	Free	200	Free
Coarse Agg	1268	5200	981.6	2889	990	3933
Sand	614	1156	614	1156	660	1165
HRWR	4	600	4	600	5	750
Total Cost	10316 BDT/m^3		8005 BDT/m^3		9208 BDT/m^3	

2.2 Life-cycle cost analysis

In this study, life cycle cost analysis (LCCA) tool was used to assess the service life and associated costs for different concrete mixes. The LCCA helps to identify optimum solutions by taking into consideration the initial construction costs, protection costs (if any) and future repair costs over the design life of a structure. The prediction of service life of reinforced concrete structure mainly consists of two distinct periods viz, initiation period and propagation period as shown in Figure 1 . The initiation period is the time to corrosion of reinforcement in the concrete, whereas the propagation period includes time from initiation to cracking, spalling and time for corrosion damage to propagate to a limit state.

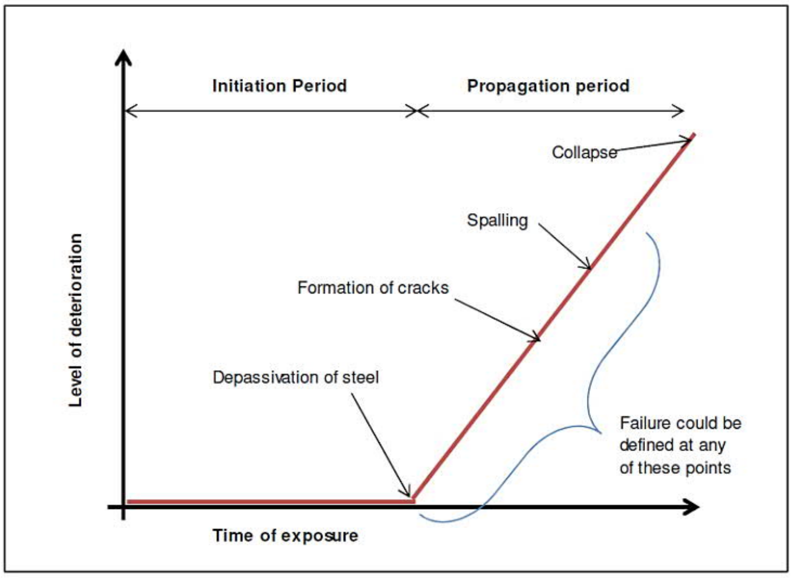

Figure 1 Two phase initiation/propagation model (Gibb 2014)

Life -365 a publicly and freely available to download at http://www.life-365.org/ , is a concrete service-life model and life-cycle costing tool for predicting the service life and whole life costing of concrete exposed to marine environments. The software was developed by life-365 consortium II, which consists of the Concrete Corrosion Inhibitors Association, the National Ready-Mix Concrete Association, the Slag Cement Association, and the Silica Fume Association. This free software program runs on both Microsoft Windows® and Apple® OS X operating systems and is particularly suitable for concrete pavement and bridge deck slab LCCA applications.

Life-365 follows the guidance and terminology in ASTM E917 Standard Practice for Estimating the Life-Cycle Cost of Building Systems. This includes the process of
1. Defining a base year, study period, rates of inflation and discount, project requirements, and alternatives that meet project requirements;
2. Calculating the present value of future costs;
3. Reporting results in present value (constant costs)

In this study, life-365 software was used to assess the life-cycle costing of reinforced concrete deck slab of a bridge or culvert for comparing concrete mixes in accordance with existing LGED standard and new durability concrete as detailed in Table 2-3. The input data for this analysis has fixed and variable data for assessing different alternative concrete mixes for the construction of the deck slab exposed to marine or salt laden environments. The fixed input data and variable input data considered for LCCA of reinforced concrete deck slab is presented in Table 2-4.

Table 2-4 Fixed and variable input values for life-365 assessment of reinforced concrete deck slab

Data Type	Parameters	Input values	
		Element	Value
Fixed data	Structural data	Dimensions	3m width X 100m length X 0.150 m depth
		Cover	60 mm
		Amount of reinforcement	1.2%
	Repair	Cost of deck slab concrete repair	BDT 1776.35 / sq. m
		Area to be repaired	10%
		Time intervals between repairs	10 years
	Materials cost	Black steel	BDT 90 / kg
	Financial data	Base Year	2017
		Analysis period	80 years
		Inflation rate	8.02 %
		Real discount rate	6%
	Weather	Average monthly temperature	Average monthly temperature data for Bangladesh
	Exposure	Max concentration	0.6% by wt. of concrete
		Years to build to maximum concentration	30 years
Variable data	Concrete mix : LGED 1:1.5:3 (100% OPC + Stone Agg)	D_{28} (m^2/s)	9.77 X 10^{-12} m^2/sec
		m	0.2
		Hydration	25 years
		Ct (% wt. of concrete)	0.05 %
		Propagation (years)	6 years
		Cost of concrete mix	BDT 10000 / m^3
	Concrete mix : LGED 1:1.5:3 (100% OPC + Brick Agg)	D_{28} (m^2/s)	21.7 X 10^{-12} m^2/sec
		m	0.2
		Hydration	25 years
		Ct (% wt. of concrete)	0.05 %
		Propagation (years)	6 years (assumed)
		Cost of concrete mix	BDT 8005 / m^3
	Concrete mix : Durable mix (70% OPC + 30% Flyash+Stone Agg)	D_{28} (m^2/s)	3.02 X 10^{-12} m^2/sec
		m	0.2
		Hydration	25 years
		Ct (% wt. of concrete)	0.05 %
		Propagation (years)	6 years
		Cost of concrete mix	BDT 9208 / m^3

The repair cost of deck slab and cost of reinforcement bar considered in the analysis were based on LGED schedule of rates 2017 edition for Cox's Bazar region (exposed coastal district) of Bangladesh.

Table 2-5 Service life prediction of different concrete mixes

Concrete mix	Initiation	Propagation	Service life
LGED 1:1.5:3 (100% OPC + Stone Agg)	15.8 years	6 years	21.8 years
LGED 1:1.5:3 (100% OPC + Brick Agg)	10.4 years	6 years	16.4 years
Durable mix (70% OPC + 30% Flyash+Stone Agg)	80+ years	6 years	86+ years

Table 2-6 Life-cycle cost analysis (discounted at 6%) for different concrete mixes

Concrete mix	Construction cost	Repair cost	Life-cycle cost
LGED 1:1.5:3 (100% OPC + Stone Agg)	BDT 2758.74 per sq. m	BDT 2673.80 per sq. m	BDT 5432.54 per sq. m
LGED 1:1.5:3 (100% OPC + Brick Agg)	BDT 2459.50 per sq. m	BDT 3178.73 per sq. m	BDT 5638.22 per sq. m
Durable mix (70% OPC + 30% Flyash+Stone Agg)	BDT 2639.94 per sq. m	BDT 0.00 per sq. m	BDT 2639.94 per sq. m

The output of service-life prediction analysis of concrete mixes by life-365 gives corrosion initiation period, propagation (based on input value) and service life of the deck slab as presented in Table 2-5. It can be observed from the service-life results for the concrete mixes that the LGED brick aggregate concrete mix has the lowest service life among the three and durable mix has service-life of 86+ years. This indicates that only durable concrete mix fulfils the 75-year design-life criteria set by LGED for concrete bridges and culverts.

Based on the service-life prediction of the concrete mixes, the life-cycle assessment computes the construction costs and repair costs needed to keep the structure in service for the intended design life of 75 years. The total life-cycle costs are calculated as the sum of the initial construction costs and the discounted future repair costs over the life of the structure. Future repair costs are calculated on "present value" basis using the discount rate 'i' provided by the user in the software. The discount rate i used in the model is the real discount rate and in the LCCA analysis a real discount rate of 6% has been considered. Asian Development bank has been using a default discount rate of 12% for all ADB projects. This rate has been recently revised to a new default rate of 9% after taking into consideration continued increase in income levels and lower foreign borrowing costs

(ADB, 2017). Moreover, ADB also recommends use of lower discount rate of 6% for social sector projects such as rural road infrastructure projects (ADB, 2017). A similar discount rate of 6% was used to assess the climate resilience of Africa's transport infrastructures (Cervigni et. al. 2015). The inflation rate is 8.02% for construction materials based on last 20-year materials data (CEIC, 2018).

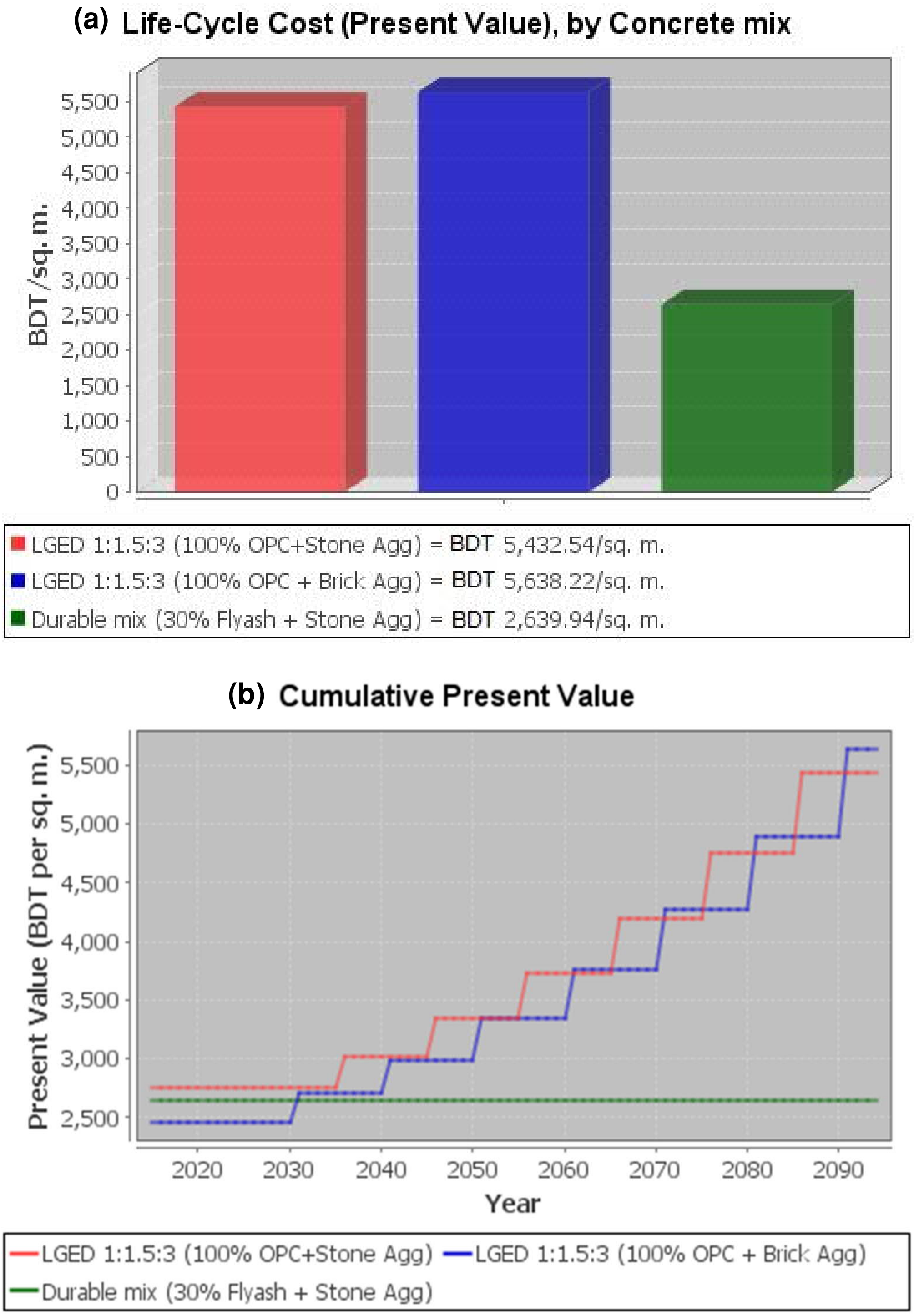

Figure 2 Present value life cycle cost and cumulative costs (discounted at 6%) over design life for three concrete mix options

The life-cycle analysis detailing the construction cost, repair cost and life-cycle cost (discounted at 6%) for the three mixes are presented in Table 2-6 and Figure 2. The total life cycle costs are calculated by adding present value of cumulative future repair costs over the design life of the structure and the initial construction costs. Figure 2b shows cumulative present value over the design life of the structure, which is adjusted for inflation. The cumulative present value costs measure the actual change in costs and not just an increase due to effects of inflation. The construction and repair costs for each year over the design life of structure is presented in Table 2-7.

Table 2-7 Present value construction and repair costs (discounted at 6%) for the three concrete mix options

	Year	Constant costs (BDT per sq. m)		
		LGED 1:1.5:3 (100% OPC+Stone Agg)	LGED 1:1.5:3 (100% OPC + Brick Agg)	Durable mix (30% Flyash + Stone Agg)
Construction cost	2017	2,758.74	2,459.49	2,639.94
Repair cost	2031	0	240.27	0
	2036	264.05	0	0
	2041	0	290.19	0
	2046	318.92	0	0
	2051	0	350.48	0
	2056	385.18	0	0
	2061	0	423.30	0
	2066	465.2	0	0
	2071	0	511.25	0
	2076	561.86	0	0
	2081	0	617.47	0
	2086	678.59	0	0
	2091	0	745.76	0
Total life-cycle cost		5432.54	5638.22	2639.94

The life-cycle cost of LGED specified concrete mixes were observed to be more than twice to that for durable concrete mix.

2.3 Sensitivity analysis of discount rate

As discussed in the previous section, in this analysis a discount rate of 6% has been considered based on the recommendation by ADB for social sector projects (ADB, 2017). However, some of the other infrastructure aid agencies still using the higher discount rates of 12% as a default rate for project appraisal. Therefore, in this section a sensitivity analysis of discount rate at 6%, 9% and 12% on the life-cycle costs of three different concrete mixes are assessed and compared as shown in Figure 3.

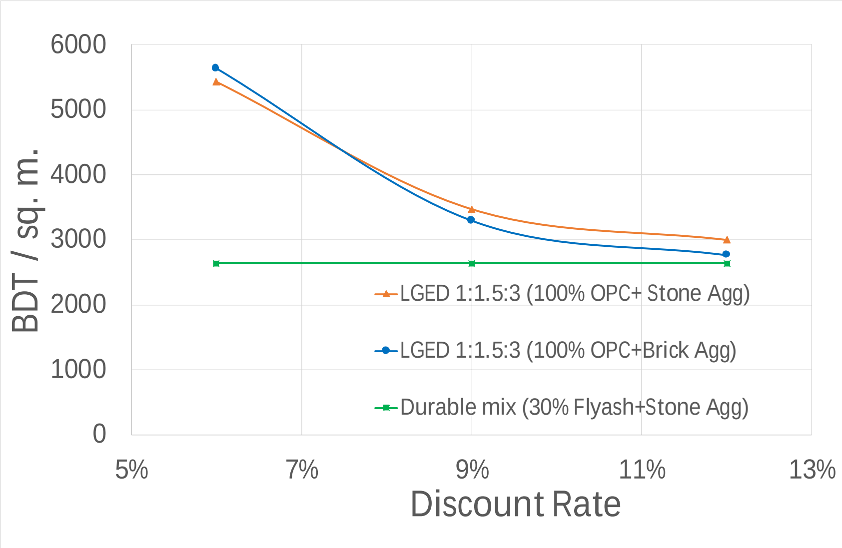

Figure 3 Sensitivity analysis of discount rate on Life-Cycle cost (Present value)

The sensitivity analysis of three different discount rates on the life-cycle cost suggest that the cost difference between the LGED mixes and the durable concrete mix increases with decrease in the discount rate. The increase in discount rates reduces the present value repair and maintenance costs for the concrete structural element and therefore the cost difference between the three mixes is low at high discount rate of 12%. At ADB recommended discount rate of 6%, the life-cycle cost of both the LGED mixes were observed to be more than twice that of the durable concrete mix. Therefore, considering the life-cycle costs of the concrete structure, durable concrete mix provides a cost-effective solution.

2.4 Least cost option

The present value of life-cycle cost for the construction and maintenance of the deck slab for three mix options are presented in Table 2-8. It is clear from the life-cycle costs presented in Table 2-8, that the durable concrete mix provides the least life-cycle cost and therefore the most economical option among the three concrete mixes. It is also interesting to note that, although the unit cost (material cost) of brick aggregate concrete is the lowest among the three concrete mixes, however this concrete provides most uneconomical option among the three concrete mixes.

Table 2-8: Present value of life-cycle cost (discounted at 6%) of three concrete mix options for 300 sq. m deck slab

Concrete mix	Material cost (BDT/m^3) (from Table 2-3)	Present value of life-cycle cost (BDT)
LGED 1:1.5:3 (100% OPC+Stone Agg)	10,316	1,629,762
LGED 1:1.5:3 (100% OPC + Brick Agg)	8,005	1,691,466
Durable mix (30% Flyash + Stone Agg)	9,208	791,982

3 Conclusions

The LCCA analysis study using life-365 software provides a comparison on the construction costs, repair costs and life-cycle costs for three different concrete mixes. The study highlights the importance of life-cycle cost analysis in choosing optimum and cost-effective concrete mixes by taking into consideration the design life and whole life-cycle cost of the structural element rather than simply relying on the unit cost of concrete at the time of construction. This study presents the following conclusions:

- The total material cost of recommended durable concrete mix (70% OPC + 30% Flyash + Stone aggregates) was observed to be lower than the standard LGED nominal mix 1:1.5:3 with stone aggregates
- The life-cycle cost of the durable concrete mix was observed to be less than half that of LGED standard nominal mixes with either stone aggregates or brick aggregates
- The present value of life-cycle costs for durable concrete mix was observed to be less than half to that for LGED nominal mix 1:1.5:3 with either stone aggregates or brick aggregates. The durable concrete mix can provide huge savings in the whole life costs for the project.

Therefore, the recommended concrete mix as an outcome of this project not only provides a durable concrete for the service life of structure in the coastal regions of Bangladesh, but also is the most cost-effective solution considering the life-cycle costs.

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