Design Code Calibration of Offshore, Coastal and Hydraulic Energy Development Infrastructures

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Abstract—With an increasing tendency of the natural hazards frequency and intensity, risk analysis of some design codes for offshore oil, nuclear power plant and hydro energy development infrastructures should be of paramount importance for about half of the population gross domestic product and environmental protection in China. Comparisons between some disaster prevention criteria for offshore platform, coastal defense for nuclear power plant and the Three Gorges Dam Project (TGDP) by widely used traditional design codes of China and abroad with predicted results by our proposed Multivariate Compound Extreme Value Distribution (MCEVD) show that any one of the American Petroleum Institute (API) recommendations for fixed platform , China Nuclear Safety Regulations for coastal nuclear power plant and China Hydraulic Design Codes (CHDC) cannot satisfy the safety requirements with the increasing tendency of the extreme natural hazards.

Keywords—Offshore platform; Coastal defense of nuclear power plant; Chinese Hydraulic Design Code; Multivariate Compound Extreme Value Distribution; Extreme natural hazards

1. Introduction

Assessment of the probable largest magnitude associated with global climate change is extremely important in disaster prevention and mitigation. In August 2005, Hurricane Katrina assaulted the Atlantic and the Gulf Coasts of the United States with a maximum wind speed of 175 mph, and caused deaths of about 1200 people. The total economic loss was about 80 billion dollars. Later, Hurricanes Rita and Wilma made landfall in the United States and Mexico, causing losses of 9.4 billion and 14.4 billion US dollars, respectively. Katrina and Rita resulted in the largest number of destroyed and damaged platforms in the history of Gulf of Mexico (GOM) operations. There are a total of 116 destroyed fixed platforms from Katrina and Rita and one floating platform [6]. There were many platforms with reported wave in deck (WID) damage, attributed to the crest of the large hurricane wave hitting the platform decks and causing major damage. Previous study of hurricanes Andrew, Lili and Ivan all reported destruction and major damage due to WID [5]. The catastrophic failures and damage of platforms in GOM region show the deficiencies of API recommendations.

In 2006, typhoon disasters were especially serious in China. Five of the most severe typhoon disasters brought about 1600 deaths and disappearances, and affected 66.6 million people. The economic loss reached 80 billion RMB and influenced agriculture areas totaling more than 2800 thousand hectares. Among these disasters, typhoon Saomai induced 3.76m surges and 7m waves, causing 240 deaths, sinking 952 ships and damaging 1594 others in Shacheng harbor. If the typhoon Saomai had landed 2 hours later, then the simultaneous occurrence of the typhoon surge and high spring tide would have inundation most areas of the Zhejiang and Fujian provinces. The results would be several times more severe than the disaster induced by hurricane Katrina in New Orleans. The hurricane disaster prevention criteria along GOM and US Atlantic coasts were based on the American National Oceanic and Atmospheric Administration (NOAA) proposed Standard Project Hurricane (SPH) and Probable Maximum Hurricane (PMH), but some predicted hurricane characteristics (central pressure，wind, surge) for Florida's East and West regions are more severe than NOAA proposed criteria [4,21,24,27]，the unreasonable design criteria become main reason of 2005 hurricane catastrophe. Similar definitions in China Nuclear Safety Regulations (HAF0100) proposes the use of a probable maximum storm surge (PMSS) induced by a probable maximum tropical cyclone (PMTC) coupled with wind wave setup and a spring tide. However, although this is recommended, in actual practice, the probability of joint occurrence of typhoon induced storm surge, wave setup, and spring tide are not taken into account. Such kind recommendations consist of different uncertainties, which may be led to all the coastal areas having NPP menaced by possibility of future typhoon disasters.

For some large-scale hydro energy development projects, such as the Three Gorges Dam Project (TGP) of Yangtze River there is a paramount significance to predict design flood accurately. According to the CHDC, the design flood volume must be predicted by Pearson Type 3 distribution model to extrapolate 100-year return

period of flood volume using annual maxima data sampling method based on observations, although some projects in China have shown the method did not provide sufficient security. For instance, in August 1975 the severe rainstorm in Huai River drainage induced a collapse of 64 reservoir dams, including a large reservoir in Banqiao with a maximum volume of 4.92 billion m3. The flooding resulted in more than 26,000 deaths. Based on incomplete data, among the 235 collapsed reservoir dams in China since 1991, about 147 dams were caused by floods over the100-year return period design values extrapolated by Pearson Type 3 model.

As mentioned above deficiency an important wish in the paper "Summary of flood frequency analysis in the United States"—"the combination of the event-based and joint probability approaches promises to yield significantly improved descriptions of the probability laws of extraordinary floods"[18]. MCEVD is one of the models which just accord with the development direction of the extraordinary floods prediction.

2. Theory of Multivariate Compound Extreme Value Distribution (MCEVD)

In 1972, Typhoon Rita attacked Dalian port in the North Bohai Bay of China, causing severe damage in this port. The authors found that, using traditional extrapolation (such as a Pearson type III model), it was difficult to determine the design return period for the extreme wave height induced by a typhoon. According to the randomness of annual typhoon occurrence frequency along different sea areas, it can be considered as a discrete random variable. Typhoon characteristics or typhoon-induced extreme sea events are continuous random variables. The Compound Extreme Value Distribution (CEVD) can then be derived by compounding a discrete distribution and the extreme distribution for typhoon-induced extreme events along China's coasts[26]. Then the CEVD is used to analyze long-term characteristics of hurricanes along the Gulf of Mexico and the Atlantic US coasts[27]. During the past few years, CEVD has been developed into MCEVD and applied to predict and prevent typhoon induced disasters for coastal areas, offshore structures, and estuarine cities [17,19,20,25]. Both CEVD and MCEVD have the following advantages: instead of traditional annual maximum data sampling, the typhoon process maximum

data sampling is used; and the typhoon frequency is used in the models.

The derivation of MCEVD has been introduced in the authors' previous papers [22,24]. The expression of MCEVD can be described by Equation (1):

$$P(\lambda; x_1, x_2, \ldots x_n) =$$
$$e^{-\lambda}\left(1 + \iint_\Omega \cdots \int e^{\lambda F(x)} f(x_1, x_2, \ldots x_n) dx_1 dx_2 \cdots dx_n\right) \quad (1)$$

in which, λ is mean value of the annual typhoon frequency; Ω is joint probability domain; $f(\cdot), F(\cdot)$ are probability density function and cumulative function; $x_1, x_2, \ldots x_n$ are random variables such as typhoon characteristics : ΔP，R_{max}，s, δ, θ and t. where $r_{i,j}$ is the correlation coefficient for i\j and i,j = 1, 2, 3.

When the dimension n $\leq$3, Eq.(1) can be solved by analytical method. For discussion on joint return period of storm surge, wave height with corresponding spring tide, the Poisson Nested Logistic Trivariate Compound Extreme value Distribution (PNLTCED) can be used for analytical solution [21,24]. When n$>$3, finding theory solution will become unpractical, the Stochastic Simulation Method (SSM) should be used to solve MCEVD [31].

When the trivariate nested logistic model [35] can be involved into formula (1), then Poisson Nested Logistic Trivariate Compound Extreme Value Distribution (PNLTVEVD) can be derived as a practically useful model of MCEVD.

The PNLTCED can be obtained from formula (1):

$$F_0(x_1, x_2, x_3) = e^{-\lambda}(1 + \lambda \int_{-\infty}^{x_3} \int_{-\infty}^{x_2} \int_{-\infty}^{x_1} e^{\lambda F(u_1)} f(u_1, u_2, u_3) du_1 du_2 du_3 \quad (2)$$

In which, the cumulative distribution function of trivariate nested logistic model is expressed as:

$$F(x_1, x_2, x_3) =$$
$$\exp\left\{-\left[\left[\left(1 + \xi_1\frac{x_1 - \mu_1}{\sigma_1}\right)^{\frac{-1}{\alpha\beta\xi_1}} + \left(1 + \xi_2\frac{x_2 - \mu_2}{\sigma_2}\right)^{\frac{-1}{\alpha\beta\xi_2}}\right]^\beta + \left(1 + \xi_3\frac{x_3 - \mu_3}{\sigma_3}\right)^{\frac{-1}{\alpha\xi_3}}\right]^\alpha\right\} \quad (3)$$

$$f(x_1, x_2, x_3) = \frac{\partial^3 F(x_1, x_2, x_3)}{\partial x_1 \partial x_2 \partial x_3} \quad (4)$$

in which ξ_j, μ_j, σ_j are the shape, location and

scale parameters of marginal distributions $F(x_j)$ to x_j （j=1,2,3）, respectively. And dependent parameters α, β can be obtained through moment estimation

$$\hat{\alpha} = \frac{\sqrt{1 - r_{13}} + \sqrt{1 - r_{23}}}{2} \qquad (5)$$

$$\hat{\beta} = \frac{\sqrt{1 - r_{12}}}{\hat{\alpha}}$$

where $r_{i,j}$ is correlation coefficient，i<j；i,j=1,2,3.

Trivariate layer structure （α- outside, β - inside layer） shows that the correlation between x_1 and x_2 is stronger than those among x_1, x_3 and x_2, x_3.

As shown above, PNLTCED can be obtained through estimation of parameters of marginal distributions and their dependent parameters.

Many application of MCEVD in engineering design and risk analysis show the scientific and reasonable of its predicted results in China and abroad [16,28,35]. As mentioned in "Summary of flood frequency analysis in the United States" [15]: "The combination of the event-based and joint probability approaches promises to yield significantly improved descriptions of the probability laws of extraordinary floods". MCEVD is the model which follows the development direction of the extraordinary floods prediction hoped for by Kirby and Moss. Since 2005 hurricane Katrina and Rita disasters proved accuracy of 1982 predicted hurricane characteristics and after disaster calculated results. It stands to reason that MCEVD is a practicable model for prediction of typhoon/hurricane/ tropical cyclone induced extreme events. Our proposed methods in [22,23,26,27]

are used as design criteria of wind-structure interaction experimentation for mitigating hurricane-induced coastal disasters [11].

3. Design code calibration of coastal defense against typhoon attacks from lesson hurricane Katrina disaster

In 1979, American National Oceanic and Atmospheric Administration (NOAA) divided Gulf of Mexico and Atlantic coasts into 7 areas according to hurricane intensity, in which corresponding Standard Project Hurricane (SPH) and Probable Maximum Hurricane (PMH) were proposed as hurricane disaster prevention criteria [37]. Using Compound Extreme Value Distribution (CEVD)[26], the predicted hurricane central pressures with return period of 50yr and 1000yr were close to SPH and PMH, respectively, except that for the sea area nearby New Orleans (Zone A) and East Florida (Zone1) coasts, hurricane intensities predicted using CEVD were obviously severer than NOAA proposed values[27]. SPH and PMH are only corresponding to CEVD predicted 30~40yr and 120yr return values, respectively. In 2005, hurricane Katrina and Rita attacked coastal area of the USA, which caused deaths of about 2000 people and economical loss of $400 billion in the city of New Orleans and destroyed more than 110 platforms in the Gulf of Mexico. The disaster certified that using SPH as flood-protective standard was a main reason of the catastrophic results [8, 9, 22,27]. Fig. 1, Tab.1 and Tab.2 indicate that both CEVD and MCEVD (see next part) predicted and hind-cast results are more reasonable than NOAA or other methods.
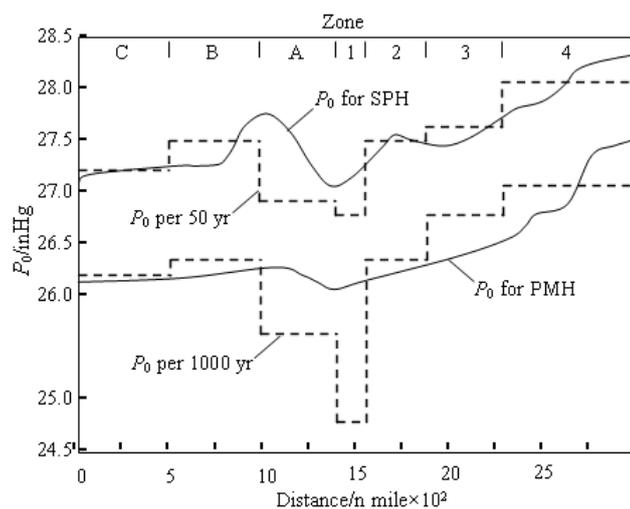
Fig.1 The comparison between the results of CEVD and SPH, PMH by NOAA [20]

Table 1 Comparison between NOAA and CEVD predicted hurricane center pressure

Zone		NOAA (hPa)		CEVD (hPa)		Hurricane (hPa)
A	SPH	941.0	50-yr	910.8	Katrina
	PMH	890.5	1000-yr	866.8	902.0
1	SPH	919.3	50-yr	904.0	Rita
	PMH	885.4	1000-yr	832.9	894.9

Table 2 Comparison between MCEVD and other methods predicted 100 yr wind velocity

Methods	MCEVD [17]	Coles et al. [5]	Casson & Coles[3]	Georgion et al [7]
100yr Wind speed (m/s)	70.6	46.0	38.0	39.0

According to safety regulations for NPP in China and IAEA [13,29]:

DBF (PMF) in coastal areas should be the combination of following parts: Spring tide; 100 years return period wave height: PMSS(Probable maximum storm surge) induced by PMT (PMH); DBF (PMF) should be taken as combinations of spring tide, PMSS and simultaneous 100 years return period wave height.

The above definitions in safety regulation of coastal defenses against typhoon attacks for NPP are influenced by many uncertainty factors such as the differences in comprehensions and calculation methods of them.

The spring tide, 100 years return period wave height and PMSS can be seen as non-Gaussian random variables with different correlation. The PMT and PMSS must involve the joint probability characters, and then DBF can be actually obtained by multivariate joint probability prediction. For example, the characteristics of PMT and PMSS in different sea area is related to annual occurring frequency of typhoon (λ), maximum central pressure difference (ΔP), radius of maximum wind speed (R_{max}), moving speed of typhoon center (s), minimum distance between typhoon center and target site (δ), typhoon moving angle (θ) and typhoon duration (t). It means that different PMT and PMSS can be derived from different combinations of typhoon characteristics. For this reason, the characteristics of PMT and PMSS inevitably involve a selection of discrete distribution (λ) and multivariate continuous distribution of other typhoon characteristic factors (ΔP, R_{max}, s, δ, θ, t), which can be described by Multivariate Compound Extreme Value Distribution (MCEVD)[23]. The calculation of PMT and PMSS by a numerical simulation method can remove the uncertainties of typhoon characteristics and may be led to different results, while the PMSS obtained on basis of them may has some arbitrary and cause wrong decision making. The lesson from 2005 hurricane Katrina showed that unreasonable calculation of the Probable Maximum Hurricane (PMH) and Standard Project Hurricane (SPH) is one of the most important reasons of New Orleans catastrophe [9,21,27].

According to HAD101[29], PMSS should be obtained based on PMT. So aiming at PMT with different combinations of typhoon characteristics, some sensitive factors should be selected as control factors and substituted into procedure of Global Uncertainty Analysis (GUA) and Global Sensitivity Analysis (GSA) (more details about GUA and GSA can be seen in [36]）. The PMSS corresponding to PMT of different sea areas can be derived by repeated forward-feedback calculations.

Based on MCEVD (analytical solution and stochastic simulation), DLNMPM can be established for long term probability prediction of typhoon characteristics and corresponding disaster factors [23].

The first layer of model is used for joint probability prediction of different combinations of typhoon characteristics (λ, Δp, R_{max},.....). In other words, in the first layer PMT with some joint return period can be calculated from different combinations of typhoon characteristics with joint return period. Based on the results of the first layer, different typhoon characteristics can be selected as the domination factors, the corresponding typhoon induced disaster factors can be taken as "objective function" and their joint probability will be calculated. For coastal defense of NPP, PMSS can be predicted in the second layer.

As shown in Fig.2, GUA and GSA are introduced into DLNMPM. In the model, typhoon characteristics in the first layer need to be varied repeatedly, and then their sensitivities to storm surge can be calculated. The PMSS corresponding to PMT of different typhoon characteristic combinations in certain sea area can be calculated by numerical simulation of repeated forward-feedback calculations of GUA, GSA in input-output procedure. The most sensitivity combination of typhoon characteristics and their induced storm surge can be selected as PMT and PMSS. PMSS with corresponding spring tide and 100 years return period wave height with joint return period calculated by MCEVD will be determined the probabilistic definition of DBF. .
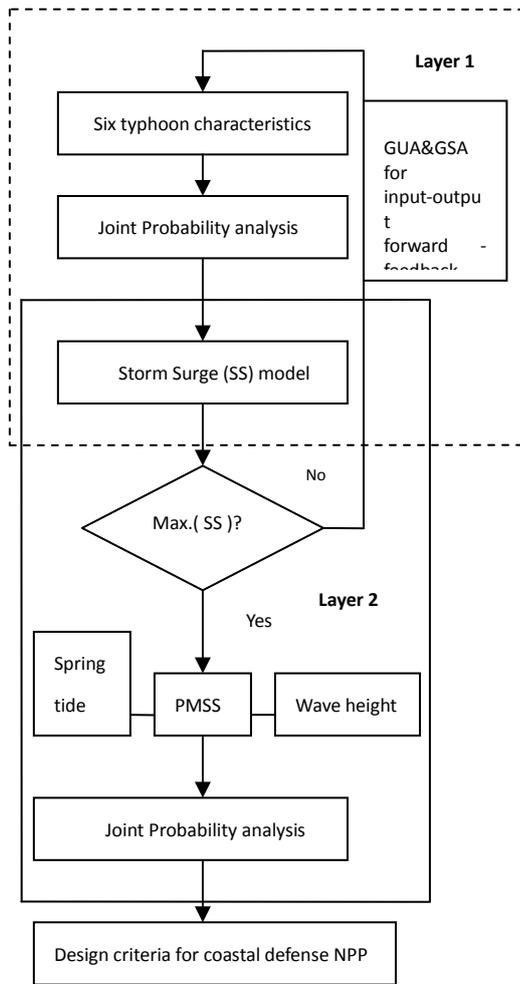
Fig. 2, Application of DLNMPM with GUA, GSA to defense code calibration for NPP

Table 3. Joint probability of typhoon induced storm surge, wave height and corresponding spring tide with confidence intervals

Return period variables (yr.)	100	500	1000
Storm surge (m)	2.79+0.51	3.49+0.71	3.85+0.80
Spring tide (m)	2.14+0.30	2.19+0.35	2.75+0.46
Wave height (m)	6.6+0.3	7.3+0.6	7.9+0.8

It can be seen from Table 3, that 500 years return values of storm surge, spring tide with confidence intervals (4.20+2.54=6.74m) and wave height (7.90m) should be more severe than HAF0111 proposed DBI (6.35m) with 100 years return period wave height (6.6m)[37,38]. Design code calibration shows that decision-making for all constructed and designed by China Nuclear Safety Regulations NPP along coastal areas in global climate change condition must be curb blindness in NPP design action.

4. Design code calibration of platform Deck elevation

In design of fixed platform, the topside structure should normally have adequate clearance above the design wave crest. Any topside structure of piping not having adequate clearance should be acted by waves and current. Loss of air gap and deck inundation has a large impact in reliability due to the following factors :

● Large increase in hydrodynamic loading.

● Large increase in the uncertainty associated with hydrodynamic loading.

● Potential increase in dynamic sensitivity.

In order to provide adequate clearance to resist these large forces and overturning moments by wave, API [2]gives some recommendations as follows: .

Omni-directional guideline wave heights with a nominal return period of 100 years, together with the applicable wave theories and wave steep-nesses, should be used to compute wave crest elevations above storm water level, including guideline storm tide. A safety margin, or air gap, of at least 5 feet should be added to the crest elevation to allow for platform settlement, water depth uncertainty, and for the possibility of extreme waves in order to determine the minimum acceptable elevation of the bottom beam of the lowest deck to avoid waves striking the deck.

There are many factors to affect the lowest deck height of the platforms. Tides, storm surges, and wave crest are the crucial ones. The predictions by different designer may differ greatly for without a clear definition of the 'applicable wave theories' in the API recommendations. Besides, API just offers the reference standards of guideline storm tide in American sea regions by the graphical interpretation; it hardly provides some referenced value for the platform design in other countries influenced by typhoons or hurricane.

The definition of water level and deck height was shown in Figure 3. The height of significant wave (Hs) is the average height of the highest one third of the waves

in the record and the crest height is the vertical distance from the top of the wave crest to the still-water. LAT is the lowest astronomical tide. Still water level is the average water surface elevation at any instant, excluding local variation due to waves and wave set-up, but including the effects of tides, storm surges and long period seiches. For other uncertain factor such as subsiding of platform and sea bed, the present author gives 1.5m obligate height in this study.

Therefore, Hs, storm surge and tide are taken as variables in PNLTCED for calculation of the deck height applied 33 typhoons in East China Sea and selects the significant wave height (Hs), concomitant surge and corresponding tide of each process as samples.

Typhoon occurring frequencies in China sea area are fits to Poisson distribution[26]. The diagnoses tests of the marginal distribution of Hs, surges and tides as shown in Figure 4, 5, 6. The sample points and the curves fit well.

Using PNLTCED, one contour surface about wave, surge and tide for certain joint return period can be obtained. Because tide has its certain law of motion, the periodical change is fluctuated by other factors such as geographical reasons. The astronomical tide height was taken as 2.45m (19 yrs return period) in this paper, and then we obtain the combination of Hs, surge and tide with 100-year return period (Fig. 7).

A traditional addition method, which defined the maximum level as the sum of MHWS (Mean High Water level Spring tide), 100-year storm surge and 100-year crest height, was used to compare with the prediction by MCEVD. The comparison and calculated results were shown in Table 6, where 1 and 2 in table 6 are two combinations with 100-year return period.

As the sea environments are constantly changing, the frequency and intensity of typhoon is gradually altering. It is very important to determine the ocean environmental design criteria in the design of platform.

Hurricane disasters in recent years show that some defense criteria by API were partly underestimated. Further more, there are some limitations in API application and promotion in other countries influenced by typhoon for its ambiguous definitions and specific standards. To solve this problem, the PNLTCED model is used to predict the deck elevation with different combination of tide, surge height and crest height in this paper. Because the PNLTCED model involves the distribution of typhoon or hurricane occurrence frequency and it induced extreme wave and surges, the joint probability method gives relatively less conservative criteria of simultaneous sea environments than other methods and it can give more reasonable design criteria by comparing with other methods.
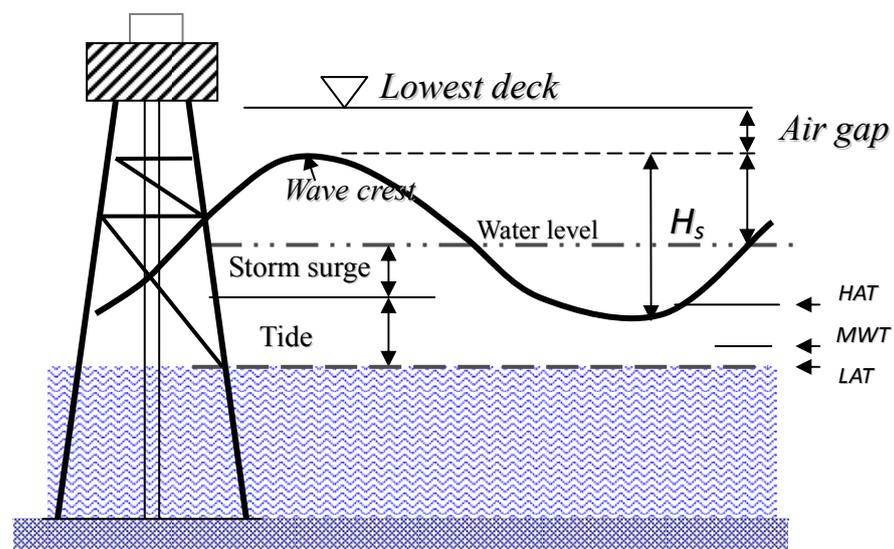

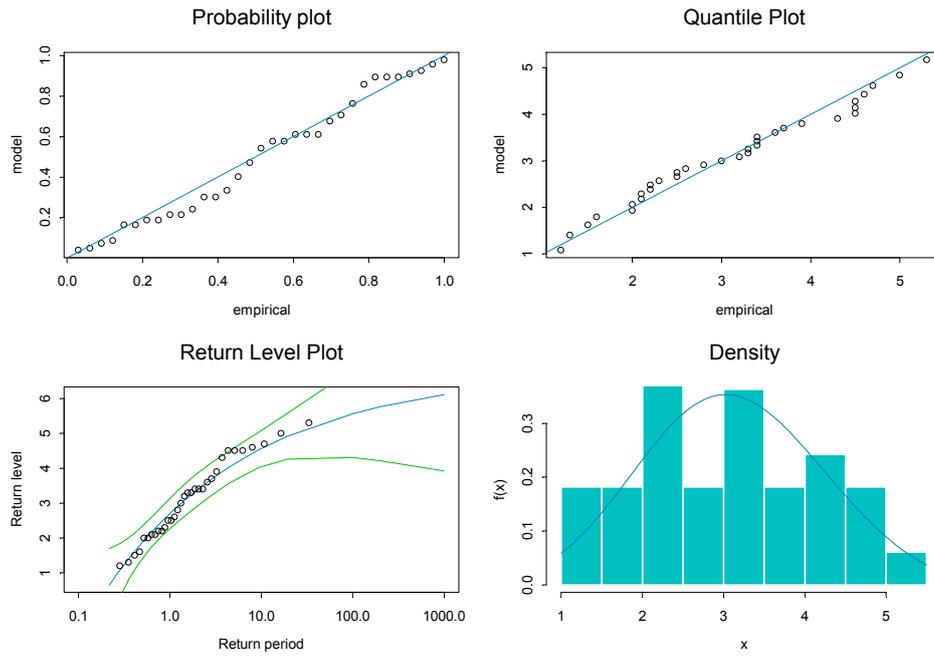Fig. 3 The definition of water levels and the lowest deck height

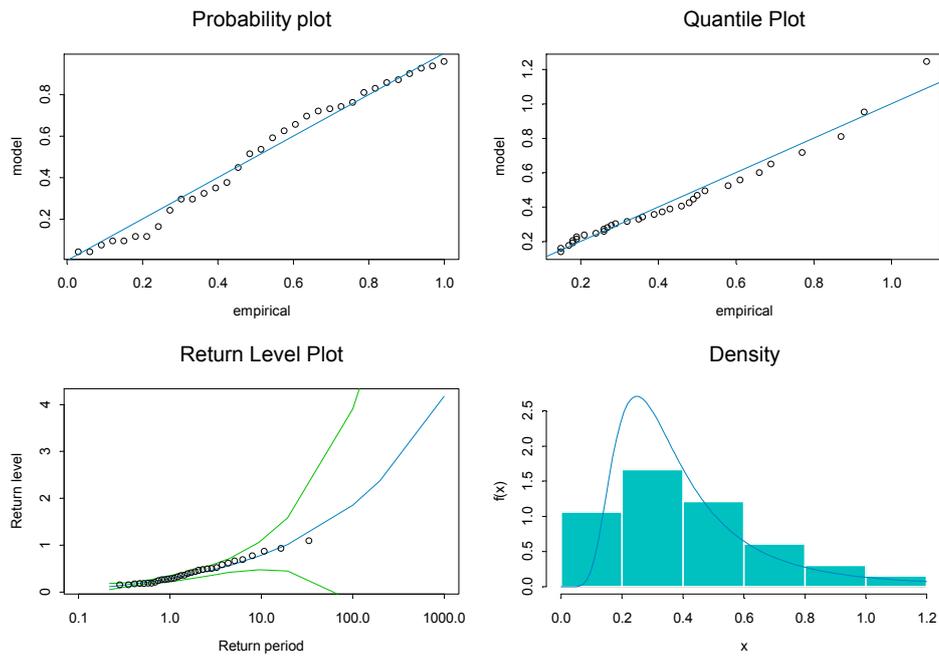Fig.4 Diagnostic checks of Hs

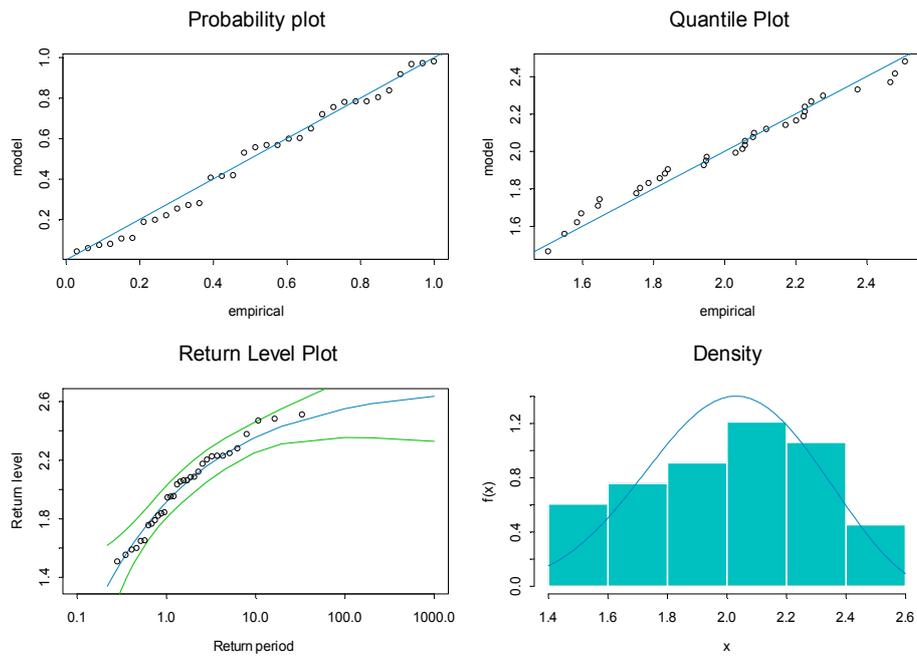Fig. 5 Diagnostic checks of surge
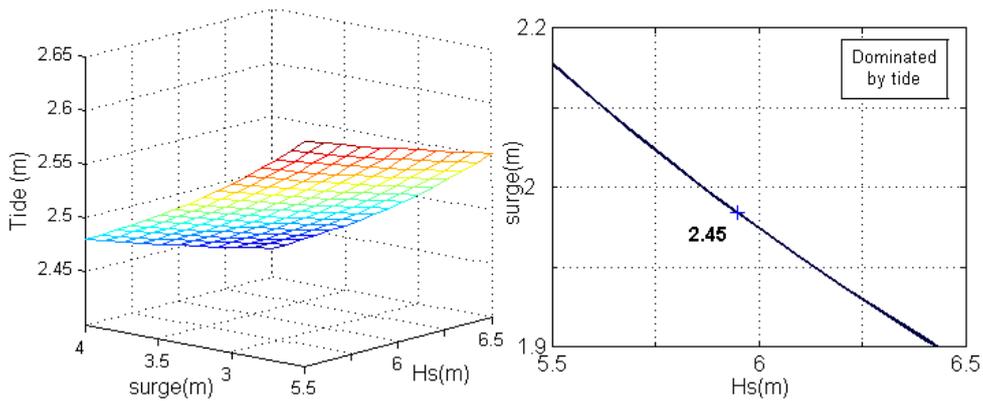
Fig. 6 Diagnostic checks of tide

Fig.7 The contour surface with 100-year joint return period and the combination

Table 4 Comparison of calculated results by traditional method and MCEVD method

Traditional method	Hs (m)		Crest height with 100 return period yrs (m)	Surge with 100 return period yrs (m)	Tide & Air gap(m)	Deck elevation above LAT(m)
	5.56		6.78	1.23		11.96
MCEVD method	Joint probability of 100-yera return period				2.45+1.5	
	Hs (m)		Crest height（m）	Surge (m)		
	1.	5.95	7.26	1.98		13.19
	2.	5.62	6.86	2.10		12.91

5. Application of MCEVD to design flood prediction of Three Gorges Dam Project (TGDP) in Yangtze river

For some large-scale hydraulic projects, such as the Three Gorges Dam Project (TGP) of Yangtze River , there is a paramount significance to predict design flood accurately.

The annual maximum series (AMS) and partial duration series (PDS) are two basic approaches in flood analysis. The AMS approach is based on annual flood series, which corresponds to fitting a distribution function to sampled values of maximum annual floods. Its most frequently used models are log-normal, Pearson Type III, Gumbel or Weibull and Generalized Extreme Value[30].

The AMS approach has been adopted by a large number of projects. According to the CHDC, the design flood volume must be predicted by Pearson Type 3 distribution model to extrapolate 100-year return period of flood volume using annual maxima data sampling method based on observations, although some projects in China have shown the method did not provide sufficient security.

5.1 Hydrological characteristics of the Yangtze River

The Yangtze River is the largest river in China, being 6,300 km long with a basin covering nearly 2 million km2 or about one-fifth of the country's territory. It is the third longest river in the world. The spectacular TGP is located in the middle of the Xiling Gorge, in Yichang of Hubei province. The mean annual discharges exceeding 1,000 m3/s are mainly through such tributary streams as the Jinsha, Min, Jialing and Wu rivers (Fig. 8). More than half a billion people or 45 percent of China's total population live in the basin, who produce about 42 percent of the country's gross domestic product.

To simplify the analysis, we set the hydrologic station at the end of each tributary stream as the control station, which represents the flood characteristics of the whole tributary. Since the Yangtze River consists of several tributary streams, the flood volume can be calculated by the ratio between drainage area of a tributary stream and the total area of the main stream.
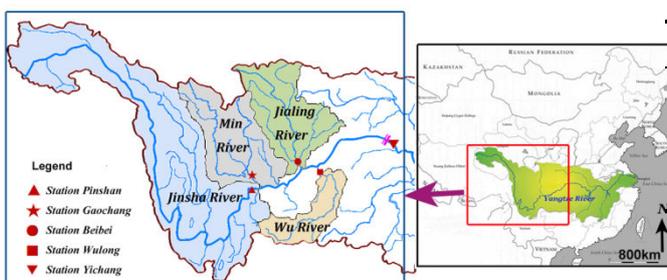
Fig, 8 Illustration of the tributaries in the Yangtze River

The flood peak's propagating time from each station upstream to Station Yichang is shown in Tab. 5.

Table 5 Propagating time of a flood peak from an upstream station to Station Yichang of the Yangtze River

Upstream station	Pingshan	Gaochang	Beibei	Wulong
Propagation time	90h	87h	56h	48h

The resultant discharge method is based on the water-balance equation of a semi-enclosed water body and empirical dependences. According to the resultant discharge method and the statistical characteristics between the tributary streams and the main stream as well as the flood volume and propagating time, the main stream flood volume (at Station Yichang) can be estimated. For example, 3-day flood volume between 08:00 local time (LT) on Oct. 2nd and 08:00 LT on the 5th at Station Yichang is a summation of flood volumes over 48 hours in the Wu River (at Station Wulong) between 08: 00 LT on Sept. 30th and 08:00 LT on Oct. 3rd, over 90 hours of the Jinsha River (Station Pingshan), over 87 hours of the Min River (Station Gaochang), and over 56 hours of the Jialing River (Station Beibei).

5.2 Application of the PNLTCED to predict 3-day flood volume at Station Yichang

The 3-day flood volume of the Jinsha, Min, and Jialing rivers are taken as variables to carry out the joint probability analysis using the PNLTCED model. Twenty-six catastrophic flood volume data between 1965 and 1982 are chosen for the analysis.

The diagnostic checks show that all the data of the Jinsha River, Jialing River and Min River fit well to the generalized extreme value distribution. It can be seen in Table 6 that the frequency of flood fits Poisson distribution very well. The parameters are shown in Table 7.

Table 6   Frequency of floods during 1965 and 1982

The number of major flood in one year					
0	1	2	3	4	Frequency
Year of occurrence					
3	8	4	2	1	$\lambda=1.44$

Table 8 shows the better correlation between the Jinsha River and the Jialing River than between any other two rivers, so the Jinsha River (1) and Jialing River (2) should be taken as inside layer variables.

Using the PNLTCED, one contour surface about the 3-day flood volume of the Jinsha, Jialing and Min rivers

for each joint return period can be obtained.

Table 7   Parameters of marginal distributions

parameters	Variables	Jinsha (1)	Jialing (2)	Min (3)
	Location parameter μ	2.17	3.72	2.55
	Scale parameter σ	0.92	2.44	1.19
	Shape parameter ξ	0.06	-0.12	0.34

Table 8 Linear correlation coefficient
and dependent parameter

Data	r_{12}	r_{13}	r_{23}	$\hat{\alpha}$	$\hat{\beta}$
	0.365	-0.0983	-0.0955	1.00	0.797

The diagnostic checks show that all the data of the Jinsha River, Jialing River and Min River fit well to the generalized extreme value distribution. The Fig. 9,10,11 show the distribution diagnostic testing of variables.

The Fig. 12 shows an example of the contour surface of 3-d flood volume calculated by PNLTCED with 100-year joint return period.   So there should be different combinations with same joint return period.

The results under the condition of different combinations of tributary flood volumes calculated by the PNLTCED are shown in Table 9. The predicted 100 years joint return period flood volume should be more severe than 1000 years return period design flood volume for TGDP predicted by CHDC recommended Pearson Type III model.
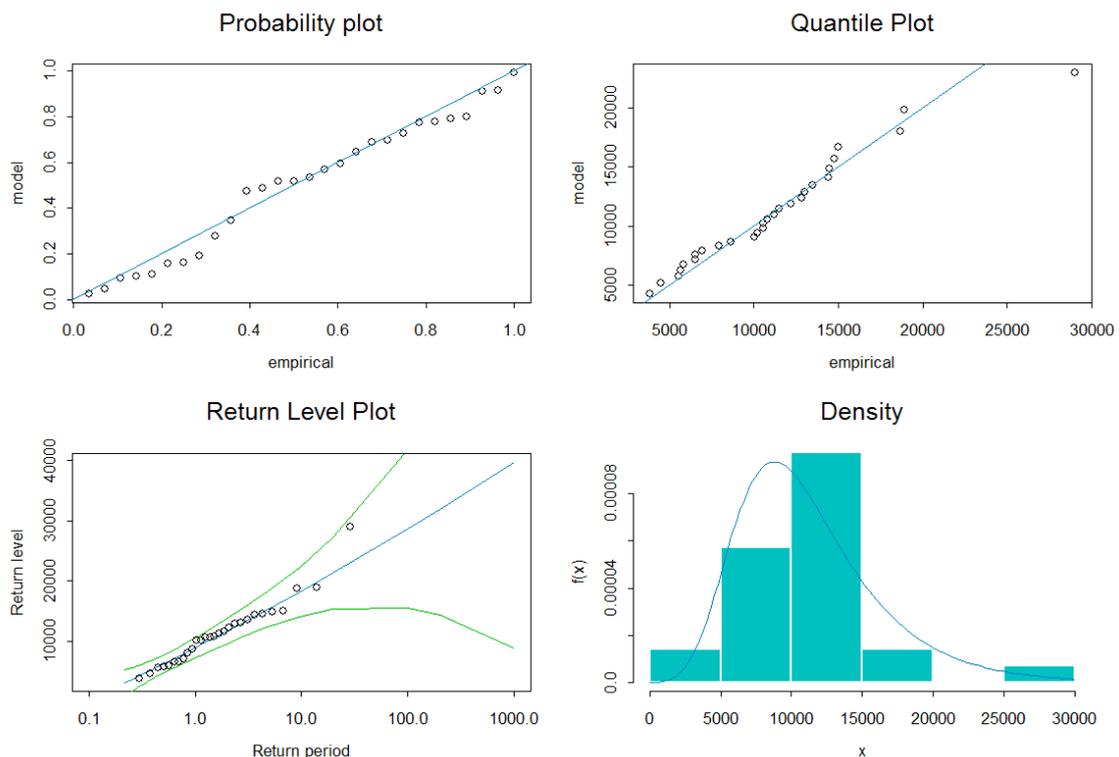

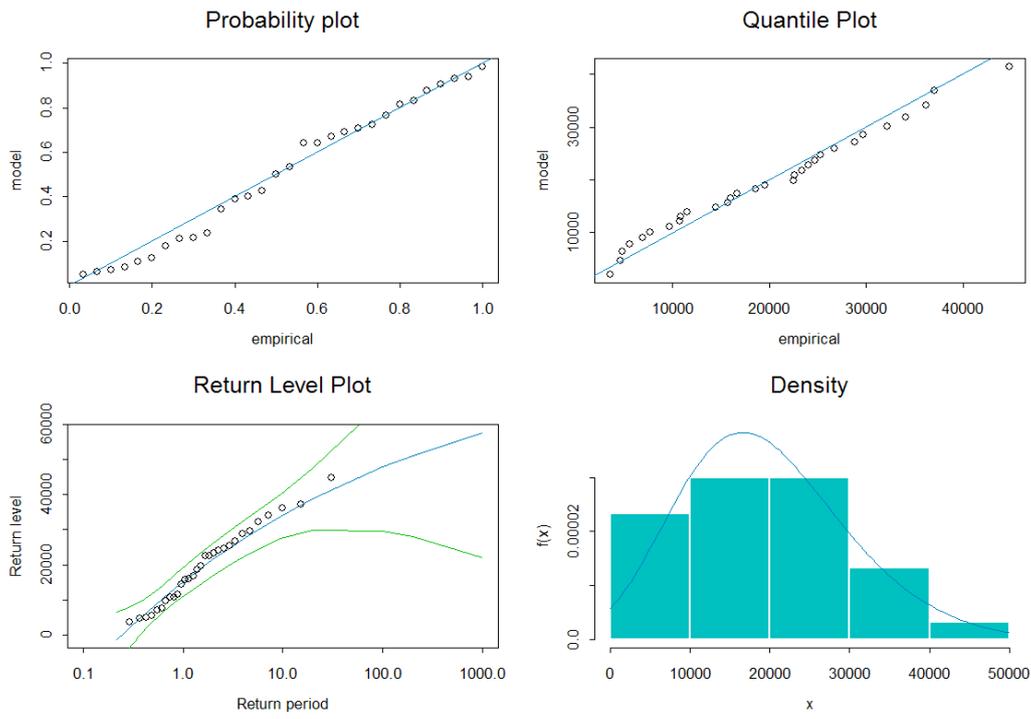Fig. 9 Distribution diagnostic testing of the Jinsha River

Fig.10 Distribution diagnostic testing of the Jialing River
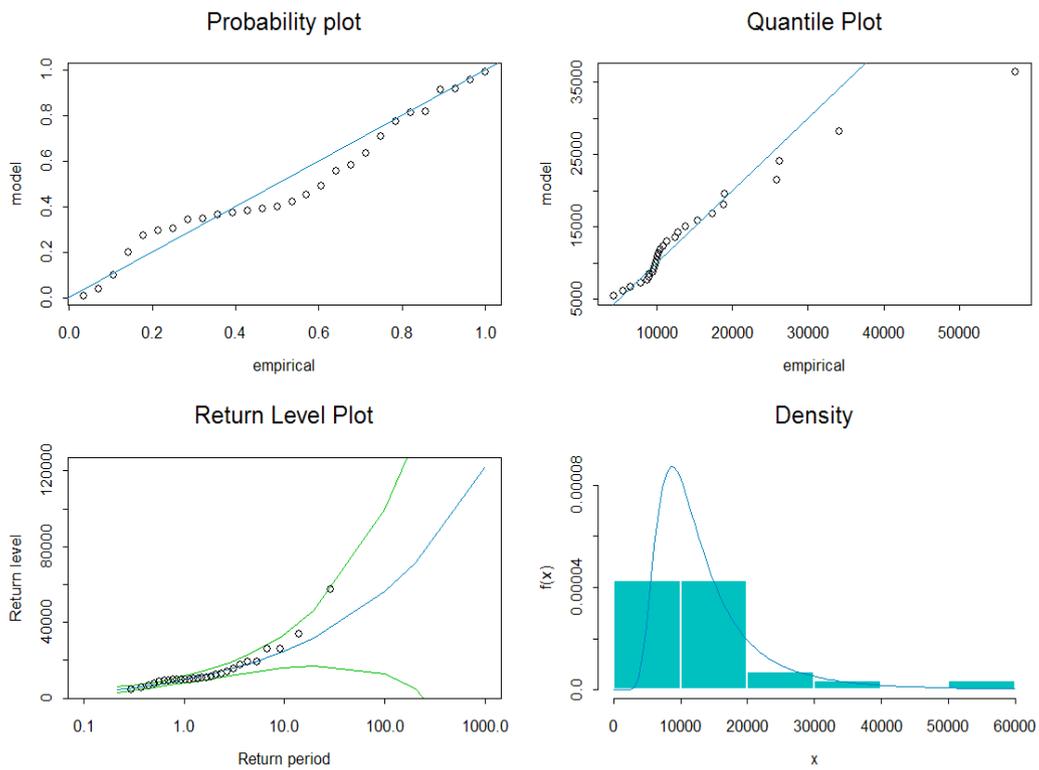

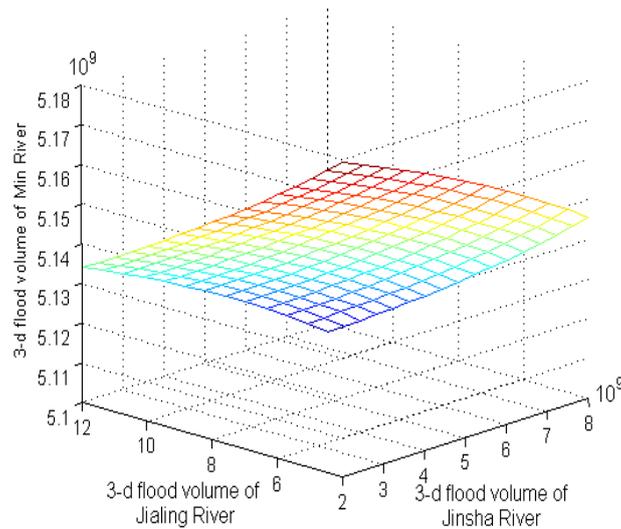Fig. 11 Distribution diagnostic testing of Min River

Fig. 12 Contour surface of 3-d flood volume

with return period of 100 year

Table 9 The combination of the tributaries flood with100-year return period

Modes	Jinsha River		Min River		Jialing River		Wu River		Fitting data of TGV 3-d flood volume	
	T	V	T	V	T	V	T	V	T	V
Mode 1	2	43.3	25	51.2	65	92.8	2	26.8	100	260.4
Mode 2	68	70.7	26	51.4	2	52.8	2	26.8	100	245.9
TGV	T=100, V=208.0;				T=500, V=235.6;				T=1000, V=247.5;	

Note: T means return period (units: year); V means 3-day flood volume (units: 10^8 m^3)..

6. CONCLUSIONS

Design codes calibration of offshore, coastal and hydraulic infrastructures show that some traditional methods and models can not support enough safety for very important infrastructures in global climate change conditions. The disasters induced by the 1975 typhoon Nina and 2005 hurricane Katrina give an important lesson: When natural hazards combined with human hubris, the natural hazards become a catastrophic disaster sooner or latter.

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