Influences of Sea Level Rise to the Once-in-many-year Water Level of Inshore Area of China

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Abstract —**The sea level rise has great effects on the security of coastal projects. The definition of check water level has always played an important role in coastal constructions. Under the circumstance of sea level arising, as time passes, the security of high check water level will descend eventually. This paper demonstrates that the sea level of inshore area of China has a tendency of ascending in general drawn from monthly average sea level data of 25 stations, with an average rate of ascending of 1.24mm/a. In the condition of sea level arising, the change of return period corresponding to high check water level with time is also studied using the method of the Gumbel distribution law. For the 21 stations in which the sea level arises, the once-in-50-year water level will decay to once-in-15.4-year one after 50 years while the once-in-100-year water level will decay to once-in-30.5-year one on average.**

Keywords: check water level, coastal projects, sea [1]level rise, return period

INTRODUTION

In recent years, the warming of climate, the melting of glacier and the sea level rise cannot be neglected to the work and life of people. In the 20th century, the average annual rate of global sea level rise was about 1.7±0.5mm/a（IPCC, 2007）, with a trend of accelerating. Juncheng Zuo etc.(1996) indicated that the yearly average rate of the sea level rise of China coast, under balanced datum, is 2.4mm/a. Weiqiang Wang (1999)indicated that the rate of the relative sea level rise of the entrance of Yangtze river nearby is between 4-7mm/a.

As for the inshore of China, the sea level will change in a magnitude of 10 centimeters in 50 years, and about 20 centimeters in 100 years. As for the check water level of which the return period is 50 years, the sea level getting up to 10 centimeters means the security of it is reduced, resulting in the fact that the return period is below 50 years.

The Ministry of Communications issued Port Engineering Standard in 1987，and on this basis, revised and issued Harbor Hydrology Specification in 1998. Curve law of Gumbel is also named the first type of extremism distribution law. Harbor Hydrology Specification prescribes clearly, that the first type of extremism distribution law is adopted to calculate high and low tides of different return period.

Man before has considered the influence of the change of sea level to the calculation of check water level, comparing the differences between check water level by considering the change of sea level or not. Yifa Yu（2003）discussed the influence of the change of sea level to the calculating of design and multiple maximum water level, and adopted the conditional distribution associated probabilistic method to analyze design and check water

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level, Yunhui Ding (2005) adopted the conditional associated probabilistic method to analyze design and check water level, considering that whether related to astronomical tides and stormy tides, in the two cases, the biggest difference of the check water level is above 30 cm. He also demonstrated the great influence of the seasonal change of water level to design water level, and obtained the conclusion that the station with the greatest impact is Lvsi. The difference between the two methods is 22cm, and at the same time, the influence of the long-term change of sea level can reach above 80cm at specific station.

This paper uses the change of the return period of coastal engineering check water level with time to measure the security of coastal projects of China inshore area (the extremism water level which can be resisted), focusing on analyzing, on the condition of the sea level rise, the changes of the return period of once-in-50-year check water level or once-in-100-year one as time passes.

distribution

Data and Methods

A. The distribution of stations and introduction of data

The location of the 25 stations chosen in this paper, which is basically evenly distributed along the coast of China, with more reliable data of tide gauge stations, is typical.

The data of every tide gauge station used in this paper is monthly average sea surface height, with a data length of more than 20 years, and the annual highest value is regarded as the annual maximum water level. Although the extremism water level derived from monthly average sea level material is less than the actual extremism water level in this year, as an approximation, it is effective to use extremism water level derived from monthly average sea level material to analyze once-in-many-year water level.

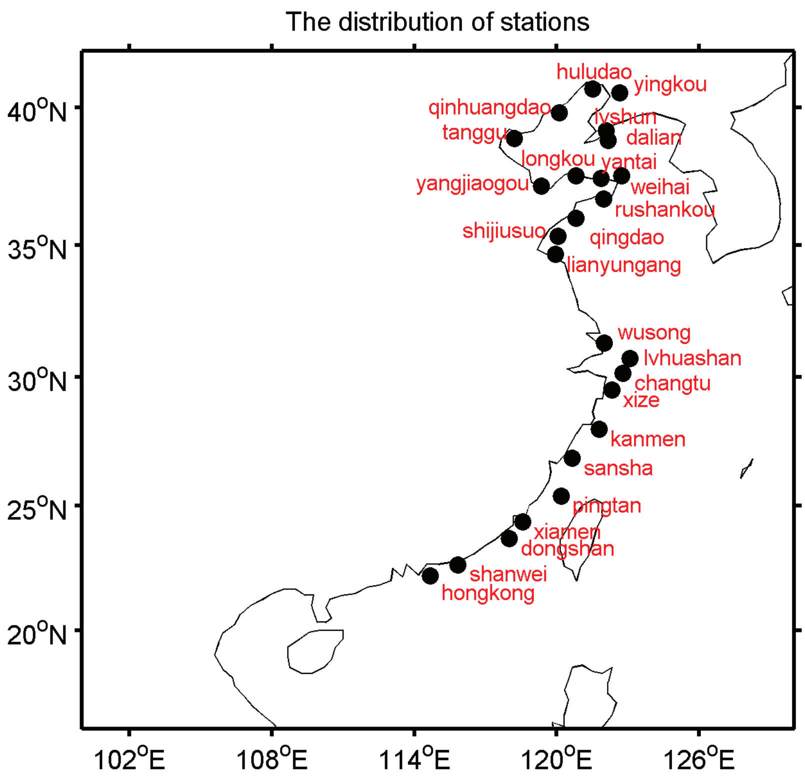

Figure 1. The distribution of the chosen stations

The table below contains the data period of chosen stations and the number of years.

B. Introduction of the first type of extremism distribution law

In coastal project design, high (low) check water level is often calculated by the first type of extremism distribution law using the practical water level material of more than 20 years in sequence.

If the value of highest water level is h_i for n consecutive years, the water level relative to the frequency of the year p is:

$$h_r = \overline{h} + \lambda_{rn} \times S \qquad (1)$$

In the formula, h_r is the value of the high tide level corresponding to the frequency of year r, and $\overline{h}$ is the average value of the extremism water level h_i of the n years. λ_{rn} is the coefficient relative to the frequency of the year p and the number of year r. S is the variance of the extremism water level hi of n years.

The occurring frequency of practical water level can be calculated from observing extremism water level. The detailed procedure is as follows: array h_i by descending firstly, and then the frequency p relative to the m*th* extremism water level h_m is:

$$P = 100\% \times \frac{m}{n+1} \qquad (2)$$

The return period Tr relative to theoretic frequency of year p% is:

$$T_r = \frac{100}{P} \qquad (3)$$

Mapping observing extremism water level and the occurring frequency of practical water level, as well as the theoretical value drawn from the first type of extremism distribution law in the same figure, taking Changtu Station for example (see figure2).Analyzing the practical data of every tide gauge station using the first type of extremism distribution law, high tide level of different return periods can be obtained, and quite agrees with the experienced frequency curve of the practical tide level. As a result, using the annual extremism of monthly average sea surface height to calculate return period is quite reliable.

Calculating the extremism water level of specific frequency by the Gumbel distribution law, as the red star points shown in the figure below, then using the spline interpolation to smooth, extremism water level relative to any frequency point can be obtained (as blue lines shown in the following figure).

TABLE 1. THE DATA PERIOD OF CHOSEN STATIONS AND DATA LENGTH (UNIT： YEAR)

Station	**Yingkou**	**Yangjiaogou**	**Yantai**	**Hong Kong**	**Xiamen**	**Xize**	**Lvhuashan**
Data Period	1953~1990	1972~1995	1954~1995	1957~1985	1960~1987	1960~1992	1958~1982
Data Length	38	24	42	29	28	33	25
Station	Weihai	Tanggu	Shijiusuo	Shanwei	Sansha	Rushankou	Huludao
Data Period	1957~1992	1950~1995	1968~1995	1971~1995	1966~1995	1960~1985	1956~1995
Data Length	36	46	28	25	30	26	40
Station	Qinhuangdao	Pingtan	Lvshun	Longkou	Lianyungang	Kanmen	Wusong
Data Period	1950~1995	1967~1995	1956~1992	1961~1995	1952~1995	1959~1995	1952~1994
Data Length	46	29	37	35	44	37	43
Station	Dongshan	Dalian	Changtu	Qingdao			
Data Period	1965~1995	1953~1995	1960~1995	1952~1995			

Data Length	31	43	36	44

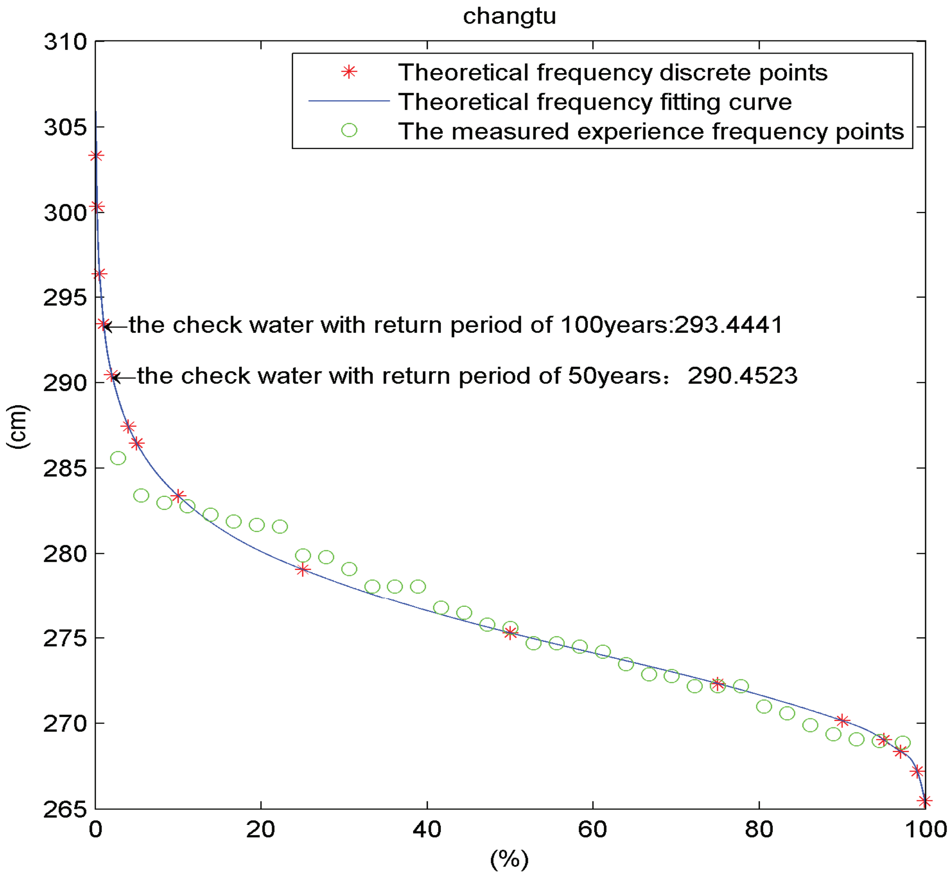

Figure 2. Theoretical frequency curve and the measured experienced frequency points of Station Changtu

At the background of the change of the average sea level (supposing the rate of annual sea level rise is a cm/year), after n years, sea level will be n×a cm higher than now, so after n years, the height of the project above sea level, according to the current standard that does not consider the change of sea level, will become h-n×a, less than h, because of the sea level arising. That means, as the average sea level arises, the ability of the project's resisting extremism water level will become worse and worse. After several years, the actual ability of resist is less than the initially designed for once in n years.

ANALYSIS AND DISCUSSION

1. The rate of the linear rise of sea level of every station

By using linear fittings for monthly average sea level data, we can obtain the rate of the Linear rise of sea level shown in the table below.

Among the 25 chosen stations, the rate of rise of 4 stations is less than 0, which means the sea level is descending. While the rate of rise of 21 stations is positive, and Lvshun station has the greatest rate of rise, up to 0.558cm per year, which is a fairly high speed and affects the check water level dramatically. The average rate of rise of the 25 stations is 0.124cm/a. The average rate of rise of the 21 stations mentioned above (with positive rate of rise) is

0.180 cm/a. In general, the sea level of inshore in China is ascending.

Table 2 The rate of the linear rise of sea level of every tide gauge station（unit：cm/a）

Station	Changtu	Dalian	Dongshan	Huludao	Kanmen	Lianyungang	Longkou
The rate of linear rise	0.254	0.162	0.160	0.084	0.188	-0.164	0.073
Station	Lvshun	Lvhuashan	Pingtan	Qinhuangdao	Qingdao	Rushankou	Sansha
The rate of linear rise	0.558	0.406	0.129	-0.212	0.011	-0.163	0.055
Station	Shanwei	Shijiusuo	Tanggu	Weihai	Wusong	Xize	Xiamen
The rate of linear rise	0.135	0.069	0.235	-0.155	0.276	0.122	0.166
Station	Hong Kong	Yantai	Yangjiaogou	Yingkou			
The rate of linear rise	0.185	0.028	0.301	0.192			

2. *The return period of every station relative to once-in-50-year or once-in-100-year water level height as time passes*

Using the check water level calculated by the Gumbel distribution law minus linear rate of rise of the local sea level multiplying the number of years, after getting appointed number of years, according to the height of the coastal project above average sea level supposed on the basis of current check water level, the return period corresponding to the height can be found in the corresponding theoretical frequency curve.

Following this method, this paper demonstrates the changes of the return period relative to once-in-50-year and once-in-100-year water level as time passes for the 21 stations in which the sea level is arising.

1) The return period of stations corresponding to once-in-50-year water level as time passes

Table 3 is showing the detail of the change of the return period of every station relative to the once-in-50-year check water level as time passes. The return period of the two stations, Lvshun and Lvhuashan, of which the rate of rise is bigger, decay much faster. After 50 years, only once-in-1-year extremism water level can be resisted. After 50 years, the average return period of the 21 stations will decay to 15.4 years. Even if Lvshun and Lvhuashan stations are eliminated, the data of other 19 stations will still decay to 16.9 years.

2) The return period of stations corresponding to once-in-100-year water level as time passes

Table 4 is the detail of the change of the return period of every station relative to once-in-100-year extremism water level as time passes. Similar to table 3, after 50 years, the average return period of the 21 stations will decay to 30.5 years. Even if Lvshun and Lvhuashan stations are eliminated, the average return period of other 19 stations will still decay to 33.6 years.

TABLE 3. THE RETURN PERIOD OF EVERY STATION CORRESPONDING TO NEARLY ONCE-IN-50-YEAR WATER LEVEL AS TIME PASSES（UNIT：YEAR）

	After 10 years	After 20 years	After 30 years	After 40 years	After 50 years
Changtu	27.8	15.7	8.9	5.2	3.1
Dalian	34.9	24.8	17.6	12.5	8.9
dongshan	39.2	31.2	24.9	19.8	15.8
Huludao	38.6	30.2	23.7	18.5	14.5
Kanmen	31.6	20.2	13	8.4	5.5
Longkou	41.9	35.4	30.1	25.6	21.7
Lvshun	18.2	6.9	2.8	1.4	1
Lvhuashan	17.4	6.4	2.5	1.3	1
Pingtan	40.9	33.9	28.1	23.3	19.3
Qingdao	48.4	46.9	45.4	44	42.7
Sansha	43.7	38.4	33.9	29.9	26.5
Shanwei	40.6	33.3	27.4	22.5	18.5
Shijiusuo	42.5	36.4	31.3	26.9	23.1
Tanggu	33.8	23.3	16	11	7.6
Wusong	33.2	22.5	15.2	10.3	7.1
Xize	38.1	29.5	22.8	17.6	13.7
Xiamen	39.3	31.3	25	19.8	15.8
Hong Kong	36.1	26.4	19.3	14.2	10.4

Yantai	48.1	46.3	44.6	42.9	41.4
Yangjiagou	41.5	34.8	29.2	24.6	20.6
Yingkou	31.8	20.6	13.3	8.7	5.8
Average	36.6	28.3	22.6	18.5	15.4

TABLE 4. THE RETURN PERIOD OF EVERY STATION CORRESPONDING TO NEARLY ONCE-IN-100-YEAR WATER LEVEL AS TIME PASSES（UNIT：YEAR）

	After 10 years	**After 30 years**	**After 50 years**	**After 70 Years**	**After 100 years**
Changtu	56.1	17.4	5.7	2.1	1
Dalian	71.7	34.6	17.4	8.8	3.4
Dongshan	80.4	49.5	30.9	19.6	9.9
Huludao	79.1	46.9	28.5	17.5	8.5
Kanmen	64.5	25.5	10.5	4.5	1.6
Longkou	85.5	61.2	42.7	30.6	18.7
Lvshun	35.8	5.1	1.2	0	0
Lvhuashan	34.3	4.5	1.1	0	0
Pingtan	83.7	56.8	38	26.2	14.9
Qingdao	97.3	92	86.9	82.1	75.3
Sansha	88.9	69.5	53.1	40.6	27.9
Shanwei	83	55.1	36.3	24.6	13.7
Shijiusuo	86.6	63.9	45.8	33.6	21.3
Tanggu	69.3	31.3	14.8	7.1	2.6
Wusong	68.2	29.8	13.6	6.4	2.3
Xize	78.2	45	26.8	16	7.5
Xiamen	80.5	49.7	31.1	19.7	10
Hong Kong	74	38.1	20.4	11	4.5
Yantai	96.7	90.5	84.6	79	71
Yangjiagou	84.7	59.3	40.6	28.6	17
Yingkou	65.1	26.2	10.9	4.8	1.7
Average	74.5	45.3	30.5	22.0	14.9

CONCLUSIONS

1. The sea level of inshore area in China has a tendency of ascending in general, and the average rate of rise is 1.24mm/year.

2. The rise of the inshore sea level will reduce the security of coastal project dramatically. For example, the once-in-50-year water level will reduce to once-in-15.4-year one after 50 years; the once-in-100-year water level will reduce to once-in-30.5-year one on average.

New coastal projects should be adapted to the situation of the sea level rise in inshore area of China, based on original standards, and increase the water level standards appropriately, for example, using once-in-100-year water level as the check water level, instead of once-in-50-year water level as check water level.

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