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CYCLONE MODELS FOR A SUBMERGED BREAKWATER

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Kahului Harbor, located on the north shore of Maui, Hawaii, is approached by waves from the northwest in winter and northeast in summer. Wave energy entering the harbor during large swell events has repeatedly caused damage to existing protective structures and operations. As a result, a 706-meter long breakwater on the west was constructed to provide additional tranquility inside the harbor. A breakwater on the east with an 843-meter length was constructed to protect against waves approaching from north and northeast. However, strong wave energy still damages the harbor through the 12-meter deep and 183-meter wide entrance channel. Consequently, a submerged breakwater could be constructed in order to mitigate the wave energy that continues to damage the pier. The objective of making these models is to determine the most appropriate construction approach for the project based on construction duration and related variable costs. The study also aims to see if the project can be completed within a 5-month window during calm water. Two construction approaches were proposed—(1) using one construction crew per geotextile grid, and (2) using multiple crews per geotextile grid. Sensitivity analyses were performed on both proposed construction approaches by adjusting the number of laborers hired. This report provides the proposed geotextile submerged breakwater details based on construction plans viewed through the simulation models using EZStrobe.

Keywords: Geotextile, Submerged Breakwater, CYCLONE Model, EZStrobe, Kahului Harbor, Simulation, Construction.

1 SUBMERGED BREAKWATER CONSTRUCTION PROCESS OVERVIEW

The proposed submerged breakwater at Kahului Harbor consists of eight layers, made of stitched geotextile tubes filled with sand and stacked in a pyramid configuration. Each layer consists of five geotextile grids. Each grid contains various numbers of geotextile tubes. The number of geotextile tubes per grid ranges from 12 tubes for the bottom layer to 5 tubes for the top layer. The tube's cross-section is 2.6 m high by 3.2 m wide. The total structure has an 11.55-meter height, a 38.78-meter base width, and a 16.32-meter upper-layer width, as shown in Figure 1.

The design of the submerged breakwater was arrived at after numerical modeling confirmed the geometric dimensions required for effective wave mitigation. The model was developed using the mild slope equation owing to its general properties for dealing with complex wave fields. The model incorporates the combined refraction and diffraction of waves along with all shoaling, reflection, and backscattering effects.

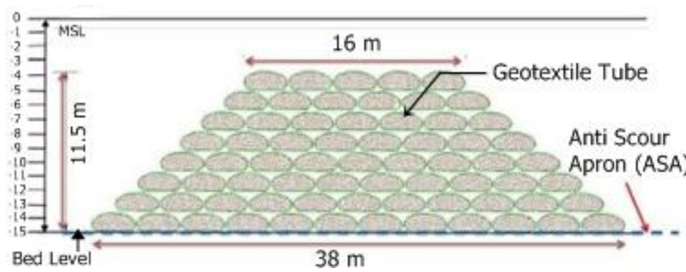

Figure 1. A schematic of the proposed geotextile submerged breakwater.

A total volume of 38,000 m^3 of sand is expected to be used, a relatively large amount. Two alternative construction processes have been proposed for the submerged breakwater, either using one crew per geotextile grid, or using multiple crews per geotextile grid.

The construction process sets up the submerged breakwater on the seabed by using one crew working on one geotextile grid at a time. It starts when a space on the seabed is ready. First, a geotextile grid for the bottom layer, containing 12 tubes, is placed on a marked area on the seabed. Second, sand is pumped into a geotextile tube until the tube is fully filled with a volume of 111.4 m^3 of sand. Next, the crew switches the pump to another tube to inject the same volume of sand into the tube, until every tube on the geotextile grid is filled. For the one-crew-per-grid approach, there are two open horizontal and vertical spaces for another geotextile grid placed adjacent to the filled grid; thus, two crews can work on the sand-pumping task simultaneously. The construction process would be performed in this manner until 40 grids are filled (5 grids/layer x 8 grids).

For the multiple-crew-per-grid approach, the crews would continue placing another geotextile grid, horizontally, next to the filled grid and pumping sand into all tubes. The process would continue in this manner until 40 grids are filled.

2 SIMULATION MODELS OF KAHULUI SUBMERGED BREAKWATER

Simulation models were developed consistent with the proposed construction approaches for the submerged breakwater via EZStrobe software.

2.1 Models of One-crew-per-geotextile-grid Construction Process (Model A)

Models A-1, A-2, A-3, A-4, and A-5 were developed to simulate the one-crew-per-grid construction process using, in total, one crew, two crews, three crews, four crews, and five crews, respectively, in order to perform a sensitivity analysis. According to the model, completion of the preceding loop triggers the operation of the following loop; e.g., the completion of section 2's loop allows section 3's loop to run. Therefore, once section 1 and section 2 loops are completed, the model can be run with three loops: section 1, section 2, and section 3. The model runs until each loop repeats itself 8 times, simulating the number of geotextile layers, to complete the construction process.

2.2 Models of Multiple-crew-per-geotextile-grid Construction Process (Model B)

Models B-1, B-2, B-3, B-4, and B-5 were developed to simulate the multiple-crew-per-grid construction process using, in total, one crew, two crews, three crews, four crews, and five crews, respectively. The model starts when NeedSpace Queue Node and NeedLayer Queue Node submit their one unit of resource to SpaceMaker Combi Node to set up the space and layer, respectively, for a geotextile grid, as shown in Figure 2.

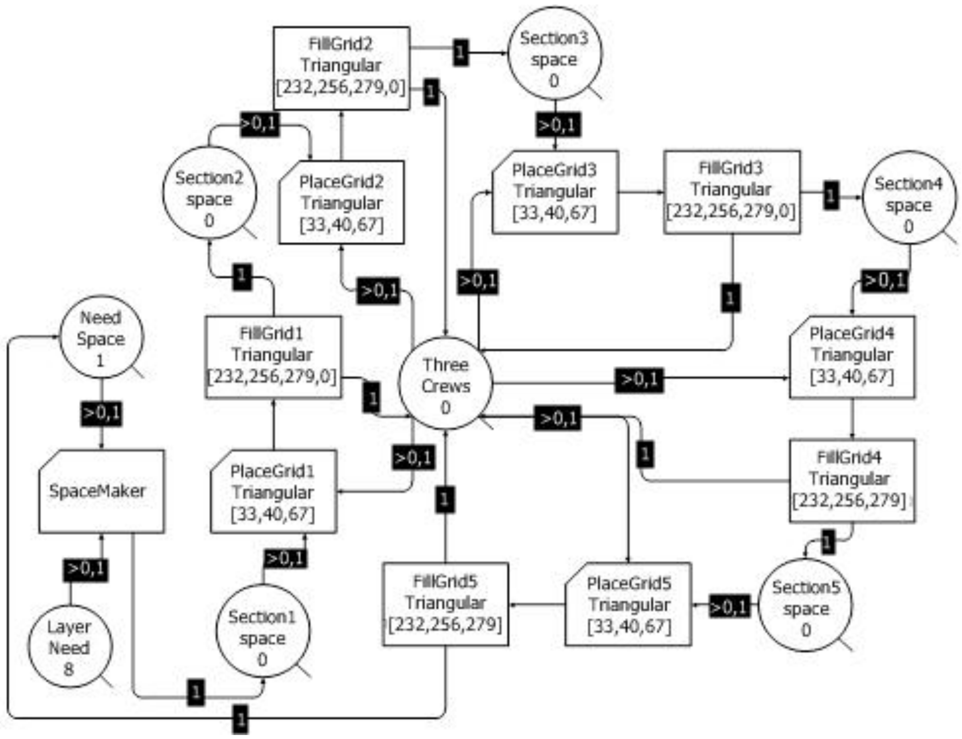

Figure 2. The multiple-crew-per-grid geotextile submerged breakwater construction model operating by hiring three crews (Model B-3).

The duration of the grid-placing task (PlaceGrid1) is programmed to vary from model to model by the number of crews assigned. Similarly, since each model is set to perform a sensitivity analysis on the number of crews working on the sand-pumping task, the duration of the task is programmed to vary linearly from model to model.

3 PARAMETERS

3.1 Geotextile Grid Filling Times

The maximum fill rate for the geotextile is 100 m^3 per hour, with a typical fill rate of 80 m^3 per hour. These rates, along with the average rate of 90 m^3 per hour, were used to simulate the grid-filling time, and simplified to have a triangular distribution. For example, a bottom-layer grid contains 12 geotextile tubes, of which each tube has a volume of 111.4 m^3; thus, the sand pump rate is expected to be between 982 minutes and 1,182 minutes per grid (Hansbrough and Singh 2013). The sand pump rates for geotextile grids on each layer, along with the overall average fill rate, for one crew working on the task are illustrated in Table 1. However, for the models applying multiple crews to work on the same task, the sand pumping time can be estimated as shown in Table 2.

Table 1. Time distributions of the sand pump rates for each layer for one crew.

Number of tubes	Grid volume (m^3)	Time to fill grid (min)		
		at Max rate	at Avg rate	at Typical rate
12	1336.8	982.08	1082.34	1182.6
11	1225.4	900.24	992.145	1084.05
10	1114	818.4	901.95	985.5
9	1002.6	736.56	811.755	886.95
8	891.2	654.72	721.56	788.4
7	779.8	572.88	631.365	689.85
6	668.4	491.04	541.17	591.3
5	557	409.2	450.975	492.75
Average	946.9	**695.64**	**766.6575**	**837.675**

Table 2. Time distributions of the sand pump rates for multiple crews.

Number of Crews	Time to fill grid (min)		
	at Max rate	at Avg rate	at Typical rate
1	696	767	838
2	348	384	419
3	232	256	279
4	174	192	210
5	139	153	168

3.2 Geotextile Grid Placing Times

The geotextile grid placing time used in these models has been adopted from a similar geotextile submerged breakwater construction project in Boscombe, UK (Hansbrough and Singh 2013). The grid placing times for multiple-crew-per-grid models are shown in Table 3.

Table 3. Time distributions of the grid placing rates for multiple crews.

Number of Crews	Time to place grid (min)		
	at Max rate	at Avg rate	at Typical rate
1	100	120	200
2	50	60	100
3	33	40	67
4	25	30	50
5	20	24	40

3.3 Cost Estimation

According to the Bureau of Labor Statistics (2012), the hourly wage for construction laborers in the state of Hawaii is $24.76 per hour, with a median of $24.94 per hour. Thus, the study adopts $25 per hour as a labor cost for crews. In addition, the price for an electric metal slurry pump (Alibaba 2013) that has a capacity between 80 m^3/h – 100 m^3/h, using power of 60 kW, is estimated to be at maximum around $3,000 per pump set. Electricity cost is estimated to be 30 cents per kWh (U.S. Energy Information Administration 2013). These variable costs were considered in sensitivity analyses.

4 SENSITIVITY ANALYSES RESULTS

Sensitivity analyses were conducted on the results in order to determine the most reasonable construction approach for the geotextile-submerged breakwater under the five-month construction window and budget constraints. The output for this model applies the definition of a work week as 5 days a week, 6 work hours a day. The sensitivity analyses results on construction duration and costs are illustrated in Table 4.

Table 4. Sensitivity analyses on the construction models.

Model	Number of Crews	Avg Idle Time per Crew		Total Crew Idle Time (hrs)	Total Construction Duration			Total Cost ($)
		minutes	hours		minutes	weeks	months	
A-1	1	0	0	0	36,462	20.3	4.7	26,943
A-2	2	82.44	1.4	2.7	19,952	11.1	2.6	32,203
A-3	3	172.91	2.9	8.6	14,644	8.1	1.9	37,849
A-4	4	264.42	4.4	17.6	12,030	6.7	1.6	43,599
A-5	5	428.12	7.1	35.7	11,152	6.2	1.4	51,616
B-1	1	0	0	0	36,462	20.3	4.7	26,943
B-2	2	0	0	0	18,237	10.1	2.4	29,952
B-3	**3**	**0**	**0**	**0**	**12,154**	**6.8**	**1.6**	**32,943**
B-4	4	0	0	0	9,126	5.1	1.2	35,971
B-5	5	0	0	0	7,290	4.1	0.9	38,937

To illustrate, when comparing the models using two crews, model A-2 takes one week longer than model B-2 to complete the process, resulting in $2,251 of additional expense for adopting model A-2 instead of B-2. Next, when comparing the models using three crews, the model A-3 takes 1.3 weeks more than the model B-3 to set up all the geotextile grids, while the model A-3 costs $4,906 more than the model B-3 for the same process.

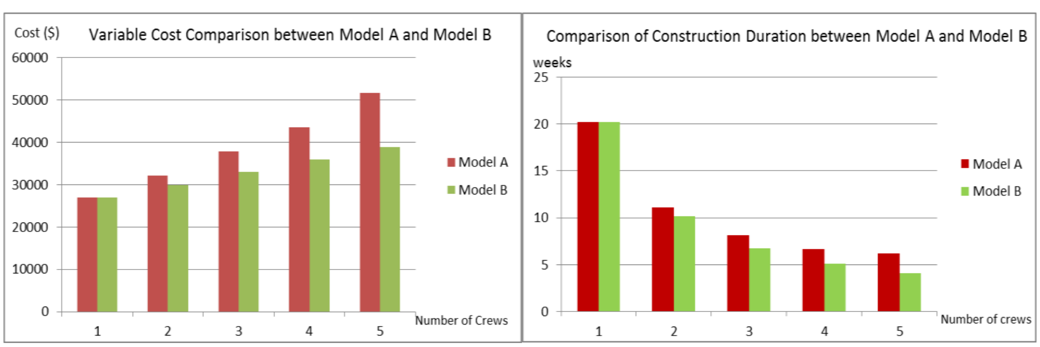

Figure 3. Variable cost comparison between model A and model B (left) and comparison of construction duration between model A and model B (right).

Similarly, it takes 1.6 weeks less and saves $7,628 to substitute the model A-4 with model B-4 as a construction approach. Also, model B-5 takes 2.1 weeks and $12,679 less than what model A-1 consumes. The cost comparison and construction duration comparison between model A and model B are shown in Figure 3.

5 DISCUSSION AND CONCLUSIONS

It can be deduced from the results that the difference in efficiency in terms of costs and time between the multiple-crew-per-grid (model B) and one-crew-per-grid models (model A) is more significant when a larger number of crews are hired. One reason why is that model A does not start at maximum efficiency, since the amount of crews working at a time depends on the available space adjacent to the filled tube. Therefore, if the greater number of crews is hired, additional idle time of crews will increase, as seen in Table 4. On the other hand, model B allows multiple crews to place and fill tubes at the same time in a way that maximizes the efficiency of the construction crews, which theoretically means they have no idle time, as seen in Table 4. Therefore, model B is preferred over model A for all numbers of construction crews used.

In conclusion, model B-3, which employs three construction crews to perform the multiple-crew-per-grid construction approach, is recommended for the geotextile submerged breakwater construction project at Kahului Harbor, since it yields optimal results in terms of costs and construction duration. Although adding another slurry pump could finish the project earlier by 12 days, the additional expense of accelerating the project by adopting model B-4 is unreasonably high—$254 per day, or $3,028 in total—compared to adopting model B-3. Similarly, it is also unreasonable to accelerate the project by using model B-5 since it takes $285 per day for 3 weeks—or $5,994—to get the project done earlier. However, changing from model B-2 to B-3 allows the project to be completed 24 days earlier with a reasonable additional cost of $125 per day, or $3,000 in total. Moreover, the simulation result of the model indicates a construction duration of 1.6 months, much shorter than the five-month construction window available. The short estimated duration can also be considered a safety factor since the actual duration may be affected by uncertainty from weather conditions.

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