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MODELING AND SIMULATION OF BREAKWATER CONSTRUCTION

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ABSTRACT

This paper discusses the application of computer simulation for the analysis of productivity of breakwater construction. Data collected from the first stage of the South Star Project in Taiwan will be used in modeling and analysis. The South Star project involves embanking land from the sea, using industrial waste as deposits and expanding the seashore line as well as increasing land for the industrial city of Kaohsiung. The main benefit of this simulation analysis is a detailed look at the techniques for improving breakwater construction.

1 INTRODUCTION

Construction engineers are involved with the efficient design of construction methods or processes. Processes in the execution of a construction method are often cyclic in nature and any increase in productivity and efficiency greatly enhances project performance (Vanegas et al. 1993). Computer simulation allows the modeling of resource driven, repetitive construction processes to assist in identifying problems in attaining satisfactory production. Once these problems are analyzed, the solutions can be applied to the cyclic processes to enhance production and resource utilization (Abraham and Halpin 1994).

The CYCLONE simulation methodology offers a graphical method for the analysis, modeling and experimentation of construction processes. This methodology has been adopted in a number of construction engineering curricula in universities across the U.S., Canada, Europe and Australia. A microcomputer based program, MicroCYCLONE, which employs this methodology was used to model, simulate and analyze the construction of breakwaters on the South Star Project in Kaohsiung, Taiwan.

2 THE CYCLONE METHODOLOGY

The CYCLONE methodology focuses on resources and their interactions. Resources may be in an active state (represented by a square element) or in an idle state (represented by a circle element). The resource will move between the two states. The modeling elements used to build the CYCLONE model and the rules for structuring CYCLONE network models using these elements are described in Table 1.

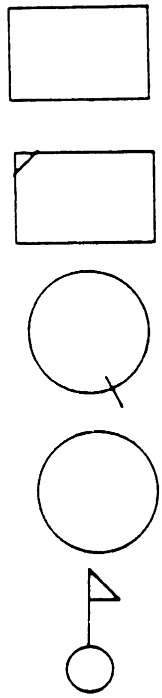
3 BREAKWATER CONSTRUCTION

A breakwater is a structure which has the function of "breaking" the "waters" and providing a shelter for the artificial area formed by the structure, thereby protecting the land from the effect of sea waves (Bruun 1985). They are usually built perpendicular to the shore to interrupt the normal transport of sand along the shore.

The most common type of breakwaters is the mound type, constructed using natural rocks and rubble or a combination of rocks, rubble and concrete blocks. Rubble mound breakwaters dissipate most of the wave energy and thereby reduce wave transmission and reflection (Quinn 1972).

Vertical wall type breakwaters reflect the wave without freeing any destructive energy. Generally, they do not have the structural flexibility to adjust themselves to settlement and wave-force disturbances. The construction of these breakwaters requires more extensive, heavy plant equipment, making them impractical in remote conditions.

Table 1: Rules for Structuring CYCLONE Models (AbouRizk, Halpin and Lutz 1992)



Element	Rule
NORMAL	A non- constraint task. It is like a serving station with an infinite number of servers.
COMBI	A task constraint by the availability of more than one type of resource. A resource arriving at a COMBI waits until all other required resources are available before it is processed.
QUEue	A waiting area for a resource. A resource arriving at a QUEue node will stay in the node until a COMBI is ready to process it.
Function	Devised so it will provide some flexibility by allowing the creation of new elements.
COUNTER	Keeps track of the number of times units pass it. It does not alter any of the resources or their properties.

4 SOUTH STAR PROJECT

The Environmental Protection Bureau of Taiwan has established the South Star Project which involves embanking land from the sea using industrial waste as deposits, expanding the seashore line and increasing land for the industrial city of Kaohsiung. Ideally, these artificial lands will be used for developing a deep water port or sea airport in the future. The main industrial wastes used in the project include fly ash and blast furnace slag, which are by-products of power plants and steel production factories in Kaohsiung city.

The South Star Project will be completed in three stages with costs at the first stage estimated at US $15 million and the cost of the final stage estimated at around US $150 million. Figure 1 shows the three stages of the project.

Data collected from the first stage of the South Star Project is used for the modeling, simulation and productivity analysis of the study. The width of the foundation of the rubble mound breakwater is 70 m and it tends to narrow down as the construction advances into the sea. The height of the structure is 17 m and the total length is 2,000 m.

5 MODELING THE BREAKWATER CONSTRUCTION PROCESS

5.1 Process Descriptions

Figure 2 shows a cross sectional view of the breakwaters at the South Star project. The main processes include:

a) Sand Excavation: Sand is excavated about 8 m under the still water level using pump boats with 8" diameter pipes. Three constraints that limit the progress of this process are: the typhoon (hurricane) season, southwest airstream and shattered waves. These conditions affect the wave action, increasing wave intensity and increasing the probability of refill of the area that has been excavated.

b) Non-Webbed Fabric Layout: Non-webbed fabric (NWF) is a plastic material which lies on top of the sand to prevent the addition or loss of sand after it reaches its required waterbed level. The fabric is processed into 12.5 m x 70 m pieces, tied with steel bars before being hauled to the site and spread onto the waterbed. The presence of the steel bars increases the weight of the fabric and prevents floating due to wave action. Spreading the non-webbed fabric is a task that needs coordination with the intensity of the tide. The process can be done only at the time of constant

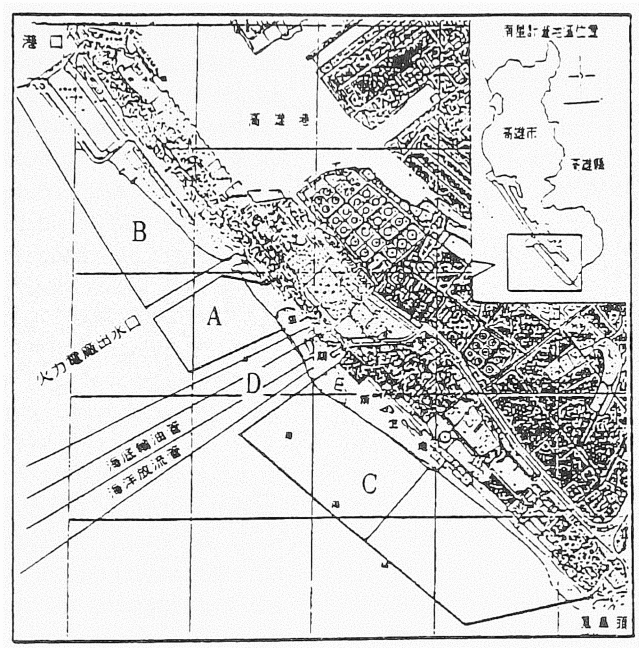


Figure 1: Stages of the South Star Project (Environmental Protection Bureau 1991)

(leveled) tide which occurs only 4-5 hours a day. A crane lifts the processed fabric to the site and divers assist in positioning the NWF on the waterbed. After the non-webbed fabric is laid out, rubble is dumped on it to prevent it from floating and repositioning.

c) Core Forming and Correction: The core (see Figure 2) is hydraulically the least important part of the structure and usually has low permeability. Rubble and blast furnace slags are the main materials for the core at the South Star Project.

d) Underlayer Construction and Correction: The main function of the underlayers is to act as a filter. They have a rough surface to support the armor layer units through friction and interlocking. The main materials for the underlayers are type A (5-100 kg) rocks and type B (100-300 kg) rocks which are hauled to the site by 25 ton flat bed trucks.

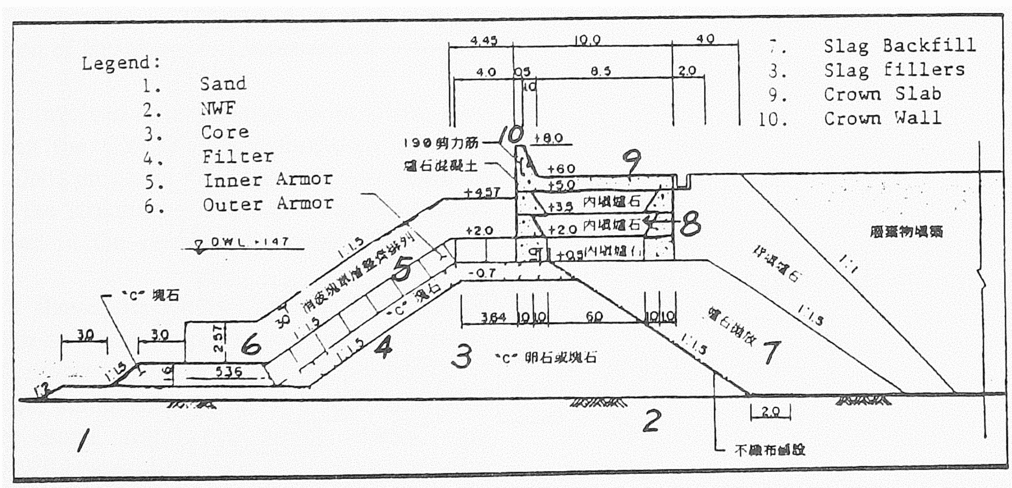


Figure 2: Cross Sectional View of the Breakwaters at the South Star Project (Environmental Protection Bureau 1991)

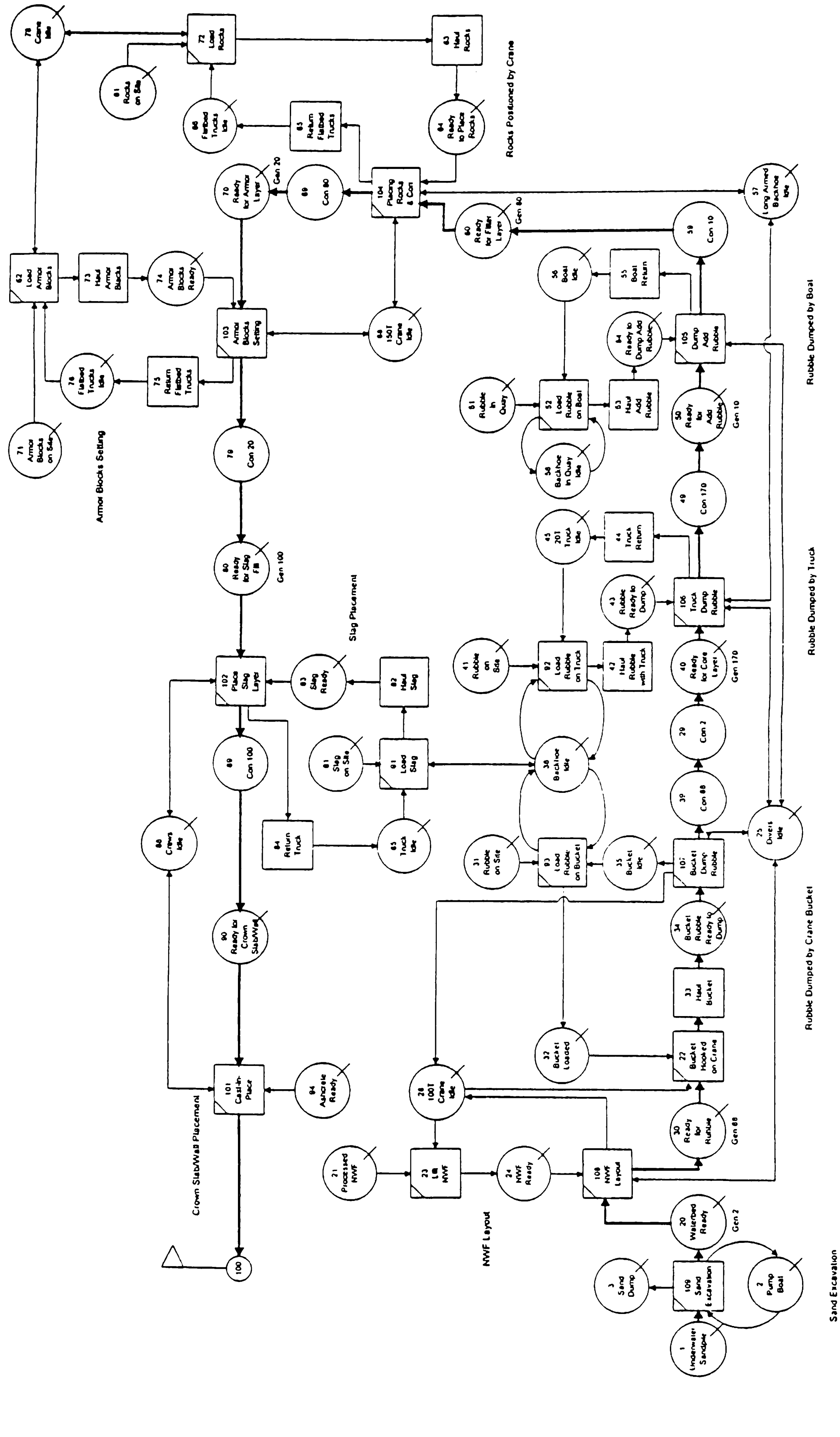


Figure 3: MicroCYCLONE model of Breakwater Construction at the South Star Project

e) Armor Block Setting: The armor, which consists of one or more layers, is the most important part for breakwater stability. It is the exposed face of the breakwater and acts against wave action. The layers are placed as soon as possible following the placement of filter sublayers to avoid damage to these sublayers. In addition to cubed armor blocks, various irregularly shaped concrete blocks are used in breakwater construction. The irregular blocks have the added advantage of permitting steeper slopes due to their better shape factor and superior absorption of wave energy. Most of the units are laid to a specific grid pattern and sometimes to a preferred armor unit orientation.

f) Slag Layer Formation: These layers consist of two parts: the backfill layers and the gap filler layers. The backfill layers are on the opposite side of the wave action face. Slag is used as a gap filler for the voids/cavities that are created by the placement of the rocks.

g) Crown Slab/Wall Placement: The final operation process of the breakwater construction is the placement of crown slab/wall. The crown slab often serves as a road for access to other facilities like piers or quays, and for maintenance vehicles. The crown wall is built on the slab at the wave-exposed face of the breakwater structure. On the South Star Project, ashcrete was used as Portland cement concrete replacement.

After the breakwater structure is built, the defined area is ready for waste landfills. In this project, the landfilled area is approximated 50 hectares and is filled with approximately 800,000 m^3 of construction and non-hazardous wastes (Environmental Protection Bureau 1991).

5.2 Simulation of Breakwater Construction

The processes involved in breakwater construction were modeled using the CYCLONE methodology and the MicroCYCLONE program. The analysis was based on one wing of the structure (1000 m). The production unit considered in the simulation model is 25 m per cycle.

Figure 3 shows the MicroCYCLONE simulation model with the nine interacting cycles: sand excavation, dumping of rubble using crane/bucket, dumping of rubble by truck, dumping of rubble by boat, positioning of rocks by crane, setting of armor blocks, slag placement, NWF layout and crown slab/wall placement. Data related to work task durations and resource utilization were collected by the project engineer in charge of the project. Three different sets of durations were used in the simulation. The work tasks involved with the main breakwater cycle have a larger variance than those of other work tasks in the model. These work tasks have durations with triangular distributions. Travel times of the trucks and boats that haul rubble, rocks and armor blocks have non-stationary durations, which are incremented at the rate of 0.5 minutes/cycle as the construction of the breakwater advances. All other work tasks are considered to have a mean duration, calculated from field data provided by the project engineer.

6 ANALYSIS OF SIMULATION RESULTS

The results of the simulation (based on 40 cycles) showed that the construction of breakwaters proceeds at the rate of 0.15 m per hour. This compares very well with the actual rate of 0.14 m per hour. Unit production varies as the number of cycles increases (see Figure 4). A dip in production occurs as the non-stationary durations of travel times are increased. After cycle number 30, the production levels to 0.15 m/hr. These summary results were discussed with the project engineer and found to be consistent with the observed progress on the actual site.

The project engineer was interested in analyzing the effects of changing the quantity of key resources on the project. Sensitivity analyses were performed, with different numbers of resources at QUEUE 2 (pump boat), QUEUE 38 (backhoe), QUEUE 57 (long-armed backhoe), QUEUE 68 (150 t crane) and QUEUE 78 (100 t crane). These resources tend to be involved in multiple tasks. Table 2 shows one of the report of sensitivity analyses. The most optimal combination of resources (run 12) was one pump boat, two backhoes, one long-armed backhoe, one 150 t crane and two 100 t cranes. This combination was deemed acceptable by the project engineer (both in terms of availability of resources and accessibility on the site) for future consideration.

Modeling and analyzing the breakwater process also proved the importance of planning the storage area of the materials more appropriately. Proper planning of the storage areas and the lay-down areas reduces the transporting time of the materials and reduces overall cycle time.

7 CONCLUSIONS

A major problem one encounters when simulating a construction project is the complexity involved in modeling. Traditionally, the construction industry has been reluctant to invest the effort to build such models. That attitude is slowly changing, as decision makers recognize that accurate and detailed representation of

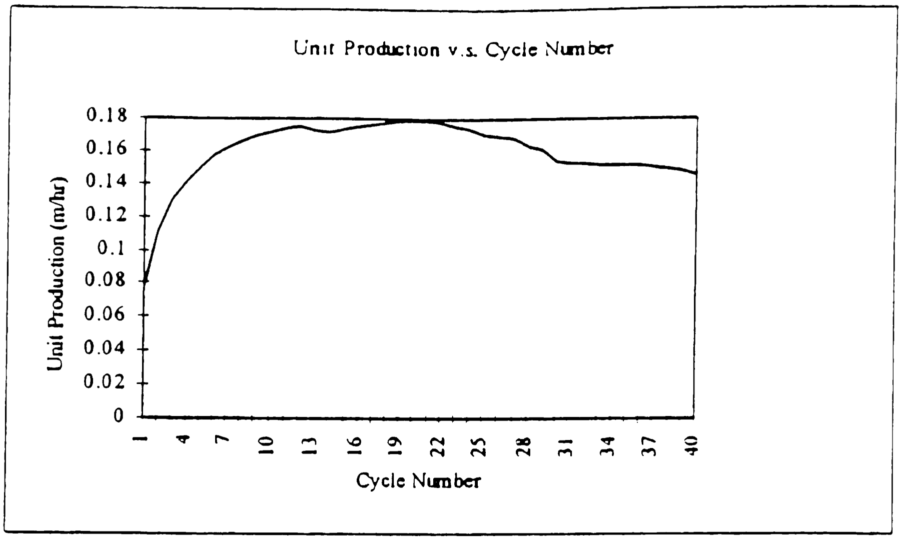


Figure 4: Unit Production vs. Cycle Time (Yeh 1995)

Table 2: Report of Sensitivity Analysis (Yeh 1995)

Run no.	**Unit Prod. (m/hr)**	**Unit Cost ($NT/m)**	**QUE 2**	**QUE 38**	**QUE 57**	**QUE 68**	**QUE 78**
1	0.15	435,400	2	1	1	1	1
2	0.15	431,900	2	1	2	1	1
3	0.15	490,500	2	1	1	2	1
4	0.14	478,000	2	1	1	1	2
5	0.15	478,300	2	1	2	2	1
6	0.15	460,300	2	1	2	1	2
7	0.14	540,700	2	1	1	2	2
8	0.15	510,800	2	1	2	2	2
9	0.15	541,600	2	1	3	2	2
10	0.15	462,800	3	1	1	1	1
11	0.19	367,900	3	2	1	1	1
12	**0.19**	**364,800**	**3**	**2**	**1**	**1**	**2**
13	0.19	410,800	3	2	1	2	1
14	0.19	371,000	3	2	2	1	1
15	0.19	437,300	3	2	1	2	2
16	0.19	397,400	3	2	2	1	2
17	0.19	413,300	3	2	2	2	1
18	0.19	442,000	3	2	2	2	2
19	0.19	378,900	3	2	3	1	1
20	0.19	405,300	3	2	3	1	2
21	0.19	417,200	3	3	1	2	1
22	0.19	389,400	4	2	1	1	1

the work tasks can help them estimate the production of the process and identify bottlenecks in the process.

Currently, breakwater construction is an important process in Taiwan's land expansion program. Improvements in the breakwater construction process would help contractors reduce the cost and duration of the operation and improve efficiency. In the productivity analysis of the South Star Project, MicroCYCLONE simulation was found to be a good tool for measuring cycle productivity and analyzing resource utilization. It is hoped that the encouraging results of this study will enhance the use of computer simulation during the planning phases of Stage 2 and Stage 3 of the South Star Project.

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