Equivalent reduction coefficient analysis of bending flow capacity for plastic vertical drains

Jing Wang, Liwen Hu & Tao Li
1. CCCC Fourth Harbor Engineering Institute Co.,Ltd. , China;
2. CCCC Key Lab of Environmental Protection & Safety in Foundation Engineering of Transportation, China
3. Guangzhou Harbor Engineering Quality Examination Co., Ltd., China

ABSTRACT: Plastic vertical drains is a vertical channel of water discharge in drainage consolidation foundation treatment. Significant settlements happens as foundation treatment process, while plastic vertical drains bending. Thus it need to be validated that the flow capacity decrease, which leads to affecting reinforcement effect. This paper studies the four types of representative of plastic vertical drains. Through fixed iron frame model, manual bending plastic vertical drains to simple simulate the bending deformation. The relationship between the bending angle and the local loss coefficient is quantitatively analyzed. The fitting formula between the local loss coefficient and the flow capacity reduction coefficient is obtained. The method of calculating the reduction coefficient through bending rate is compared and analyzed.

Keywords: plastic vertical drains; bending; flow capacity; reduction coefficient

1 INTRODUCTION

In the treatment of foundation by vacuum preloading, the drainage plate is an important part. As the vertical passage of water discharge in the foundation, the drainage plate helps to accelerate the consolidation of the foundation. The plastic drainage board is used as the vertical passage of water discharge in the vacuum preloading foundation treatment method, and the large settlement of the foundation treatment process causes the drainage board to bend, which leads to the decrease of the water flux. And then affect the reinforcement effect (Jing Wang 2014, Jing Song 2012).

Plastic drains are compressed and deformed along with the soft soil in engineering applications. In many cases, the drains are not drained vertically, More often than not, they work in a bending state (Walker R T. 2011, Jing Wang 2017). The longitudinal water flux measured in the laboratory can only simulate the drainage plate's water flow performance at a relatively small stage of initial settlement and compression of the soft soil consolidation. But it takes up most of the time of the consolidation in the bending state (Rujikiatkamjorn C 2007, 2008). Therefore, in this paper, four kinds of representative plastic drainage boards are used to simulate the bending deformation of the drainage boards by fixing the iron frame model and bending the drainage plates manually. The relationship between bending angle and local loss coefficient is quantitatively analyzed, and then the fitting formula between local loss coefficient and water flux reduction coefficient is obtained, and the method of calculating reduction coefficient by bending rate is compared and analyzed for engineering reference.

2 TESTING PROGRAM

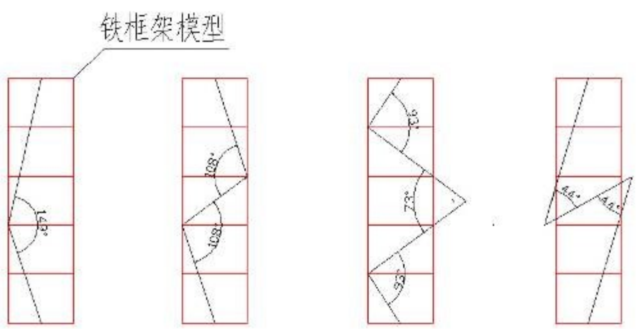
Four different types of drainage plates are selected. The first type is conventional separation, which is the ordinary hot rolled non-woven filter membrane, and the membrane core plate is separated. The second is conventional integral, which is the ordinary hot-rolled non-woven cloth filter membrane. The third is anti-silting separation, which is a new type of anti-blockage hot-rolled non-woven fabric, and the separation of the filter membrane core board. The fourth type is the anti-silting integral, which is a new type of anti-silting hot-rolled non-woven fabric. The basic properties of the drain board are shown in Table 1.

Table 1. Physical properties of drain board.

Number	Sample	Thickness (mm)	Width (mm)	Vertical tooth thickness (mm)	Transverse tooth thickness (mm)	Overall cross sectional area (mm^2)	Cross sectional area of core panel (mm^2)	Cross section water area (mm^2)
A	conventional separation	4.0	100.04	0.43	0.38	402.16	86.06	316.10
B	conventional integral	4.5	101.63	0.45	0.67	459.01	124.14	334.88
C	anti-silting separation	4.1	100.65	0.40	0.33	408.65	91.67	316.99
D	anti-silting integral	4.2	100.50	0.59	0.40	421.10	107.93	313.16

The ZEP-I vertical water conveyer and the prefabricated rigid iron frame are used to fix the bending angle of the drainage plate, and the bending water flow of the drainage plate is tested. The upper and lower chucks of the drainage plate are covered with rubber film along with the drainage board. The water pressure is applied to the rubber film by applying water pressure to the hydraulic system. The test instrument and the specific bending form are shown in Figure 1 and Figure 2.

Figure 1. ZFP-Ⅰ longitudinal sealing drain water meter.



(a) One bending (b) Two bending (c) Three bending (d) Reverse bending

Figure 2. Different bending forms of plastic vertical drains.

3 REDUCTION COEFFICIENT ANALYSIS

The reduction coefficient of flow capacity is related to the local loss coefficient. The local loss coefficient is caused by the single bending angle of the drainage plate. The local loss coefficient corresponding to the bending angle is equal to half of the local loss coefficient of the whole drainage plate, because the angle of bending is the same in the form of two bending and reverse bending. For the three-bend form, the three bending angles are one 73 °bending in the middle of the drainage plate and one 93 °bending in the upper and lower symmetry respectively. The local loss coefficients of these two angles are calculated by linear interpolation.

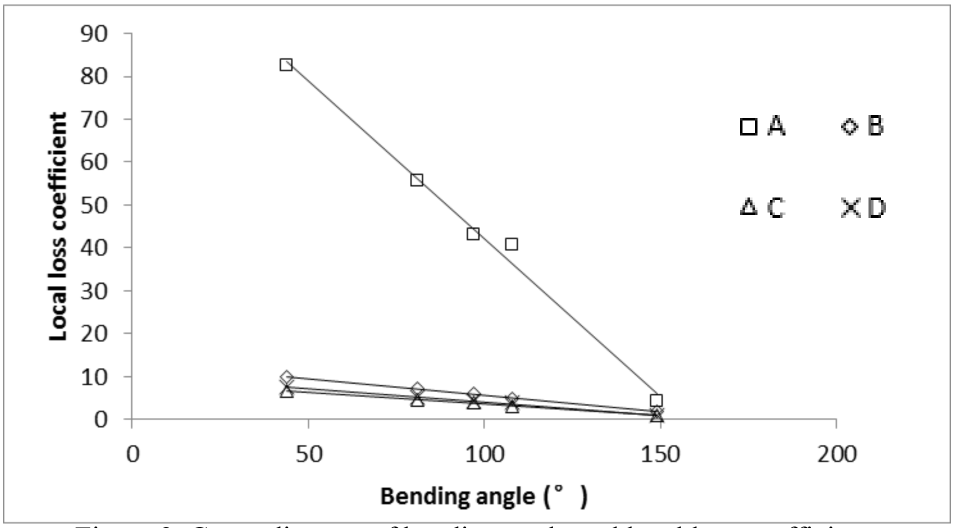


Figure 3. Curve diagram of bending angle and local loss coefficient.

A: Conventional separation $\zeta = -0.728\theta + 114.6$ (1)

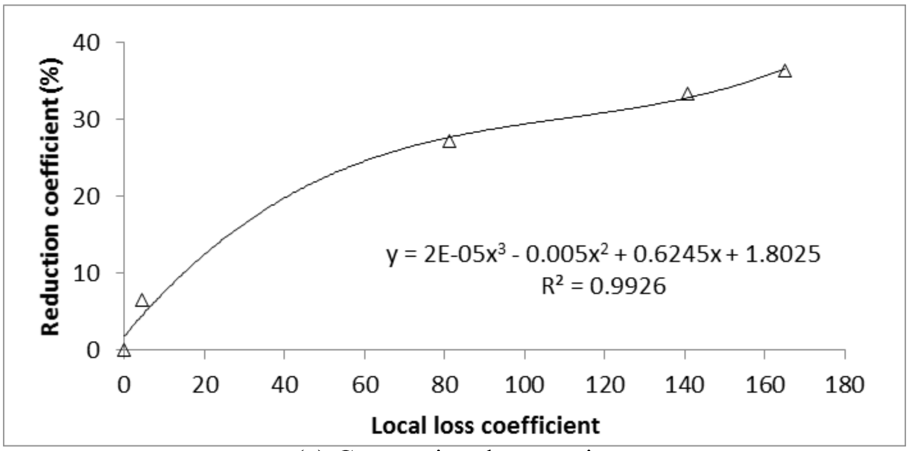
B: Conventional integral $\zeta = -0.077\theta + 13.4$ (2)

C: Anti-silting separation $\zeta = -0.053\theta + 9.0$ (3)

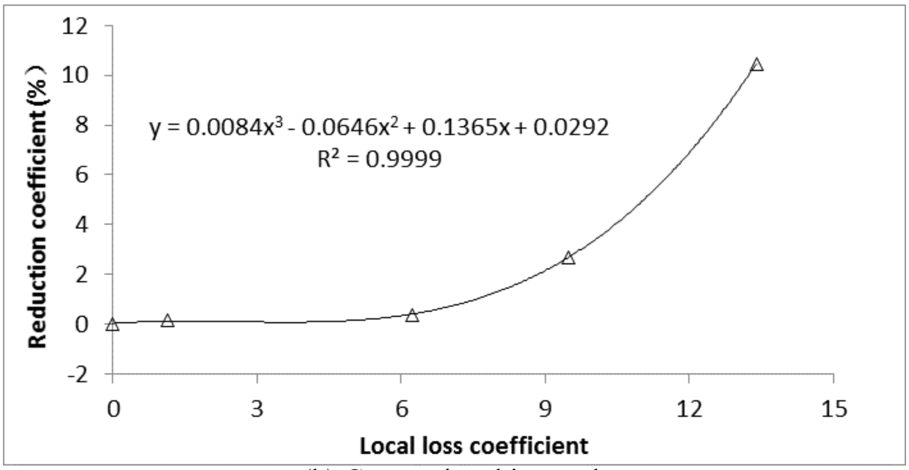
D: Anti-silting integral $\zeta = -0.062\theta + 10.43$ (4)

where ζ= local loss coefficient, θ = bending angle, respectively.

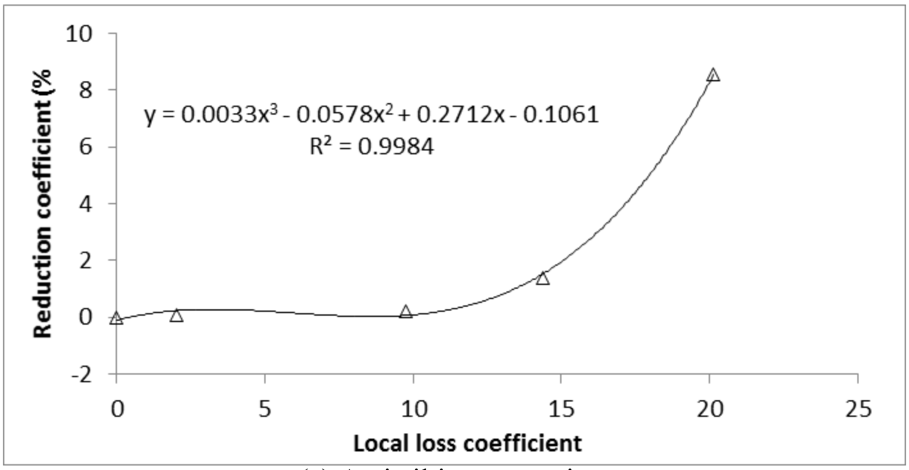
The regression curve is obtained by the least square method, and the curve fitting is carried out by cubic polynomial function. The correlation coefficient R is above 0.99, so the reduction coefficient between the bending angles of 44 °and 149 °can be basically fitted.



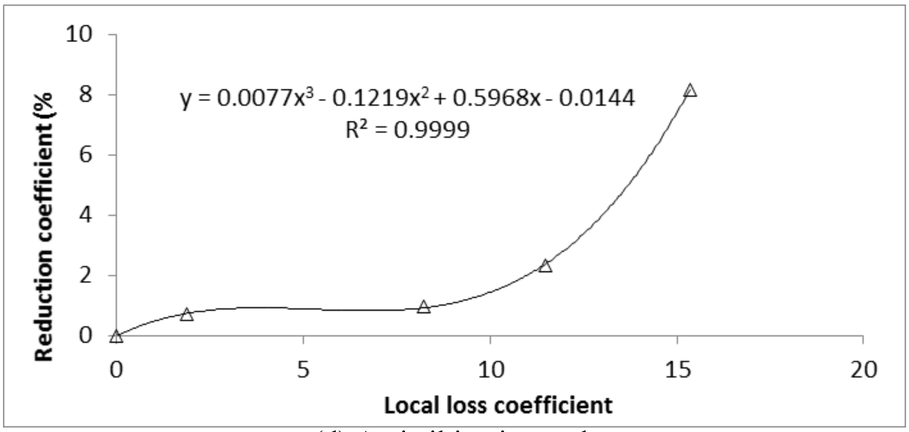
(a) Conventional separation.



(b) Conventional integral.



(c) Anti-silting separation.



(d) Anti-silting integral.

Figure 4. Curve diagram of the coefficient η ~ ζ of bending water flow reduction.

It can be seen from figure 4 that all four types of drains can be fitted with cubic polynomial functions. For conventional separation, the curve shape is convex. It shows that the drainage plate can produce a large reduction of flow capacity, when the coefficient of local loss is lower. That is, the critical bending angle of the conventional separated drain plate is between 108 °and 149 °, which is between one and two bends). The critical bending angle is large. This means that when the bending degree of the drainage plate is low, the condition of "lower than the critical angle" may be reached. It will result in a large local loss coefficient, which will result in a large reduction in the amount of flow capacity. For the other three types of drains, the shape of the curve is convex. The coefficient of reduction begins to increase rapidly after ζ is 6 ~ 10. It shows that within three bends, the amount of water passing through the curve will not be reduced too much. That is, the critical bending angle is between 44 °and 73 °. Between the three bends and the reverse bending, the critical angle is relatively low. It shows that the bending degree of the drainage plate can be deeper without obvious reduction of the flow capacity.

For each type of drain, the local loss coefficient is different. The comparison between the ζ values of two different types of plastic drains is unreasonable. For example, the conventional separation can reach

20 under the form of two bends. For the other three, the degree of bending must be greater than that of the two bends. In this case, the coefficient of reduction must be larger than that of the conventional separation.

In the study, the local loss coefficient under different bending conditions can be calculated by measuring the bending angle of the drainage plate after loading. The corresponding coefficient of flow capacity reduction can be obtained according to the cubic polynomial fitting equation.

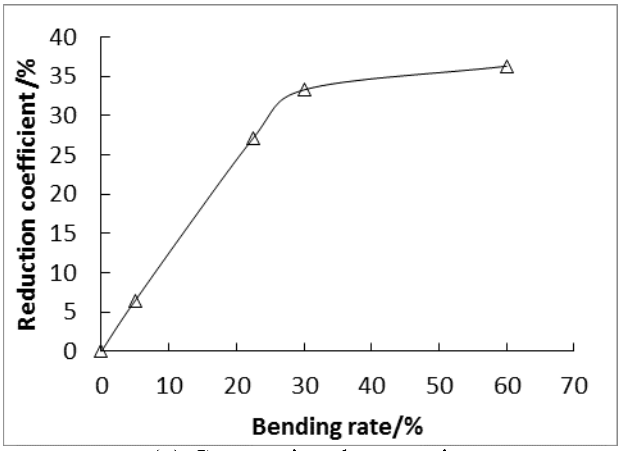
4 BENDING RATE AND REDUCTION COEFFICIENT

In engineering applications, the bending of the drainage plate inside the soil is unknown. It is even more impossible to know the exact bending angle in the calculation. The bending ratio κ, a method to measure the bending degree of the drainage plate, can be used to determine the reduction coefficient, in which the bending rate is the ratio of the drain plate compression amount to the effective length of the drain plate. The bending rate formula can be written as:

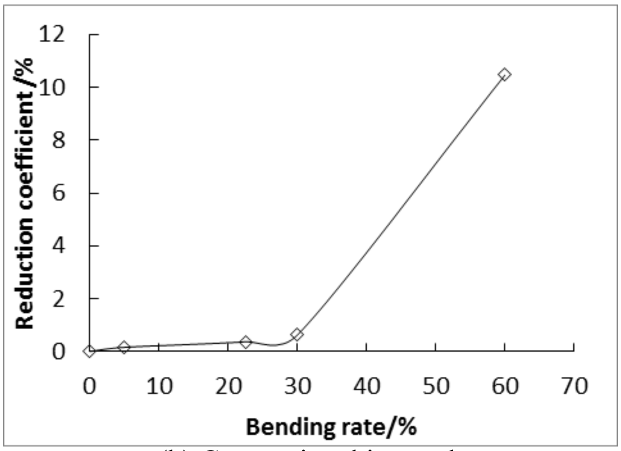
$$\kappa = \frac{\nabla l}{l_0} = \frac{l - l_0}{l_0} \tag{5}$$

where κ= bending rate, l= actual length of drain plate, l_0 = vertical length of drain plate after bending, respectively.

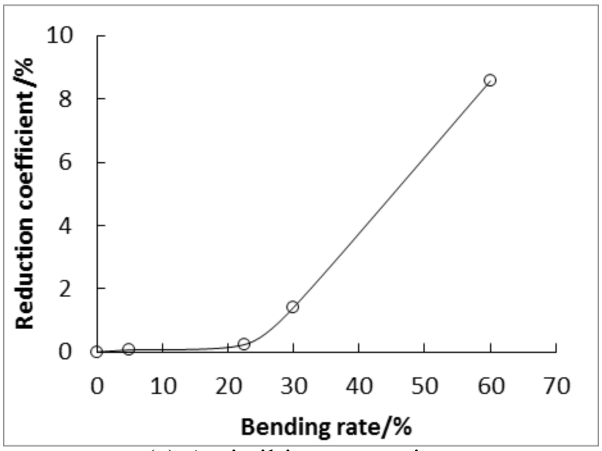
In this flow capacity test, the vertical length of drain plate after bending is 40 cm. The drainage plate bends and deforms with the consolidation of the soil. The more the soil is consolidated, the more serious the bending degree of the drainage plate is, and the greater the bending ratio κ is. The relationship between the bending rate κ and the coefficient of reduction η is established. The relationship curve is shown in figure 5.



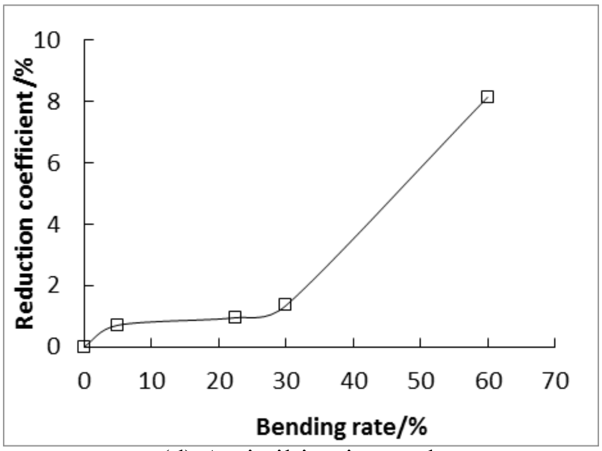
(a) Conventional separation.



(b) Conventional integral.



(c) Anti-silting separation.



(d) Anti-silting integral.

Figure 5. Curve of the coefficient η ~ κ of bending flow capacity

It can be seen that the curve of bending rate κ and the reduction coefficient η of four kinds of drainage plates are very similar to the curves of ζ ~ η. The conventional separated curve form is upper convex, and the other three are sub convex.

In previous studies on the bending of drainage plates, the bending rate was mostly used to measure the degree of bending. However, there are some limitations, for two reasons. First, the bending rate only takes into account the amount of change in compression. The plastic drains have a concept of critical bending angle, so long as the bending angle is less than the critical angle, it will lead to a larger attenuation of the water flux. The result will be small. Second, the degree of bending is not certain at the same bending rate. It can be reversed or made up of many small bends, which is related to the flexural strength of the drains.

Although the κ ~ η diagram is not as accurate as the ζ ~ η curve, it can still be used when the settlement of soil is small. Because in the case of small settlement, the bending of the drainage plate is smaller, and the form of the drainage plate is relatively simple. It will not cause excessive deviation of the reduction coefficient.

5 CONCLUSION

In this paper, the relationship between bending angle and local loss coefficient is quantitatively analyzed for four kinds of representative plastic drainage plates, and the fitting formula between local loss coefficient and water flux reduction coefficient is obtained. The method of calculating the reduction coefficient by bending ratio is analyzed. The conclusions are as follows:

(1) With the deepening of the bending degree, the flow capacity of the four kinds of drainage plates is reduced to a certain extent. There is a critical bending angle. When the bending angle of the drainage plate is lower than the critical angle, the vertical teeth of the drainage plate fall over, resulting in a great reduction of the flow capacity.

(2) The critical bending angle of conventional separation is between 108 °and 149 °, which is between one and two bends, and it is easy to achieve. The critical bending angle of the other three is between 44 °and 73 °, which is between three and reverse bends, and it is hard to achieve.

(3) The lower the bending angle, the greater the local loss coefficient. The relationship between the bending angle of drainage plate and the local loss coefficient is approximately linear, and the correlation coefficient is more than 0.99. Because of the existence of critical bending angle, the local loss coefficient and the water flux reduction coefficient are fitted by cubic polynomial equation, and the correlation coefficient can also be above 0.99.
(4) The reduction coefficient of flow capacity can be obtained by two methods, one is to calculate the coefficient of reduction by local loss coefficient, the other is to calculate the coefficient of reduction by means of bending rate, which is less accurate than the former.

REFERENCES

Jing Wang H M S L. 2014. Effect of mineral composition on macroscopic and microscopic consolidation properties of soft soil. Soil Mechanics and Foundation Engineering. Vol. 50(No. 6): 232-237.

Jing Song, Qing Wang, Peng Zhang. 2012. Laboratory research on fine particles migration of high clay dredger fill in consolidation process. Journal of Engineering Geology. Vol. 20(6): 1042-1049.

Walker R T. 2011. Vertical drain consolidation analysis in one, two and three dimensions. Computers and Geotechnics. Vol. 38(8): 1069-1077.

Jing Wang Z D A H. 2017. Fractal Properties of Filter Membrane for Silt Clogging Evaluation on PVD Improved Soft Clays. KSCE Journal of Civil Engineering. Vol. 21(3):636-641.

Rujikiatkamjorn C, Indraratna B. 2007. Analysis of Radial Vacuum-Assisted Consolidation Using 3D Finite Element Method. Faculty of Engineering and Information Sciences..

Rujikiatkamjorn C, Indraratna B, Chu J. 2008. 2D and 3D Numerical Modeling of Combined Sur-charge and Vacuum Preloading with Vertical Drains. International Journal of Geomechanics. Vol. 8(2): 144-156.