Review of the OPW cost estimate Little Island Tidal Barrier Cork

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Final

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Background & General observations regarding flood safety Cork

The Office of Public Works (OPW) of Ireland has proposed a flood protection scheme for the city of Cork, built at the river Lee, that includes retention basins upstream of Cork and construction of walls and embankments , about 15 km in total over a 10 year period, in the city centre of Cork and surroundings. It seems the scheme is mainly concerned with fluvial flood protection, i.e. considers tidal floods of a lesser thread for the next decades. In the long run, say in the year 2050, OPW does foresee the construction of a barrier to cope with tidal flooding or storm surges that will be occurring more frequent in future due to sea level rise.

Save the City of Cork (SCC), as an alternative to the OPW scheme, has proposed to construct the tidal or storm surge barrier right away, mainly to avoid the construction of all the walls in Cork's city centre.
The SCC proposed barrier would be crossing Lough Mahon from Little Island to Horse Head, see Appendix 1 for a short description; it shall be referred to as Little Island Tidal barrier from hereon. On behalf of SCC, HR Wallingford has looked into the (pre-feasibility) design of the barrier and prepared a cost estimate for it.

Estimating the cost of the Little Island Tidal barrier has become the subject of debate between SCC and OPW. Both parties involved use a low or high estimate to defend, respectively, disqualify a decision to construct the barrier in the near future (instead of walls and embankments in Cork's city centre). A key issue in the cost estimate debate is the interpretation and use of several academic papers written or co-authored by S.N. Jonkman now acting Professor for the section Hydraulic Structures and Flood Risk, department of Hydraulic Engineering, Delft University of Technology. Professor Jonkman and his section haven been assigned by SCC to produce a memo on the following:

1. A brief explanation on the interpretation and use of the academic Jonkman papers for estimating the costs of coastal defences and/or storm surge barriers;
2. An opinion on the order of magnitude cost of the Little Island Tidal Barrier in line with the Jonkman papers as explained in previous point;
3. A critical review of the OPW cost estimate for the Little Island Tidal Barrier.

The points above will be addressed subsequently in the remainder of this memo. Conclusions and Recommendations finish this memo.

1. A brief explanation on the interpretation and use of the academic Jonkman papers for estimating the costs of coastal defences and/or storm surge barriers

Obviously unit cost estimates of past projects provide only a first order indication of expected price levels for future projects. Construction prices are heavily dependent on factors such as market circumstances, prices of raw materials and the complexity of the adopted design. Nowadays, the latter in most Design & Construct contracts to a large extend determined by the expertise of and the equipment owned by the contractor.

Unit cost estimates for storm surge barriers in Mooyaart and Jonkman (2017) are derived as a unit cost based on the length of the gated elements of the barriers (indicated as cumulative span in the clarifying figure in Appendix 2). These costs are "all-in" and do include the costs of impounding / connecting embankments and equipment for barrier operation (control towers etc.). The reason for this choice is twofold:

1) cost estimates are often only reported for the total barrier (not just for the gates);
2) the control structures and connecting embankments are part of the barrier system.

In hindsight the fact of using “all-in” costs should have been stated even more explicitly in the original paper. It is recommended to collect more unit cost from other projects to serve as a reference for the other barrier elements.

The unit cost estimates from Mooyaart and Jonkman (2017) are associated with a considerable bandwidth and are therefore most useful to give an estimate of the order of magnitude of costs in the planning and screening phase. On average, the unit cost for a storm surge barrier was found to be €2.2 million per meter of span. The coefficient of variation is 0.56 and most of the observed costs are within a factor 2 of the prediction formula (see figure below).

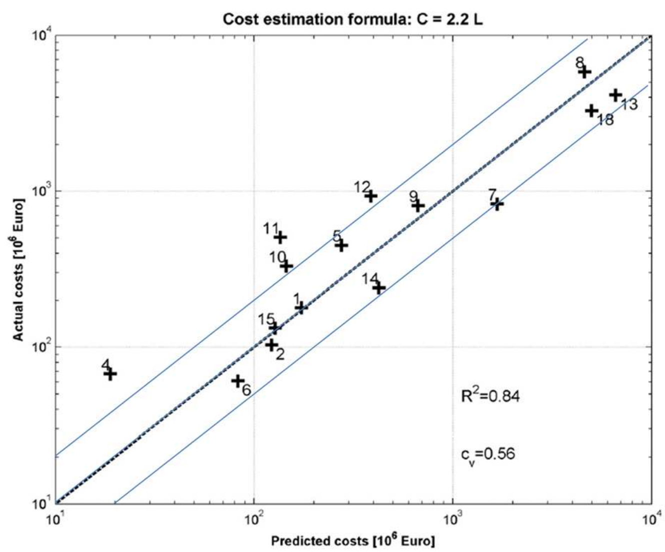


Figure: Actual and predicted costs of storm surge barriers (from Mooyaart and Jonkman (2017)) with the bandwidth added with blue lines.

Unit cost estimates for other elements of the barrier system (e.g. sluice gates, embankments or dam sections) were not derived in the Mooyaart and Jonkman (2017) paper. The Jonkman et al (2013) paper does give cost indications of other coastal interventions such as embankment construction, nourishments etc., but not for sluice gates or closure dams. It is recommended to collect more unit cost from other projects to serve as a reference for these barrier elements.

2. An opinion on the order of magnitude cost of the Little Island Tidal Barrier in line with the Jonkman papers as explained in previous point

In the Mooyaart and Jonkman (2017) paper actual costs for a mix of gates and or barriers types were used to come up with a method to predict barrier costs, duly taking a bandwidth and other limitations into account.

The description of the Little Island Tidal barrier can be found in Appendix 1 of this document. The gate type used for closing the navigation channel is a sector gate spanning 60 meter. Simpler gate types can be used for (in total) 90 meter of sluice or discharge gate openings.

It would be worth to investigate the effect of including the barriers either with sector gates or with lift gates only. Such an investigation would come down to the selection of the subsets of sector gates and lift gates from the whole mix of gate types considered in the Mooyaart and Jonkman (2017) paper. Due notice should be taken that selecting a subset decreases the statistical basis for conclusions.

<u>Sector gates within the complete mix of gate types in the Jonkman papers</u>

For the sector gate summary again the same assumptions were used as in the Mooyaart and Jonkman (2017) paper and the related supplemental document, with 2013 price levels in Euros and using the conversions and exchange rates stated in the paper. The first seven barriers in Table 1 are reported in the paper and the original number is used.

Notes:

- Although the Harvey canal gate, no. 16 in the original paper, was mentioned, it's cost was not included to arrive at the unit cost to be used for prediction. (Neither were the costs of the Bildwerder Bucht, Germany, and West Closure Complex, USA used for the determination).
- The cost indication for the Harvey Canal gate was added to Table 1, because HR Wallingford, on behalf of SCC, referred to this gate for their cost estimate of the Little Island Tidal Barrier.
- The last barrier in the table, the Caernavaron barrier in New Orleans, has been added for completeness sake – see Appendix 3 for more information on this barrier.

Table 1: Overview of storm surge barriers with sector gates. All information from Mooyaart and Jonkman 2017, unless indicated in italics.

No.	Barrier	Year	Type of sector gates	Length of barrier (m)**	Span of gate(s) (m)**	Sill level	Unit costs M€/m (2013 price level)
2	New Bedford, USA	1966	Sector	1370	46	-11.9	2.7
9	Maeslant, NL	1997	Floating sector	610	360	-17	1.9
13	St. Petersburg, Russia	2011	Floating sector (200m)	25,400	1846	-5.2	3.6
14	IHNC, USA	2011	Sector (45m), barge (45m), lift (17m)	2300	107	-5.2	4.0~~
15	Seabrook, USA	2011	Sector (29m), lift (2 x 15m)	130	59	-5.5	2.2
16	Harvey Canal, USA	2011	Sector gate	120	38	-4.9	0,87##
17	GIWW West Closure complex, USA	2012	Sector gate (69m)	525	69	-4.9	n/a^^
-	*Caernavaron, USA*	*2011*	*Sector gate (18m)*	-	*18*	*-3.1*	*0.86*

**	See Appendix 2 for clarification of definition of dimensions
~~	Only costs of gated sections included
##	A cost estimate of 43,2M$ is reported in: http://www.gccprd.com/pdfs/05_Phase%202%20Report_Appendix%20G.3%20Data%20Library%20of%20Costs.xlsx
^^	The total costs of the West Closure complex are around 1 Billion US $, but this includes a very large pumping station. Because of the bias in the cost introduced by the pumping station, this sector gate barrier has not been included in the present analysis

The average unit cost for sector gates is 2.3 M€/m with a bandwidth between 0.86 and 4.0 M€/m. There seems to be no clear relationship between sill level and depth of the canal, although it could be interesting to collect more information on size and dimension of the gates and see if there is a correlation with costs. The average of unit costs for sector gates found here is very similar to the overall unit costs (2.2 M€/m) for all types of storm surge barriers reported in the Mooyaart and Jonkman (2017) paper.

Lift gates within the complete mix of gate types in the Jonkman papers

Compared to the sector gate, the gates only used for the discharge of water, so called sluice gates, are less complex structures than storm surge barriers, with less complex operation systems. So applying the unit cost estimates for storm surge barriers to the sluice gates is over conservative. Lift gates are frequently used for discharge of water. An overview of lift gate storm surge barriers has been presented in Table 2. Barriers with a mix of gates were omitted.

Table 2: Overview of storm surge barriers with lift gates. All information from Mooyaart and Jonkman 2017

No.	Barrier	Year	*Type of lift gate(s)*	*Type of dominant load*	Length of barrier (m)**	No. of and span of gate(s) (m)**	Height of gate (m)	Unit costs M€/m (2013 price level)
1	Hollandsche IJssel	1956	*Flat front*	*Water head*	200	2 x 80	12	2.2 M€/m
6	Hull	1980	*Rotates in lifted position*	*Water head*	40	1 x 30	10.5	0.6 M€/m
8	Eastern Scheldt	1986	*Flat front*	*Water head + Wave impact*	9,000	62 x 42	13.2&&	1.8 M€/m
10	Hartel	1997	*Curved front*	*Water head*	250	1 x 98 1 x 49	13	1.0 M€/m

**	See Appendix 2 for clarification of definition of dimensions
&&	This is an average gate height. Gate heights vary from 10. 5 m (15 no.'s) up to 16.5 m (7 no.'s) in the Eastern Scheldt barrier

The average unit cost for the lift gates is 1.4 M€/m with a bandwidth between 0.6 and 2.2 M€/m.

Using the average unit cost for lift gates ,without paying any attention to the specific conditions applicable to the lift gates of the future Little Island Tidal Barrier, does not make sense, basically because of the significantly smaller dimensions of the span (30 m) and the height (6 m) of the anticipated gates.
In case of the three Dutch gates the front plate of the gate is backed up or supported by trusses (generally 2 no.'s) to transfer the load from the front skin plates to the support and lift towers. Optimal use of the trusses could be made because there were no restrictions to the overall gate thickness, i.e. the distance from front to back of the gate. Looking at these three gates, based on engineering judgement and experience, it should be mentioned that there is a roughly linear relationship between both the span and the height and the cost of a gate.

Anticipated, in case of the Little Island Tidal Barrier, are a 30 m spans and gate heights of about 6 m, without overall gate thickness restrictions, for three sluice gate openings. Given the linear length or height to cost ratio, this would imply that, even if the bottom range cost price of 0.6 M€/m was used, a conservative cost estimate for the sluice gate openings would be the result.

The order of magnitude cost of the Little Island Tidal Barrier in line with the Jonkman papers

For the Little Island Tidal barrier the gate type used for closing the navigation channel is a sector gate spanning 60 meter; lift gates can be used for the 90 meter of sluice or discharge gate openings (three times 30 m).

Using the unit costs for sector and lift gates, basically derived from subsets, the resulting cost of the Little Island Tidal Barrier would be about 186 M€ (60 m at 2.2 and 90 m at 0.6 M€/m). This information will be used in the next section to reflect on the OPW cost estimate for the Little Island Tidal barrier.

Note: without taking into account the anticipated dimensions of the Little Island Tidal Barrier sluice gates, which would be inappropriate, applying the unit cost rate of 1.4 M€/m for lift gates would over conservatively result in a total cost of 258 M€ for the whole barrier.

3. A critical review of the OPW cost estimate for the Little Island Tidal Barrier

In the report "Lower Lee (Cork City) Flood Relief Scheme, Supplementary Report – Option of Tidal Barrier" the OPW has described the SCC proposal for the Little Island Tidal barrier, changed it into an OPW acceptable version and developed a third alternative, respectively named Little Island Option1, Little Island Option 2, and Great Island. See Appendix 4 for some more information. In this memo only OPW's Little Island Option 1 will be dealt with since this remains closest to what SCC proposed.

- Rigorously adopting the unit cost of 2.2 M€/m found in the Jonkman papers the estimate for the Little Island Tidal Barrier by OPW should have been 340 M€ (rounded value). This does include an acceptable correction for 2013 versus 2017 rates.
- The unit costs taken from the Jonkman papers do include the costs of a limited length of impounding / connecting embankments. Table 13 of the OPW report, that adds an approximate value for embankments etc., should be disregarded, from that point of view. However, given the relatively small part of the cumulative span, compared to the embankment length, about 15% it could be argued for some additional consideration.
- It is clear that the unit rate for sector gates has also been applied to simpler tidal sluice gates by OPW. This is a very conservative choice and not justified given the anticipated spans and gate heights of respectively 30 m and 6 m.

Conclusions & Recommendations

TU Delft Conclusions / Recommendations on Cost Estimate for the Little Island Tidal Barrier

1. Tidal barriers can be constructed to temporarily close off bays and estuaries during storm surges to provide coastal flood protection. This is particularly relevant in the context of sea level rises and an increased frequency of storms due to Climate Change. Tidal barriers can also be closed to exert a level of downstream control to help alleviate fluvial (river) flooding.
2. Tidal barriers can significantly reduce the length of coastline that is directly exposed to coastal flooding and thereby reduce (or prevent) raising of embankments behind the barrier, this is particularly beneficial in densely populated areas i.e. in the case of well-established and historic cities.
3. A tidal barrier can therefore facilitate additional benefits for waterfront development and use. A tidal barrier may even serve as a landmark and can provide numerous amenity usages within a harbour.
4. The use of Academic Papers based on the out turn cost of existing Tidal Barriers is useful for pre-feasibility cost estimates only.
5. A review of the OPW cost estimate for the Little Island Tidal Barrier reveals that a unit rate for tidal sector gates has also been applied to the simpler tidal sluice gates. This approach is not considered appropriate.
6. Compared to the sector gate, the gates used for the discharge openings are less complex structures. Applying the unit cost estimates developed for tidal gates through Academic Research papers, or any similar approach, to the sluice gates would output an unrealistic cost estimate.
7. Unit cost estimates for the sluice gates were not derived in the Mooyaart and Jonkman (2017) paper. The Jonkman et al (2013) paper does give cost indications for coastal interventions such as embankments, nourishments etc., but not for sluice gates. It is recommended to collect more unit cost on similar projects to serve as a reference point other barrier elements/ structures such as sluice gates.
8. The unit cost rates derived from existing barrier projects include varying lengths of connecting embankments as part of the barrier system i.e. an “all-in” cost. The OPW appear to have accounted twice for this element of the barrier through the inclusion of an additional cost estimate for embankments without a corresponding reduction in the unit cost rate derived from past projects.
9. A first order cost estimate for the Little Island Tidal Barrier based on Academic Research into tidal barriers would result in an approximation of €258m compared with the comparable OPW cost of €340m.
10. A second order examination of the Little Island Tidal Barrier, undertaken by extracting the most applicable information to this particular example from the Academic Research, would result in an approximate cost below €200m.
11. The development of a more detailed, and project specific, cost estimate for the Little Island Tidal Barrier is highly recommended. Construction prices are heavily dependent on factors such as market circumstances, prices of raw materials and the adopted design.
12. The Little Island Tidal Barrier option should not be discounted on the grounds of the cost estimate presented.
13. Overall, the TU Delft review team considers the proposed tidal barrier at Little Island, Cork as an interesting and attractive option which certainly warrants further investigation.

References

- Mooyaart L.F., Jonkman S.N. (2017) Overview and design considerations of storm surge. ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering Vol. 143 Issue 4 http://dx.doi.org/10.1061/(ASCE)WW.1943-5460.0000383#sthash.H6wdGIFV.dpuf

- Jonkman S.N., Hillen M.M., Nicholls R.J., Kanning, W., van Ledden M. (2013) Costs of adapting coastal defences to sea-level rise – new estimates and their implications. *Journal of Coastal Research,* 29 (5) 1212-1226

- Office of Public Works, Lower Lee (Cork City) Flood Relief Scheme, Supplementary Report – Option of Tidal Barrier, Job no. 230436-00 by Arup, 5 December 2017

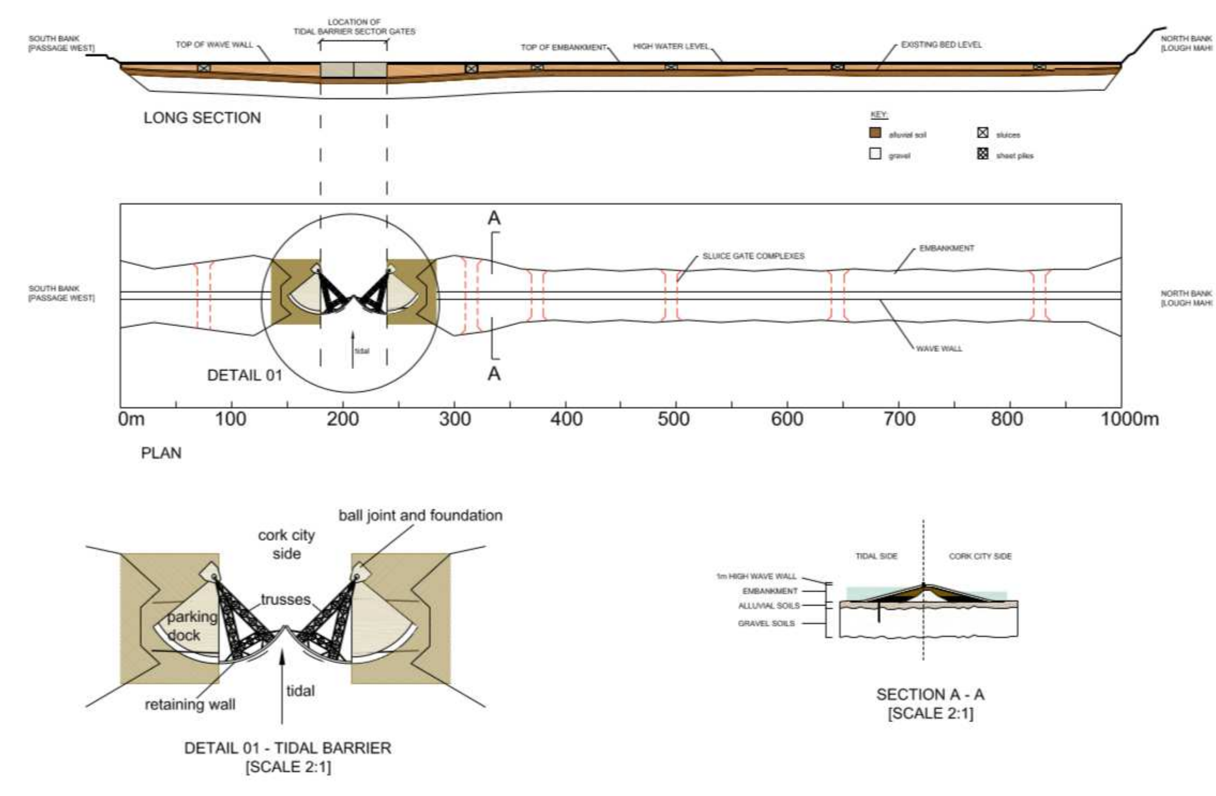
- HR Wallingford, Cork City Tidal Barrier, Cost estimate, Report MCM8055-RT001-R04-00, October 2017

Appendix 1

SCC pre-feasibility design Little Island Barrier

The Little Island Tidal barrier, as envisaged by SCC, however, amended by Arup on behalf of OPW, is made up of the following elements:

Navigable Gate (Sector Gate)	60m wide	Depth used in Supplementary Report is 14.55m	14.55m is conservative as sill level 1m below current channel depth and 1m higher protection level than proposed City centre walls.
Sluice Gates	90m cumulative width	3 no. banks of sluice gate complexes made up of 2 x 15m gates	6m depth for sluice gates
Embankment	810m long	Depth varies from 6m to 10m it is thought.	5m width at crest level required and 1:3 side slopes (?). I believe that sheet piling was included in the consideration to be conservative.

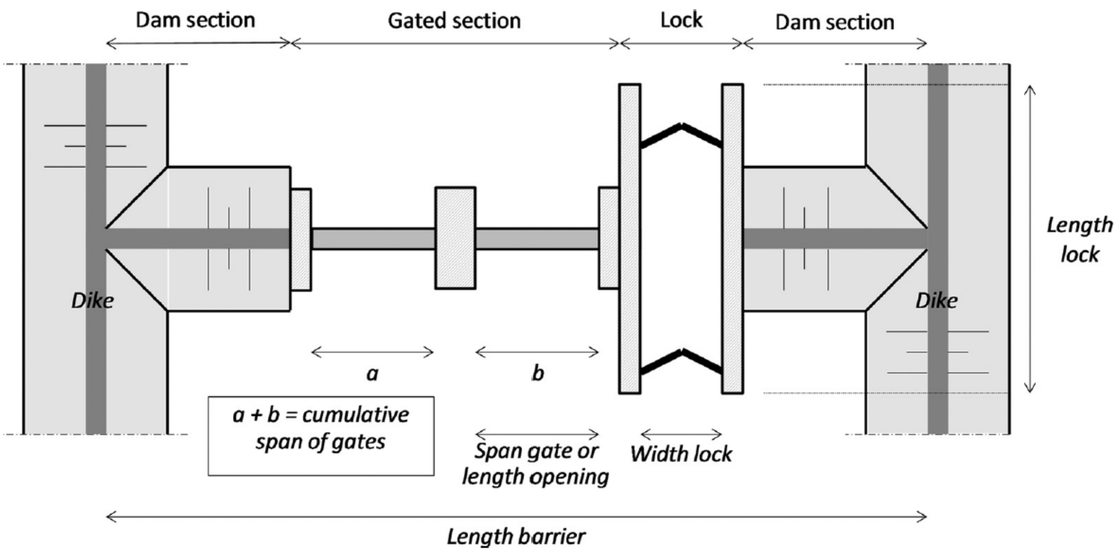


DRAWING OF TIDAL BARRIER AT LOUGH MAHON

Appendix 2

<u>cumulative span definition</u>

Figure illustrating/clarifying the term cumulative span from Mooyaart and Jonkman (2017)



Appendix 3

Caernarvon sector gates

The sector gates are constructed in the southeastern part of the New Orlreans flood protection system. The gates are 56ft (18m) wide and 36ft (12m) tall, of which 10ft below and 26ft above the water. The weight of each gate is about 95 tonnes.

Source: https://www.floodauthority.org/the-system/caernarvon-sector-gate/
Information on costs: http://www.mvn.usace.army.mil/Media/News-Releases/Article/474099/corps-installs-two-95-ton-sector-gate-leafs-in-caernarvon-canal/

“The sector gate cost approximately $20.2 million, the entire contract was awarded for $46.9 million.”

So the costs for the sector cate are $20.2 million / 18m = 1.12 M$/m

If this is converted to 2013 price levels in Euros using the same assumptions as in the paper, the unit costs would become 0.86 M€/m.

Appendix 4

<u>OPW Barrier alternatives:</u>

From the OPW report page 133

Table 11: Concept Cork Barrier Configurations

	Little Island Option 1	Little Island Option 2	Great Island	
Overall Length	1020	1020	595	
Navigation Gates			Monkstown	Marlogue
Type	Sector	Rotary Seg.	Rotary Seg.	Rotary Seg.
Number	1	2	2	1
Span (excl. piers) (m)	60	60	60	60
Cumulative Span (m)	60	120	120	60
Gate Height (m)	14.55	14.55	24.7	13.43
Flow Gates				
Type	Vertical lift	Vertical lift	Vertical lift	Vertical lift
Number	6	6	4	6
Span (excl. piers) (m)	15	50	35	27.5
Cumulative Span (m)	90	300	140	165
Gate Height (m)	6	6	12	8
Embankment				
Length (m)	810	600	0	

From the OPW report page 135

Table 12: Cost Estimate Method 1 - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Cumulative Span (m) (excludes piers)	150	420	485
Rate	€2,200,000	€2,200,000	€2,200,000
Rate (2017)	€2,256,119	€2,256,119	€2,256,119
Estimated Cost (2017)	€338,417,802	€947,569,847	€1,094,217,561

Adding an approximate value for the cost of the embankment element yields the following results. This value was calculated based on international studies and previous Arup experience.

Table 13: Cost Estimate Method 1 Plus Embankment - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Embankment cost	€38,235,416	€28,322,530	€0
Total Estimated Cost	**€376,653,218**	**€975,892,377**	**€1,094,217,561**