

Research Article

Research on Reliability of Vertical Bearing Capacity of Pile Foundations in the Aquaculture Food Farm

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Abstract: This study aims to investigate the reliability of the vertical bearing capacity in the aquaculture food farm piles in damage condition. The aquaculture farm construction ensures the aquaculture safety. Literature review indicates that many work has addressed the pile reliability assessment using empirical data, but very little has been done to address the updating of the empirical data. This is because the piles in the empirical data have not been completely damaged while the reliability has been calculated using the damage condition. As a result, the reliability is not accurate in practice. To solve this problem, this study proposes a new method based on the Bayesian statistical theory for the assessment on vertical bearing capacity of the piles in damage condition. The Bayesian Updating Method (BUM) was derived to eliminate the error between the theoretical value and actual value. The empirical analysis results show that the proposed BUM is effective for empirical data updating. The error caused by the underestimation of the damage condition has been eliminated by the BUM. Hence, the proposed method could provide correct reliability assessment on the vertical bearing capacity in the aquaculture food farm piles for practical reference.

Keywords: Aquaculture farm, aquaculture food, pile reliability, safety

INTRODUCTION

The aquaculture farm is the foundation for aquaculture. Hence it is essential to construct reliable aquaculture farm (Ma *et al.*, 2010). Reliability design method is superior to the traditional allowable stress design method, because the reliability design method in the design fully considers the influence of various uncertain factors (Pietrak *et al.*, 2012). In the design of aquaculture farm pile foundation, the uncertain factors affecting reliability of pile foundation design are mainly parameter uncertainty and model uncertainty. Zhang *et al.* (2009), Zheng *et al.* (2012), Zhang *et al.* (2005) and Zhou and Li (2007) have investigated the influence of uncertainties on the reliability of the piles foundation. Collecting a large amount of accurate static load test data is the most effective way to process parameter and model uncertainties. However, little work has addressed the piles in damage condition. In addition, in the study of pile bearing capacity reliability, the collecting data are not the ultimate bearing capacity of the piles; therefore there is an error between calculation and the actual value. To solve this problem, Zhang (2004) used the theory of probability and a large number of field data of vertical bearing capacity of the

pile to study in detail in the probability distribution characteristics of the vertical bearing capacity and proposed a new failure judge criterion of vertical bearing capacity limitation. However, literature review indicated that little work has addressed the vertical bearing capacity limitation of the piles in damage condition.

In order to investigate the reliability of the vertical bearing capacity in the aquaculture farm piles in damage condition, a new method based on the Bayesian statistical theory for the assessment on vertical bearing capacity of the piles in damage condition. The engineering example is carried out to verify the proposed method on reliability of pile vertical bearing capacity. The analysis results show the effectiveness of the proposed method.

MATERIALS AND METHODS

Assuming that the prior distribution $f'_x(X)$ of the random variable X , the posterior distribution is (Zheng *et al.*, 2012):

$$f''_x(X) = K \times L(X) \times f'_x(X) \quad (1)$$

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where, $f''_x(X)$ is the posterior distribution of X , K is the normalization constant and $L(X)$ is the likelihood function.

Because there is an error between calculation value in (1) and the actual value, an upgrade term is required. Then the design safety ratio λ is introduced into the probability distribution. If the ratio λ follows the logarithmic normal distribution, then the probability of λ exceeding the safe value λ_T is:

$$p(\lambda \geq \lambda_T) = \int_{\lambda_T}^{+\infty} \frac{1}{\sqrt{2\pi\xi\lambda}} \exp\left\{-\frac{1}{2}\left\{\frac{\ln(\lambda)-\eta}{\xi}\right\}^2\right\} d\lambda \quad (2)$$

where, x is the standard deviation of $\ln(l)$ and h is a constants. Let $y = \frac{\ln(l)-h}{x}$, (2) could be rewritten as:

$$p(\lambda \geq \lambda_T) = \int_{\frac{\ln(\lambda_T)-\eta}{\xi}}^{+\infty} \frac{1}{\sqrt{2\pi\xi\lambda}} \exp\left\{-\frac{1}{2}y^2\right\} d\lambda \quad (3)$$

$$= \Phi\left\{-\frac{\ln(\lambda_T)-\eta}{\xi}\right\}$$

where, $F(x)$ is the cumulative distribution function. If the likelihood function $\ln(S_{tot})$ is corresponding to the failure load, then in the static load test the pile failure probability distribution is:

$$L(\mu) = \prod_{i=1}^n [p_X(\lambda \geq \lambda_T)]_{\mu} = \Phi^n\left\{-\frac{\ln(\lambda_T)-\eta}{\xi}\right\} \quad (4)$$

where, n is the number of piles, x is the standard deviation of $\ln(l)$, $s_{S_{tot}}$ is the mean value of $\ln(l)$, $L(m)$ is the likelihood function of m . If $\ln(S_{tot})$ is known, according to (1) we can derive the posterior distribution of m :

$$f''(\mu) = k\Phi^n\left\{-\frac{\ln(\lambda_T)-\eta}{\xi}\right\} f'(\mu) \quad (5)$$

where, $f'(\mu)$ is the prior distribution of μ , k is the normalization constant:

$$k = \left[\int_{-\infty}^{+\infty} \Phi^n\left\{-\frac{\ln(\lambda_T)-\eta}{\xi}\right\} f'(\mu) d\mu \right]^{-1} \quad (6)$$

Then from (6) we can obtain the posterior distribution:

$$f_{\lambda}(\lambda) = \int_{-\infty}^{+\infty} f_{\lambda}(\lambda / \mu) f''(\mu) d\mu \quad (7)$$

If the piles are safe after r tests, then the probability distribution is:

$$L(\mu) = \binom{n}{r} [p(\lambda \geq \lambda_T |_{\mu})]^r [1 - p(\lambda \geq \lambda_T |_{\mu})]^{(n-r)} \quad (8)$$

Then the normalization constant is:

$$k = \left[\int_{-\infty}^{+\infty} \binom{n}{r} [p(\lambda \geq \lambda_T |_{\mu})]^r f'(\mu) d\mu \right]^{-1} [1 - p(\lambda \geq \lambda_T |_{\mu})]^{(n-r)} \quad (9)$$

Hence, the posterior distribution of μ is:

$$f''(\mu) = k \binom{n}{r} [p(\lambda \geq \lambda_T |_{\mu})]^r [1 - p(\lambda \geq \lambda_T |_{\mu})]^{(n-r)} f'(\mu) \quad (10)$$

Let $X = (X_1, X_2, L, X_n)$, the mean value, variance and variable coefficient of X are:

$$\mu_X = \frac{1}{n} \sum_{i=1}^n X_i \quad (11)$$

$$\sigma_X^2 = \frac{1}{n-1} \sum_{i=1}^n (X_i - \mu_X)^2 \quad (12)$$

$$COV_X = \frac{\sigma_X}{\mu_X} \quad (13)$$

where, m_x is the mean value, s_x is the variance and COV_x is variable coefficient.

Then the Bayesian Updating Method (BUM) is applied to m_x and s_x . If X follows Gaussian distribution, assume m'_X and S'_X are the mean value and variance of the prior distribution of X , respectively and then the prior density function of X is:

$$f'_X(X) = N(\mu_{Xp}, \sigma_{Xp}) \quad (14)$$

If the mean value and variance of the prior function are m_X^K and s_X^K , respectively, then the value and variance of posterior distribution of COV_X are:

$$\mu'_X = \frac{\mu_X^K \sigma_X' + \mu_X \left(\frac{\sigma_X'^2}{n}\right)}{\sigma_X'^2 + \left(\frac{\sigma_X^{2K}}{n}\right)} \quad (15)$$

$$\sigma_X'^2 = \sigma_X^{2K} + \frac{\sigma_X'^2 \left(\frac{\sigma_X^{2K}}{n}\right)}{\sigma_X'^2 + \left(\frac{\sigma_X^{2K}}{n}\right)} \quad (16)$$

where, m''_X is the value and $s^{2''}_X$ is the variance. Hence the value and variance have been updated.

Then the reliability could be calculated as (Zheng et al., 2012):

$$\beta = \frac{\ln\left(\frac{\bar{R}}{\bar{Q}} \sqrt{\frac{1+COV_Q^2}{1+COV_R^2}}\right)}{\sqrt{\ln(1+COV_R^2)(1+COV_Q^2)}} \quad (17)$$

where, \bar{R} and \bar{Q} are the mean of vertical bearing capacity and load effect, respectively; COV_R and COV_Q are the variable coefficients of vertical bearing capacity and load effect, respectively.

RESULTS AND DISCUSSION

The field monitoring data collected by Meyerhof (1976) has been used in this study to verify the proposed method for reliability assessment on the vertical bearing capacity of piles. In the field monitoring data, the piles have not been completely destroyed. So these data are less than the actual value. The BUM has been used to update the data. Table 1 lists the updating results.

From Table 1 one can see that l increased with the increase of failure number. For instant, when the test number is 4 and the failure number is 0, l is 0.69 while l is 1.77 when the failure number is 4. Figure 1 to 4 gives the reliability analysis results.

It can be seen in Fig. 1 to 4 that the reliability index will increase with the increase of failure number. In Fig. 1 when the load ratio is 3, if the failure number is 4, the reliability is 2.64 and the failure probability is 4.15×10^{-3} ; however, if the failure number is 0, the reliability is 0.65 and the failure probability is 2.58×10^{-1} . Thus, the higher failure number related lower failure probability. The same results could be obtained in Fig. 2 to 4. Hence, the proposed method could provide important reference for the reliability assessment for the aquaculture farm pile foundations.

Table 1: BUM updating results

Test number	Failure number	l	COV_X
4	4	1.77	0.38
	3	0.19	0.24
	2	1.04	0.24
	1	0.91	0.24
	0	0.69	0.30
3	3	1.74	0.38
	2	1.14	0.25
	1	0.96	0.25
	0	0.72	0.31
2	2	1.68	0.39
	1	1.06	0.26
	0	0.75	0.32
1	1	1.59	0.41
	0	0.82	0.34

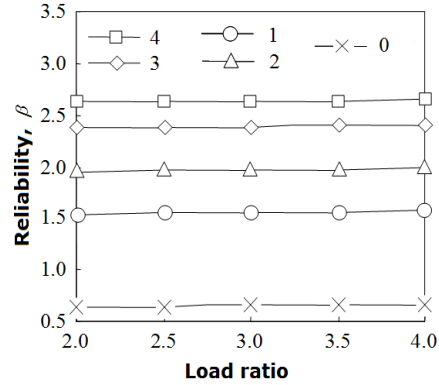


Fig. 1: The reliability calculation when the test number is 4

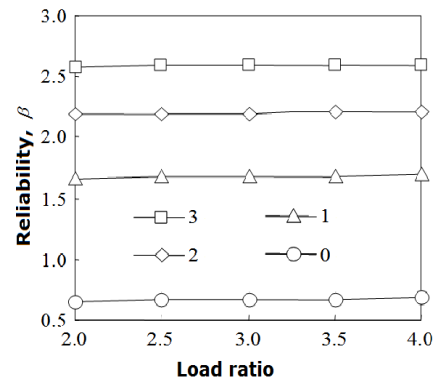


Fig. 2: The reliability calculation when the test number is 3

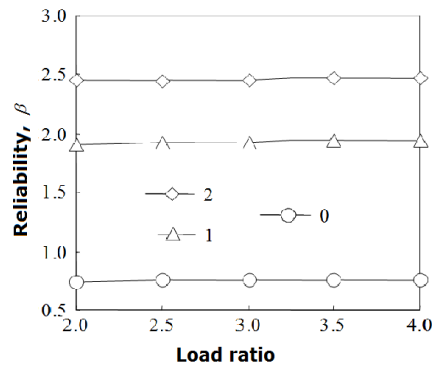


Fig. 3: The reliability calculation when the test number is 2

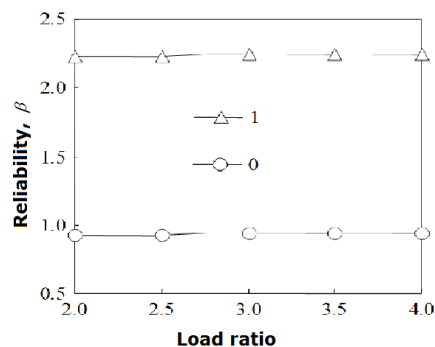


Fig. 4: The reliability calculation when the test number is 1

CONCLUSION

In the static load test, the piles have not been damaged yet. The reliability of the piles has been underestimated. For this reason, this study has proposed a new method based on the Bayesian statistical theory for the assessment on vertical bearing capacity of the aquaculture farm piles in damage condition. Through theoretical analysis and numerical calculation, the analysis results demonstrate that the proposed Bayesian Updating Method (BUM) could provide precise data for practical analysis; reliability index will increase with the increase of failure number. The findings of this study could provide important reference for practical reliability assessment for aquaculture farm piles.

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