ISSN 1009 - 3095 *Journal of Zhejiang University(SCIENCE)* V.1,No.2,P.144 - 147,Apr. - Jun.,2000

http://www.zju.edu.cn; http://www.zjupress.com; http://www.chinainfo.gov.cn/periodical

NUMERICAL ANALYSIS OF BURIED PIPE CHARACTERISTICS*

ZHANG Tu-qiao(张土乔), SHAO Wei-yun(邵伟云)

(*Dept. of Civil Engineering, Yuquan Campus of Zhejiang University, Hangzhou 310027, China*)

Received Dec.12, 1998; revision accepted Oct.15,1999

Abstract: Voluminous statistical data on the breakage and leakage of pipelines occurring frequently in water supply and drainage engineering, were collected and analyzed to find the causes and solutions for the breakage and leakage. Then the original parameter method of foundation beam on elastic semi-infinite plane subgrade was applied to verify the statistical results. Numerical computational results showed that the performance of the original parameter method of foundation beam was satisfactory.

Key words: numberical analysis, buried pipe, breakage and leakage
Document code: A **CLC number:** TU992

INTRODUCTION

Up to 1994, about 200 000 km water-supply and drainage pipelines had been laid in 612 cities in China. Over 130 000 km are the water supply lines and over 68 000 km laid length are discharge piping (Wu, 1996). Cast-iron pipes accounted for about 80% of the small and medium diameter service pipes. Prestressed reinforced concrete pipes accounted for over 50% of the large diameter service pipes. Others were steel pipes or pipes made of other materials. Based on statistical data, the average annual occurrence rate of leakage and breakage of service pipes was about 0.5 ~ 0.6 times per kilometer. The annual economic loss was about 300 ~ 500 million yuan(about US $ 36 ~ 60 million). Up to 1993, there were 1 404 km water supply piping and 771 km discharge piping in Hangzhou. The majority of service pipes were cast-iron pipes and prestressed reinforced concrete pipes. Most discharge pipes were butt joint reinforced concrete pipes. The breakage and leakage rate of water supply piping was up to 8% and has caused 13 million yuan(US $ 1.6 million) economic loss during the period of 1990 to 1993.

STATISTICAI DATA

1. Statistics on causes of piping troubles

Voluminous data on piping troubles such as breakage and leakage in the water-supply and drainage network were collected and analyzed to find the causes of, and preventive measures against, service pipe troubles (Yuan, 1994). The causes of piping troubles based on statistical data can be classified as follows.

Bad quality of piping materials It plays an important role in the bursting of some pipelines such as continuous cast-iron pipes and asbestos cement pipes.

The operating problems of the network Such as water hammer trouble due to power failure, or the closing and opening of gate, air hammer, etc.

Bad construction quality Some construction qualities, such as those of pipe conjunctions and its packing materials, and water pressure tests, do not meet strictly construction and acceptability criteria. The soft clay interlayer in the soil, the bond area and the binding strength of the interface between piping shell and pipe saddle are not considered comprehensively which will induce the uneven settlement of the subgrade and piping stress concentration in the future.

Mismanagement and poor maintenance of piping network Such as backward technical management of network and weak network maintenance measures, etc.

2. Statistical results

Aside from the above causes, statistics show that small and medium diameter pipes often burst

---

* Project supported by Zhejiang Province Science & Technology Foundation for Construction.

along the transversal section due to longitudinally forces. Big diameter pipes are always cleaved longitudinally along the pipeline or sockets are pulled apart from faucets. Longitudinal stress is the chief problems of small and medium diameter pipes while hoop stress is the main problem of large diameter pipes.

COMPUTATIONAL MODELING

In the structural design specifications of water supply and sewerage engineering (GBJ69 – 84) in China, the calculation of the transverse section is specified detailedly, while longitudinal stress is converted from the results of the transversal section or is computed using the continuous beam concept. The 3-moment equation of structural mechanics is used to compute the stress of a continuous beam with stiffness supports. Its specific application in the field of water supply and sewerage engineering was discussed by Shao (1996). The major merit of structural mechanics modeling is simplicity and the apparent shortcoming is that the subgrade reaction is not taken into account. To overcome this fault, foundation beam modeling was adopted.

1. Original parameter method of foundation beam

The distribution of subgrade reaction along the pipeline is based on Winkler assumption that the subgrade reaction is directly proportional to the beam deflection. The transversal section stress distribution is based on the assumption that the bedding coefficient is directly proportional to the soil saddle depth if the pipes have a soil saddle.

The equation of the foundation beam's deflection curve is:

$$\frac{d^4 y}{d(\alpha x)^4} + 4y = \frac{4}{k} q(\alpha x) \qquad (1)$$

where α is the characteristic elastic value of the foundation beam, $\alpha = \sqrt[4]{\frac{k}{4EI}}$; k is bedding coefficient; E is elastic modulus of beam and I is the inertia moment of beam; $q(\alpha x)$ is the distributed load acting on the beam. In this paper, it represents the sum of soil weight, pipeline weight and water weight in the pipe, namely q_0.

Eq. (1) can be solved as a differential equation after the original parameters are resolved on the basis of the known boundary conditions of the foundation beam, the piping deflection y, moment M, piping longitudinal stress σ_p and subgrade reaction σ_f at the calculated point of the foundation beam. y and M are defined by the following formulas.

$$y = y_0 \varphi_1 + \theta_0 \frac{1}{2\alpha} \varphi_2 - M_0 \frac{2\alpha^2}{k} \varphi_3 - Q_0 \frac{\alpha}{k} \varphi_4 + \frac{q_0}{k}(1 - \varphi_1) \qquad (2)$$

$$M = y_0 \frac{k}{2\alpha^2} \varphi_3 + \theta_0 \frac{k}{4\alpha^3} \varphi_4 + M_0 \varphi_1 + Q_0 \frac{1}{2\alpha} \varphi_2 - \frac{q_0}{2\alpha} \varphi_3 \qquad (3)$$

$$\sigma_p = \frac{M}{W} \qquad (4)$$

$$\sigma_f = ky \qquad (5)$$

where y_0, θ_0, M_0, Q_0 are the deflection, slope, moment and shear of the left end of the foundation beam (the coordination origin); W is sectional modulus; $\varphi_1, \varphi_2, \varphi_3, \varphi_4$ are hyperbolic trigonometric functions whose definitiions are:

$$\varphi_1 = \mathrm{ch}\alpha x \cos\alpha x \qquad (6)$$

$$\varphi_2 = \mathrm{ch}\alpha x \sin\alpha x + \mathrm{sh}\alpha x \cos\alpha x \qquad (7)$$

$$\varphi_3 = \mathrm{sh}\alpha x \sin\alpha x \qquad (8)$$

$$\varphi_4 = \mathrm{ch}\alpha x \sin\alpha x - \mathrm{sh}\alpha x \cos\alpha x \qquad (9)$$

2. Foundation beam on elastic semi-infinite plane foundation

The presumption of the foundation as an elastic semi-infinite plane is equivalent to presuming that the subgrade under the beam is an infinite elastic body that can be simplified as a plane. Its moment M, piping longitudinal stress σ_p and foundation subgrade reaction σ_f can be computed employing the integral equation of foundation settlement. Here, the approximate flexibility index of the foundation beam is available to both the issues of plane stress and plane strain:

$$t = 10 \frac{E_0}{E} \left(\frac{l}{h} \right)^3 \qquad (10)$$

where E_0 is the elastic modulus of the subgrade;

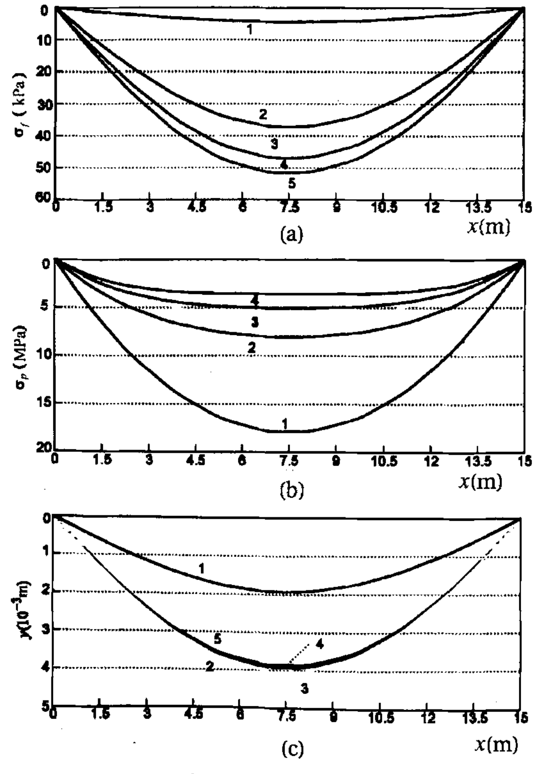
l is the beam half length, and h is the transversal section height of the beam.

ANALYSIS OF COMPUTATIONAL EXAMPLE

A reinforced concrete pipeline was embedded in the silty soil with continuous soil pipe saddle. A pipeline whose length $L = 2l = 15.0$ m was taken as a computational example. The pipeline parameters were: embedded depth $H = 2.0$ m, elastic modulus $E = 0.35 \times 10^5$ kg/cm^3, specific gravity $\gamma_p = 2500$ kg/m^3. The soil parameters were: elastic modulus $E_0 = 160$ kg/cm^3, specific gravity $\gamma_s = 1800$ kg/m^3, and lateral pressure coefficient $n_s = 1.1$. The water specific gravity $\gamma_w = 1000$ kg/m^3.

1. Original parameter method of foundation beam on elastic semi-infinite foundation

In this computation, foundation beam with two fixed ends was considered.



(a)

(b)

(c)

Fig. 1 Computational example using original parameter method with variable central angles

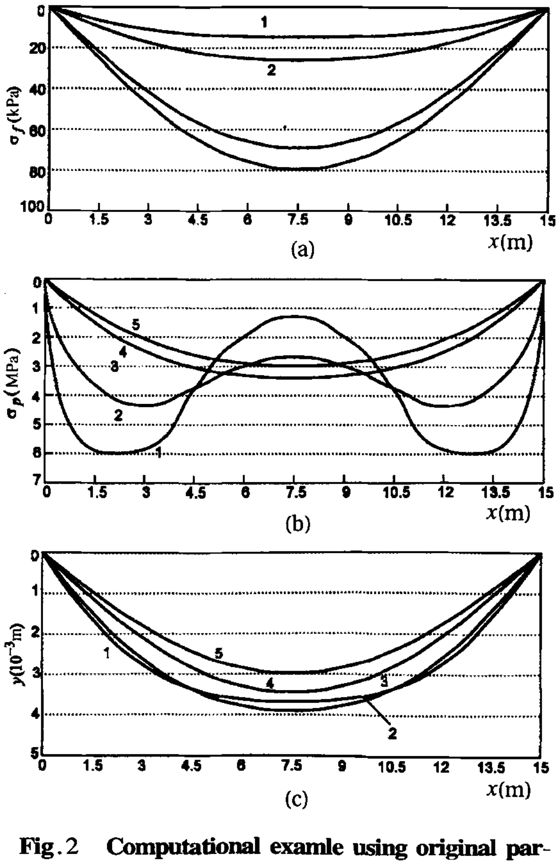
(a) subgrade reaction distribution; (b) longitudinal stree distribution; (c) piping deflection

The central angle: 1. 20°; 2. 90°; 3. 120°; 4. 135°; 5. 180°.

Central angle of pipe saddle variable Fig. 1 shows the distribution of subgrade reaction σ_f, deflection of pipeline y and longitudinal stress of pipe σ_p (the maximum tensile stress of the section) when the pipe saddle has different central angles.

With increasing pipe saddle central angle, the subgrade reaction is increased while the longitudinal stress is reduced. When the pipe saddle central angle is larger than 90°, the subgrade reaction, pipeline deflection, and pipe longitudinal stress are varied slowly, especially the deflection, they are hardly turned (Fig. 1). Therefore, it is not necessary to a select big central angle of pipe saddle to improve the longitudinal stress distribution and reduce the piping deflection during the structural design of water supply and drainage engineering piping network.

Pipe diameter variable Fig. 2 is for the case when the pipe caliber is variable and the



(a)

(b)

(c)

Fig. 2 Computational examle using original parameter with variable angles pipe diameter

(a) subgrade reaction distribution; (b) longitudinal stress distribution; (c) piping deflection

The pipe diameter: 1. 30cm; 2. 50cm; 3. 100cm; 4. 150cm; 5. 200cm.

pipe saddle central angle is limited to 180°. The pipeline deflection does not reduce until the pipe diameter is larger than 1.0 m, and the reducingrange is small (Fig. 2c). So the pipe diameter is not the major factor which influences the pipeline deflection.

On the other hand, with decreasing pipe diameter, the maximum value of the longitudinal stress curve not only increases (Fig. 2b), but also has two reversals near the pipeline ends or attached piers when the pipe diameter is less than 1.0 m. It can be used to predict the position of breakage and explain why small and medium diameter pipe are always broken or burst near the checking well or attached pier.

When the pipe diameter is increased, the weight of the pipeline and water are increased and the subgrade reaction is increased. (Fig. 2a).

Above all, the influence of pipe diameter on longitudinal stress and subgrade reaction is greater than on pipeline deflection. Relative large diameter could be adopted properly with the aim of improving the piping longitudinal stress if the conditions permit.

2. Foundation beam on elastic semi-infinite plane foundation

The beam with free ends is considered here. The computational results are shown in Fig. 3. When the foundation is assumed to be an elastic semi-infinite plane, the subgrade reaction is infinite at the bean ends is greater than the actual pipeline deflection and can't meet the actual requirements.

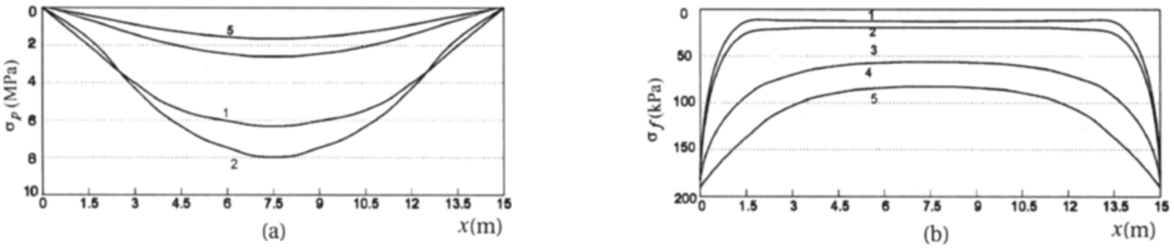


Fig.3 Computational example assuming beam on elastic semi-infinite plane
(a) subgrade reaction distribution; (b) longitudinal stress distribution
The pipe diameter: 1.30cm; 2.50cm; 3.100cm; 4.150cm; 5.200cm.

In this paper, fixed beam ends are assumed in the computation using the original parameter method while free ends are assumed in the computation using elastic semi-infinite plane foundation. They show one common tendency: the longitudinal stress of the small diameter pipeline is larger than that of bigger diameter pipeline.

CONCLUSIONS

The bigger the central angle is, the more slowly σ_f, y and σ_p vary; especially when the central angle is larger than 90°. So a big central angle is not always necessary when the central angle of the pipe saddle is larger than 90°. When the pipe diameter is small (less than 1.0 m), the expansion joint should be placed near the check-well or built-in attached pier to improve longitudinal stress distribution and to avoid the possibility of breakage or leakage of pipes. If conditions permit, big pipe diameter is more preferable.

The original parameter method of foundation beam is available to be applied to predict the broken position of small and medium diameter service pipes.

References

Shao, W.Y., Zhang, T.Q. and Wu, S.R., 1996. Characteristic analysis of projecting conduit, Proceedings of '96 International Conference on the Development of Urban Infrastructure. Zhejiang University Press, Hangzhou, China, p.600 - 606.

Wu, Z.S. and Liang, M.H., 1996. The selection and development of piping material for water-supply/drainage engineering, Proceedings of '96 International Conference on the Development of Urban Infrastructure. Zhejiang University Press, Hangzhou, China, p. 586 - 593.

Yuan, Y.X. and Guo, L.J., 1994. The accident reason and preventive measurement of service pipe. *J. of Water and Wastewater Eng.*, **19**(1): 49 - 51.