Application of Water Exchange Physical Model in Artificial New Port Town

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Abstract: The water exchange capacity of artificial river system in the new town formed by reclamation in the coastal water is studied by means of water exchange tidal physical model test. The model test results show that the water exchange capacity of Lake Wood area with good hydrodynamic condition is best and except for the top of the curve and the north port, the water exchange capacity of meandering canal is better, while that of south port is the weakest. Through comprehensive analysis, it is found that water exchange capability is mainly depend on the unidirectional flow velocity and duration. Taking prototype current data as reference, it indicates that long time unidirectional flow exists in the artificial river system which is conducive to the water exchange of the artificial river system. The results of typical tide water exchange test point out that the Lake Wood, north port and Strolling Canal can meet the requirement of fulfilling one exchanging per week, but the south port which is semi-closed and weakest in hydrodynamic can’t meet the water exchange requirement. So it is suggested that the south port should be modified to meet the requirement of water exchange.

1. Introduction

With the development of society, human beings produce land from the sea, especially the developed coastal cities increase urban land through Reclamation [1], expand the deep-water coastline by building docks and building up aquaculture farm, etc. With the economic development and the progress of reclamation technology, reclamation project has gradually evolved from a small-scale to the offshore island building project[2]. And the emergence of large-scale offshore cities, such as offshore airport and artificial island, is possible[3,4]. Whether it's the inshore reclamation project or offshore island building, the hydrodynamic characteristics of the original water areas is changed and the environment[5], tidal field[6] and sediment erosion and deposition[7] of the coastal waters will change accordingly. At the same time, the water system of the new town may also have weak hydrodynamic force, poor water exchange capacity[8], high cost of water environment maintenance in the later stage, which affects the overall environmental quality of the reclamation area. Therefore, scholars have carried out extensive research on the shape, size[9], construction location[10], hydrodynamic characteristics, water environment[11] and water exchange[12] of the artificial island.
with the method of physical model, mathematical model, remote sensing analysis and prototype data analysis.

In this paper, the characteristics of water exchange and the risk of water quality in the artificial river system are analyzed by taking a coastal reclamation project as an example. According to the master plan, the artificial river system is divided into four sub-systems with their own functional characteristics. The new port town is positioned as a modern high-tech development zone, which integrates commerce, tourism, entertainment and is the centre of the city in the future. The quality of the artificial water system plays an important role in the overall environment of the new town. Therefore, the water exchange characteristic of the artificial river system is an important part of the design of the new town. The prototype data analysis and water exchange physical model test are used to study the water exchange characteristics and potential water quality risk of the new town river system in this paper.

2. Water Exchange Physical Model Design and Verification

2.1. Model Scope and Scales

The tidal physical model is used to simulate the water exchange characteristics of the artificial river system and the water exchange of different sub-systems under different ocean current conditions is mainly studied. According to the physical model test results, the optimization suggestions are put forward for the design scheme to provide technical basis for the improvement of the water environment of the artificial river system in the new town.

According to the experience of similar model research, the influence of model variability on the water environment simulation of bend and braided rivers is great, so it is usually required to be small.

The model similarity scales list in Table 1.

| Name of Scale          | Symbol | Numerical |
|------------------------|--------|-----------|
| Horizontal             | \( \lambda_l \) | 60        |
| Vertical               | \( \lambda_v \) | 10        |
| Velocity               | \( \lambda_u \) | 3.162     |
| Time Scale for Water Flow | \( \lambda_t \) | 18.974   |
| Discharge              | \( \lambda_0 \) | 1897.4    |
| Roughness Coefficient  | \( \lambda_{n_s} \) | 0.599     |

The physical model of water exchange includes all the artificial water systems. In order to simulate the characteristics of water exchange, the boundary of the model is 200m away from the artificial water system as the transition section (Figure 1).

2.2. Model Verification

The velocity and seawater flow that are extracted through the mathematical model which simulates the flowing of the open sea and artificial river system is the validation data of the physical model.

Two velocity measuring sections in Strolling Canal are arranged in upstream and downstream. One velocity measuring section is setted in the Lake Wood. At the same time, there are several tidal level measuring points arranged along the canal and lake. The measuring point layout is shown as Figure 1 and the verification results are shown in Table 2.
The physical model test results show that the velocity distributions and total seawater flow are close and the tidal levels at the south and north entrance also have few difference no matter the water flowing from north to south or from south to north. The result shows that it satisfies the similarity requirements on the aspects such as tidal level and flow velocity which say that the hydrodynamic characteristic of the model has achieved similarity to the prototype.

### Table 2. Model Validation Results

| Category | Flow Direction | From South to North | From North to South |
|----------|----------------|---------------------|---------------------|
|          | Measuring Points | Mathematical Model | Mathematical Model | Physical Model | Physical Model |
|          |                 | $Q=318\text{m}^3/\text{s}$ | $Q=286\text{m}^3/\text{s}$ | $Q=320\text{m}^3/\text{s}$ | $Q=290\text{m}^3/\text{s}$ |
| Velocity of Flow (m/s) | 1-1 | 0.08 | 0.11 | 0.07 | 0.09 |
| | 1-2 | 0.08 | 0.15 | 0.07 | 0.08 |
| | 1-3 | 0.08 | 0.20 | 0.07 | 0.07 |
| | 2-1 | 0.08 | 0.15 | 0.07 | 0.06 |
| | 2-2 | 0.08 | 0.15 | 0.07 | 0.07 |
| | 2-3 | 0.08 | 0.15 | 0.07 | 0.09 |
| | 3-1 | 0.11 | 0.22 | 0.11 | 0.10 |
| | 3-2 | 0.15 | 0.19 | 0.13 | 0.12 |
| | 3-3 | 0.16 | 0.16 | 0.13 | 0.13 |
| | 3-4 | 0.16 | 0.12 | 0.14 | 0.13 |
| | 3-5 | 0.17 | 0.10 | 0.15 | 0.15 |
| | 3-6 | 0.15 | 0.08 | 0.13 | 0.13 |
3. Water Exchange Test

3.1. Hydrodynamic Axis Test

In order to study the characteristics of water exchange in the artificial river system, the hydrodynamic characteristics physical model test is carried out firstly and the trend of the hydrodynamic axis in the river system is studied. At the same time the stagnation area is found. The distribution of hydrodynamic axis is illustrated in Figure 2.

![Schematic Diagram of Hydrodynamic Axis](image)

The experimental results show that, the water in the artificial river system also behaves reciprocating flow and there will be long-term unidirectional flow under the action of tidal power. At the same time, it is seen that the hydrodynamic of Lake Wood is the strongest, followed by north port and Strolling Canal, but the south port hydrodynamic is the weakest and the flow velocity is very small during the flood tide and ebb tide. In the Strolling Canal, the water flow is slow at the corner where is the stagnation area.

So the research effort has focused on tracing the water exchange characteristics and quality of the area with weak hydrodynamic.

3.2. Water Exchange

3.2.1. Lake Wood

According to the physical model test, the split ratio of Lake Wood and Strolling Canal is about 8.3:1 in average, but the flow area ratio is 5.6:1 under the condition of unidirectional flow. It can be seen that the resistance of Lake Wood water area is small, the flow capacity is strong, the water flushing time is short and the water quality is good in whole. Under the condition of unidirectional flow, the water renewal can be realized in a rising or a falling tide period.

3.2.2. Strolling Canal

According to the hydrodynamic characteristics, the Strolling Canal is divided into 8 areas to carry out water exchange tracing test (Figure 1). At the beginning of the experiment, the Strolling Canal is blocked in high tide level at which time the river storage capacity was the largest and that was most unbenefficial to water exchange. The canal water body is added with rhodamine B as the tracer. When the water in Strolling Canal is dyed evenly and the tide level comes to climax, the partitions are opened and the rhodamine tracer water begins to transport and diffuse. Through a series of experimental steps, the experimental results are obtained by collecting water samples measured with a
spectrofluorimeter, monitoring the concentration change of rhodamine B and analyzing the water exchange capacity. According to the concentration change of rhodamine B in different water area, the water exchange rate of the Strolling Canal is got and listed in Table 3.

| Time | Southwest Monsoon Spring Tide | Average (%) |
|------|--------------------------------|-------------|
| 6h   | 1# 8.1 12h 13.8 24h 45.8 48h 61.9 72h 74.1 | 1.7 5.3 41.8 57.8 69.9 |
|      | 2# 0.7 12h 10.5 24h 45.6 48h 61.8 72.3 |             |
|      | 3# 0.0 12h 1.2 24h 12.1 48h 24.9 37.2 |             |
|      | 4# 0.0 12h 4.9 24h 43.9 48h 60.6 72.1 |             |
|      | 5# 0.0 12h 0.0 24h 3.6 48h 14.7 21.5 |             |
|      | 6# 0.0 12h 0.0 44.5 48h 61.8 74.0 |             |
|      | 7# 0.0 12h 0.0 13.3 24h 25.6 38.3 |             |
|      | 8# 0.0 12h 0.0 45.9 48h 61.9 75.4 |             |

| Time | Northeast Monsoon Neap Tide | Average (%) |
|------|-----------------------------|-------------|
| 6h   | 1# 53.7 12h 69.4 24h 84.9 48h 96.4 72h 98.9 | 49.7 65.1 80.1 91.8 95.3 |
|      | 2# 53.5 12h 69.3 24h 84.8 48h 96.4 72h 98.9 |             |
|      | 3# 19.6 12h 31.4 24h 44.6 48h 55.6 67.8 |             |
|      | 4# 52.1 12h 68.6 24h 83.6 48h 95.8 78.4 |             |
|      | 5# 15.4 12h 19.7 24h 27.7 48h 43.2 55.4 |             |
|      | 6# 52.8 12h 69.0 24h 84.9 48h 95.9 88.5 |             |
|      | 7# 20.2 12h 32.0 24h 45.1 48h 55.9 68.2 |             |
|      | 8# 53.0 12h 69.1 24h 84.3 48h 96.1 98.6 |             |

The measured data show that during the monsoon period, the coastal current of the open sea presents a unidirectional flow with a long period.

Spring tide in the southwest monsoon period: at the initial time, the flow of open sea flows from north to south. Because the tide level difference between the north and south entrances of the artificial water system is small, the flow velocity of Strolling Canal is small too and the water exchange rate is poor. In the first 12 hours, the water exchange rate of Strolling Canal is only 5.3%; from 12 to 24 hours, the open sea water flows from south to north, the tide level difference between the north and south sides is larger and the flow velocity of canal is also increased, so the water exchange rate reaching 41.8% is improving; 48 hours later, the water exchange rate of the artificial canal reaches 57.8%; 72 hours later, it could increase to 69.9%.

Neap tide in the northeast monsoon period: according to the measured data, the current in the open sea always flows from south to north. At the beginning, the tide level difference between the north and the south entrances is large and the flow velocity of the artificial Strolling Canal is also high, so the water exchange is good. In the first 12 hours, the water exchange of the Strolling Canal reaches 65.1%; from 12 to 24 hours, the water flow still flows from the south to the north, but the tide level difference between the two sides is reduced. With the change of hydrodynamic, the flow velocity of the canal is reduced and the water exchange rate of the canal reaches 80.1%; 48 hours later, the exchange rate of the artificial canal reaches 91.8% ; 72 hours later, the it can reach 95.3%.

As shown in Table 3, water exchange in the top of corners(3#, 5#, 7#) is poor. On the overall, the exchange rate of stagnant areas is smaller than that of the whole canal. At the middle corner(5#), the water exchange capacity is the weakest.
3.2.2.3. North Port and South Port

The north port is designed as a dug in port basin, but the depth of the concave is small and the distance between the two ends is short. At the same time, the north and south sides of the port basin are open, so the fluctuation tide can directly pass through the port area. The north port has strong hydrodynamic and water exchange capacity.

The south port is also a dug in basin, but it is seriously concave and has only one entrance. The hydrodynamic of the south port is weak, which is not conducive to water exchange. The results of hydrodynamic tests show that the water flow at the top of the port is basically non-flowing and the water exchange capacity is weak.

The southwest monsoon spring tide was used as the experimental boundary condition to study the water exchange characteristics of the south port. The results show that in the first 2 days the water exchange rate of the south port is 8%; 4 days later, the water exchange rate is only 17%; 8 days later, it is about 40%; 16 days later, it is about 70%. It means that 30% of the water in the south port is still not exchanged in 16 days.

It is obvious that the shape of the south port is designed as a dug in basin with the weak hydrodynamic characteristics and water exchange capacity. When the water flows from south to north, the dilution effect of the tide on the port is not significant; on contrary, the basin is mainly exchanged by southward flow.

4. Conclusions

The hydrodynamic characteristics of the artificial river system are quite different in north port, Lake Wood, Strolling Canal and south port. And the water exchange capacity is quite different too. Except for south port, the water exchange capacity of other water areas meets the requirements in whole.

The measured hydrological data show that as long as there is a small tidal level difference between the north and south control boundary of the artificial water system, unidirectional flow and a certain amount of water exchange flow can be formed. In a rising or falling tide period, Lake Wood can complete water renewal. There is a circumfluence area at the top of corners in the Strolling Canal which has an impact on the water exchange rate, but the canal basically meets the goal of water exchange requirements. The north port shape is benefit for water exchange. Due to the deep depression of the south port, the water is mainly changed by the flow from north to South and the self-renewal capacity that does not meet the water change requirements is poor. It cannot be purified through natural exchange if the water is polluted. There is a great risk of water quality in south port.

Through the water exchange test, the following suggestions are put forward for the optimal design. In the design of artificial water system, the tidal range of the open sea cannot be controlled, but the sewage discharge system in the urban area should be planned as a whole. The waste water cannot be directly discharged into the artificial water system before being treated and purified. The design scheme of south port needs to be optimized to ensure that the water quality does not deteriorate. By reducing the submerged groyne, the tide wave can enter the artificial water system that is beneficial to enhance the hydrodynamic force, increase the water exchange rate and reduce the risk of water quality.

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