Reinvestigation of the Dynamic Tidal Power Dams and their Influences on Hydrodynamic Environment

Dong Shao¹⁺, Weibing Feng¹, Xi Feng¹ and Yinfeng Xu²

¹ College of Harbor Coastal and Offshore Engineering, Hohai University, Nanjing, 210098, China
² Nanjing Hydraulic Research Institute, Nanjing 210029, China

shao20130905@163.com

Abstract. Dynamic tidal power (DTP) system is known as an efficient method to exploit the tidal power. Large storage of tidal power in the Yellow Sea and the Bohai Sea along the Chinese coastline is revealed by previous studies. In the consideration of the local environment, combination of smaller DTP dams located at three attractive positions in this area is investigated. Their efficiency is compared with that of larger DTP dams working singly. The influences of the triple smaller dams are also discussed together with those of the single larger dams placed at the same locations.

1. Introduction
As a new form of exploitation of the tidal power, the dynamic tidal power system (DTP) becomes popular and interests many researchers of this domain. Different from other methods, for example, constructing a barrage across an estuary or the mouth of a bay to form a basin or installing submerged small devices (fixed or floating) in open water to extract kinetic power from the currents, the DTP may have less important ecological and environment impact and a good efficiency. The concept of dynamic tidal power exploitation was firstly introduced by Hulsbergen et al.¹, which consists of creating a long dam-like structure perpendicular to the coastline. The DTP dam would interfere with local tidal dynamics and lead to water level differences on both sides of the dam providing considerable water head over the dam. It is known from the early work of the researchers like Hulsbergen et al.¹ and Adema and Hartsuiker ² that the DTP dams may be located where the form of the coastline is prominent in order to obtain a good efficiency. For the sites of the DTP dams along Chinese coastline, the ideal ones include the those in the Yellow sea, the Taiwan Strait and Qiongzhou Strait. In the area of the Yellow sea, the capes of Liaoning Peninsula and Shandong Peninsula together with the prominent part of northern Jiangsu coast present the locations which store relatively large DTP potential.
However, although the DTP dams are not barrages which form a basin with the coastline, they are nevertheless very huge structures and furthermore, in the pursuit of larger water head, they may extend very far into the open sea. From the DTP investigations of the Yellow sea, it can be seen that sometimes a large DTP dam at the cape of Liaoning Peninsula or Shandong Peninsula may occupy one third or even half the opening of the Bohai Bay, which may cause extreme changes of the local hydrodynamic conditions within the Bohai Bay and furthermore the ecological and environmental system there. As an alternative solution, smaller structures may be placed at the locations with large dynamic tidal potential instead of very large ones. The stem of the T-form DTP dams may be reduced to make it occupy less space and the bar of the T-form dams may be removed since its construction can become very difficult and costly in relatively deep water (as the position of the bar is far from the coast). Although this solution with smaller dams may render each dam a lower efficiency (a smaller difference of water level on both sides of the dam comparing with a larger T-form dam), this disadvantage may be compensated by a combination of several small dams with less impact on the local environment system than a huge dam.

In this study, combinations of small DTP dams located at three attractive positions (triple small DTP dams) in the Yellow Sea and the Bohai Sea (A: the prominent part of northern Jiangsu coast, B: the cape of Shandong Peninsula and C: the cape of Liaoning Peninsula) are investigated. Their efficiency is compared with single larger T-form dams placed at the same position. As for sure that smaller dams may have less impact on the area close to them than larger ones, in this study, more attention will be paid to the influences on the hydrodynamic environment at a certain distance from the dams within the area of Yellow Sea and Bohai Sea.

2. Numerical model
As the water depth of the Yellow sea and Bohai sea is small comparing with the horizontal scale in this study, a two dimensional tidal model ADCIRC[3][4] is applied. The governing equations include the primitive continuity equation

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial VH}{\partial y} = 0$$

(1)

the primitive momentum equation

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - jV = -g \frac{\partial}{\partial x} \left[ \frac{P}{\rho_0} \zeta - \alpha \eta \right] + \tau_{s,usta} + \tau_{s,swave} - \tau_{in} + \frac{M_y}{H} \frac{M_x - D_x}{H}$$

(2)

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + jU = -g \frac{\partial}{\partial y} \left[ \frac{P}{\rho_0} \zeta - \alpha \eta \right] + \tau_{s,usta} + \tau_{s,swave} - \tau_{in} + \frac{M_y}{H} \frac{M_x - D_x}{H}$$

(3)

with $\zeta$ the free surface departure from the geoid, $H$, the total water depth, $h$ the average sea level from the bottom. $U, V$ indicate the average velocities in the horizontal plane. $j = 2\Omega \sin \phi$ is the Coriolis parameter with $\Omega = 7.29212 \times 10^{-5} \text{ rad/s}$. $P$ represents the atmospheric pressure at the sea surface. $\eta$ is the Newtonian tidal potential. $\tau_{in}, \tau_{in}$ are the bottom stress components and $\tau_{s,usta}, \tau_{s,swave}$ denote the surface stress components imposed by
the winds and the waves respectively. $M_x, M_y$ are lateral stress gradients and $D_x, D_y$ represent the baroclinic pressure gradients in the x and y direction.

The investigation area is a little larger than that of Hulsbergen et al.[1] for the Yellow Sea. The land boundary is controlled by the wetting and drying parameters while the ocean boundary is defined by the tidal components. Thirteen short-period constituents were applied to define the open boundary including the principal lunar, principal solar, lunar solar, elliptical solar, elliptical lunar constituents and they were derived from the satellite altimeter data (Matsumoto et al.[5]) and the application of the components to the numerical simulation is feasible. The numerical model established was validated with the tidal data records from three stations on the Chinese coastline of the Yellow Sea. The simulation period was from the 25th Oct. 2015 to the 30th Oct. 2015. Following the results of the research of Hulsbergen et al.[1], for the single large DTP dams located at the three positions indicated below, the length of the stem of the T-form DTP dams is fixed at 50km and the length of the bar is 0.75 times that of the stem. As the efficiency may decrease much more than linearly when the dams become shorter, for the triple small DTP dams, the length of their stem is chosen to be 25km, half that of the large dams, with a bar always 0.75 times that of the stem, so that the total efficiency of the triple small DTP dams may reach that of a single large dam. The positions of the DTP dams and the water level recording locations on both sides of the dams are shown in figure 1.

![Figure 1](image_url)

**Figure 1.** Investigation area and positions of the three single large DTP dams A, B and C and the triple small dams D, E and F with the water level recording locations (1 and 2) on both sides of the dams (The observation points of the hydrodynamic environment are marked by small circle P1, P2, P3 and P4 in (b))

3. Results and discussion
Similar to the research of Hulsbergen et al.[1], the working efficiency of the DTP dams (predominantly the water level difference across the dams) is examined with the numerical model described in the previous section, including those of the three single large dams and that

\[\text{equation}\]
of the three small dams working in triple. The water levels at the observation locations on the
two sides of the DTP dams are shown in figure 2 and figure 3 for each dam which give the water
level differences at every moment. It can be observed that the water level differences at DTP
dam A, B and C may reach 2.02m, 1.69m and 1.43m respectively. The water level differences for
the three small dams working in triple are obviously smaller than those of the larger ones as their
sizes are reduced. The efficiencies of the small dams at the prominent part of northern Jiangsu
coast (D) and the cape of Shandong Peninsula (E) are slightly better than half of their larger
counterparts and that of the small dams F at the cape of Liaoning Peninsula decreased more
grievously (only one third of its counterpart). The triple small dams may have a total efficiency
equivalent to that of a single large one and even slightly better. In fact, a good efficiency may be
achieved conveniently by triple or even double small dams. The water level differences are listed
in table 1.

| Table 1. Water level differences of the large DTP dams and the triple small DTP dams |
|-----------------------------------------------|---------------|---------------|
| Single DTP dams                               | Δh\(_{\text{max}}\) (m) for each dam | Total Δh\(_{\text{max}}\) (m) |
| large DTP A                                   | 2.02          | 2.02          |
| large DTP B                                   | 1.72          | 1.72          |
| large DTP C                                   | 1.5           | 1.5           |
| Small DTP D                                   | 1.17          |               |
| Small DTP E                                   | 0.92          | 2.75          |
| Small DTP F                                   | 0.65          |               |

As it is obvious that smaller DTP dams make less interference on the hydrodynamic
environment within the area very close to them than larger ones, attention may be paid to the
area relatively farther form the positions of the DTP dams to compare the impacts of single
larger dam and triple small dams. Four points P1, P2, P3 and P4 are chosen for observation in
both the Yellow Sea and the Bohai Sea as shown in figure 1. The water levels simulated at these
points in different cases (with large dam A, B or C or with triple small dams D, E and F) are
compared with those simulated without any DTP dams presented in the investigation area in
figure 4.

It is revealed that the single large dams A and B may interfere very little with the area at a
certain distance from them (the area relatively far from them) as they situate in relatively open
water, especially the single large dam A at the prominent part of northern Jiangsu coast. However,
it can be seen that the impact of the single large DTP dam C at the cape of Liaoning Peninsula is
very important for the observation points within the Bohai Sea since it occupies a certain space
right at the opening of the Bohai Sea (nearly one third of the width of the opening) and disturbs
the movements of the inward and outward currents. For the small dams, as they work in triple, it
is reasonable that they have slightly stronger influence on the farther hydrodynamic environment
than a single large dam in relatively open water like the DTP dam A and B, but their impact is to
some extent limited and much less important than that of DTP dam C.
Figure 2. Water levels and their differences for each small DTP dams D, E and F working in triple

Figure 3. Water levels and their differences for each single large DTP dams A, B and C
Figure 4. Comparison of the impacts of different DTP dams (with large dam A, B or C, with triple small dams D, E and F and without DTP dam)
4. Conclusion
The numerical investigation of the dynamic tidal power systems in the Yellow Sea and the Bohai Sea along the Chinese coastline for single larger DTP dams and triple smaller DTP dams reveal that combination of two or three small dams (half the size of a regular one) may reach or even exceed conveniently the efficiency of a single larger one working alone. While the small dams may not interfere very strongly with the area close to them, triple small dams have not much more impact on the hydrodynamic environment than one larger dam neither. For the larger DTP dams in the investigation area of this study, the dam at the cape of Liaoning Peninsula influences strongly the hydrodynamic environment within the Bohai Sea whereas the two others have very little impact.

5. Acknowledgement
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6. References
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