PERMAFROST - Seventh International Conference (Proceedings),
Yellowknife (Canada), Collection Nordicana No 55, 1998

ADFREEZE STRENGTH OF MODEL PILES IN FROZEN SOIL UNDER DYNAMIC LOADS

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Abstract

Based on experiments, this paper discusses the adfreeze strength of model piles under dynamic loads. The test results indicate that the adfreeze strength under dynamic loading decreases rapidly with elapsed time under all test conditions, and that the decrease speed is faster than that under static loading. Under the same test conditions, adfreeze strength decreases linearly with increasing frequency of dynamic loading. The moisture content of frozen soil around model piles has a significant effect on the adfreeze strength. As the moisture content of frozen soil approaches the saturation value, the adfreeze strength of model piles reaches a maximum. The rigidity of the pile foundation has an obvious effect on the adfreeze strength of concrete piles: the greater the rigidity, the lower the adfreeze strength. This effect is not obvious for steel-pipe piles.

Introduction

Pile foundations are widely used in permafrost regions, so it is very important to study their behavior under various loads. Presently many test data can be found in the literature; however, most of them are related to static loads (e.g., Wu *et al.*, 1981; Neukirchner, 1988) and the data concerning the behavior of piles under dynamic loads are rather scarce (Parameswaran, 1981; Stelzer and Andersland, 1988). To provide more information on this problem, a systematic research program has been carried out in our laboratory. This paper presents some of the results and focuses on the adfreeze strength of model piles in frozen soil under dynamic loads. In addition, the factors affecting adfreeze strength, including the amplitude and frequency of dynamic loads, the temperatures and moisture contents of frozen soil, the roughness of pile surfaces and the rigidity of pile foundations, are discussed in this paper.

Experimental conditions

Experimental Equipment

The equipment used in the experiments is shown in Figure 1. In order to investigate the effect of pile-surface roughness on adfreeze strength, two kinds of model piles were tested in the experiments. The concrete piles had a diameter of 48 mm and the steel-pipe piles had a diameter of 57 mm. Both were 250 mm in length. The frozen soil samples were 300 mm in diameter and 200 mm in height. The temperature in the thermostatic chamber was controlled with a cold bath and was accurate to 0.2˚C according to our measurements.

Sample Preparation

The soil used in the experiments was Lanzhou loess (silt) with a plastic limit of 15.3 and a liquid limit of 23.0. The dry density of the soil samples chosen for this study was about 1.60 g/cm^3 and their corresponding saturated water contents were 25-28%. After the soil was air dried, it was sieved to remove foreign matter and then mixed with distilled water. When the moisture

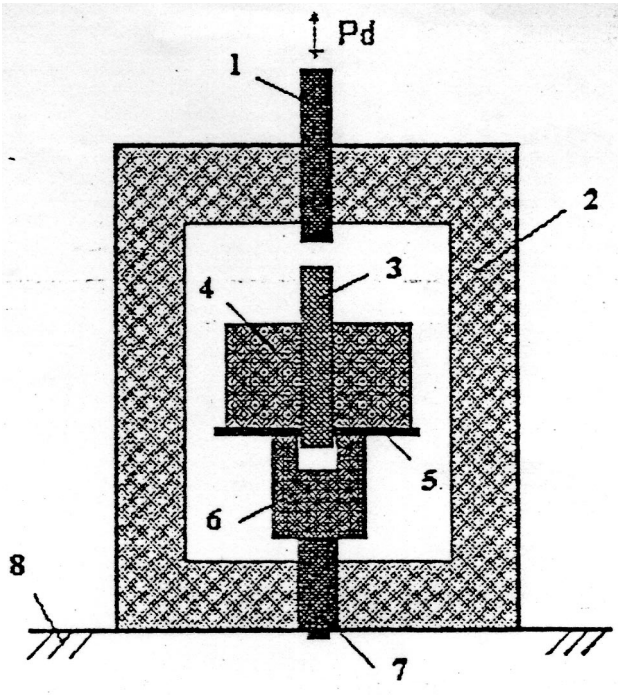


Figure 1. Schematic diagram of experimental equipment. 1-piston rod 2-thermostatic chamber 3-model pile 4-frozen soil 5-steel plate 6-nylon column 7-steel column 8-base plate

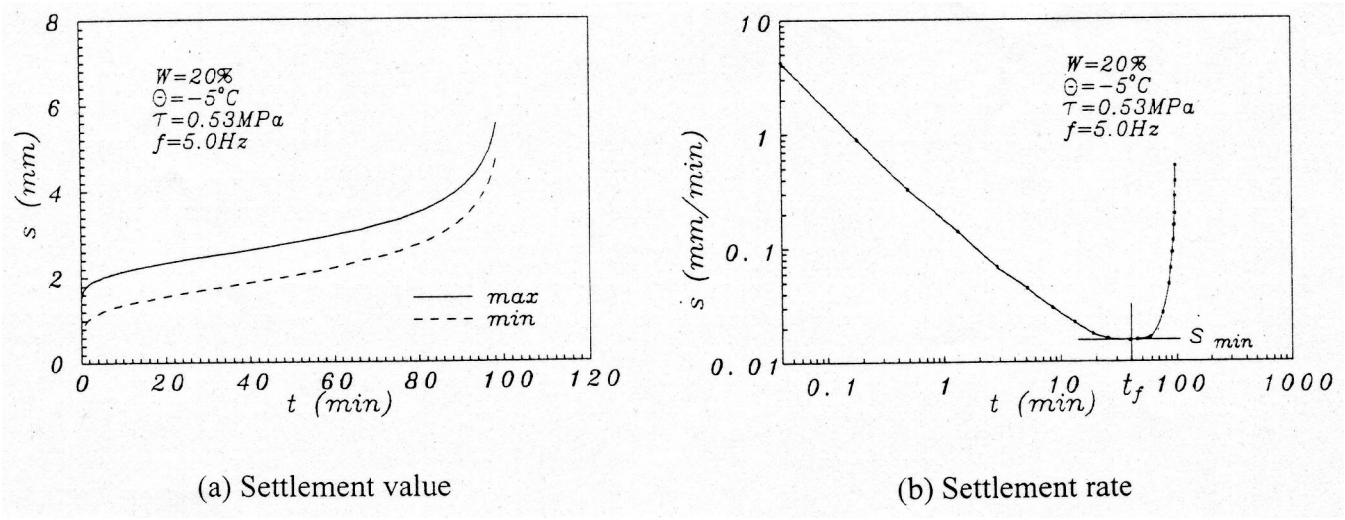


Figure 2. Settlement process of model pile: (a) settlement amount; (b) rate of settlement.

of the soil was satisfactory for the experiments, the soil was compacted around the model piles and carried into a cold room to freeze for more than 48 hours. Before testing, the samples were kept in a thermostatic chamber for another 48 hours to ensure that the temperature in the samples was uniform.

Test Method

All of the tests were conducted with a Material Test System (MTS). The dynamic loads were all controlled by a sine wave provided by a computer program. During the testing process, the maximum load, minimum load (approximately zero) and the frequency of dynamic loads were all kept constant and applied to the top of the model piles vertically through the loading piston. The displacement (settlement) values and the adfreeze strength were monitored and recorded against elapsed time by the computer. One hundred readings were taken during a loading cycle.

Experimental results

Pile Settlement Process

The settlement process for the model piles under a certain dynamic load is shown in Figures 2a and 2b). These figures show that the settlement process for model piles is similar to the creep process in frozen soil. Thus, following the method of creep test analysis, we defined the time when the settlement rate reached the minimum as the failure time of adfreeze strength, as shown in Figure 2b.

Long-term Adfreeze Strength

According to the failure time of the adfreeze strength defined in Figure 2b and the relevant load, we obtained the long-term adfreeze strength curves shown in Figure 3. In this figure we found that all the curves could be described by the following equation:

$$\tau = \frac{\beta}{\ln \frac{t_f}{\alpha}} \qquad [1]$$

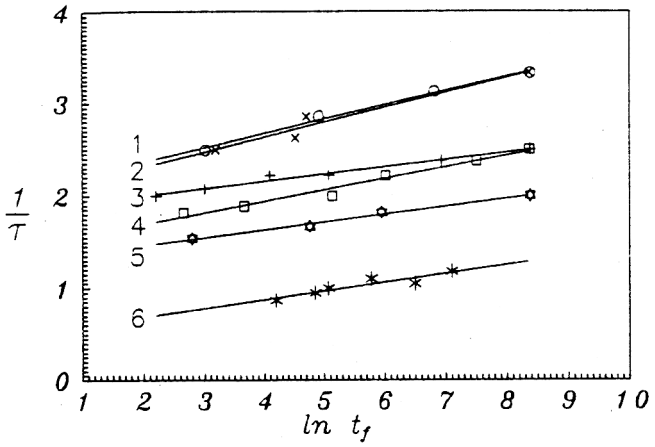


Figure 3. Adfreeze strength versus failure time. Note: numbers correspond with the numbers in Table 1.

Table 1. Values of α and β in equation (1)

№	type of pile	Temperature (℃)	Moisture (%)	Frequency (Hz)	Rigidity (kN/mm)	α	β	r
1	Steel-pipe	-5	20	5	21	1.52×10^{-6}	6.50	0.994
2	Steel-pipe	-5	20	5	18	4.15×10^{-6}	6.21	0.988
3	Concrete	-5	20	5	21	8.62×10^{-6}	8.07	0.973
4	Concrete	-5	20	0	21	3.54×10^{-11}	12.99	0.977
5	Concrete	-5	20	5	18	2.47×10^{-7}	11.77	0.988
6	Concrete	-10	20	5	21	4.48×10^{-3}	10.75	0.870

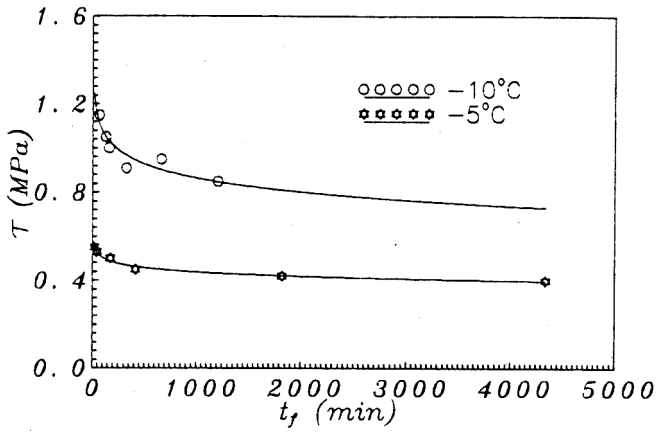


Figure 4. Long-term adfreeze strength curves for concrete piles at different temperatures.

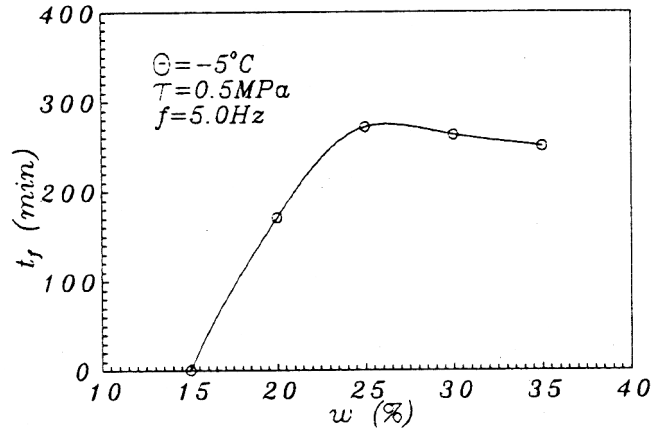


Figure 5. Failure time of adfreeze strength versus water content in frozen soil.

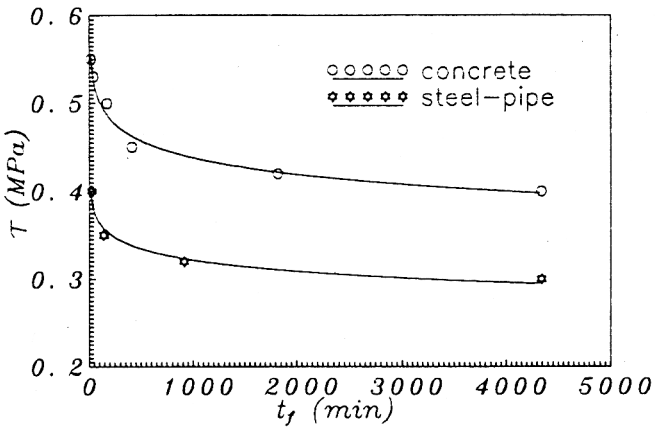


Figure 6. Long-term adfreeze strength curves under different pile surface roughness.

Where τ is the adfreeze strength in MPa, t_f is the failure time in minutes, and α and β are parameters depending on the test conditions (see Table 1).

Discussion

Temperature Effect

Figure 4 provides two long-term adfreeze strength curves of concrete piles at the temperatures of -5˚C and -10˚C respectively, in which all the other test conditions are the same (W=20%, f=5Hz). In this figure we can see that both of the adfreeze strengths decrease with the elapsed time. Under the same elapsed time, the adfreeze strength at -10˚C is much higher than that at -5˚C. This indicates that the temperature of the frozen soil has a significant effect on the adfreeze strength under dynamic loading, as it has under static loading.

Moisture Effect

Figure 5 shows the relationship between the failure time of adfreeze strength and the water content in frozen soil. This curve indicates that, when the water content is less than a certain value (in this case, when W<15%), the adfreeze strength is rather low. Afterwards, the adfreeze strength increases with the increasing water content. As the water content of frozen soil approaches its saturation value (25%) the adfreeze strength reaches a maximum. When the water content exceeds its saturated value, the adfreeze strength remains almost constant. From this analysis we can conclude that the water content in the frozen soil around the piles has a very important effect on the adfreeze strength under dynamic loading.

Roughness of Pile Surface

Figure 6 provides two long-term adfreeze strength curves for concrete piles (rough surface) and steel-pipe piles (smooth surface), in which all the other test conditions are the same (W=20%, T=-5˚C, f=5Hz). In this figure we can see that the adfreeze strength of concrete

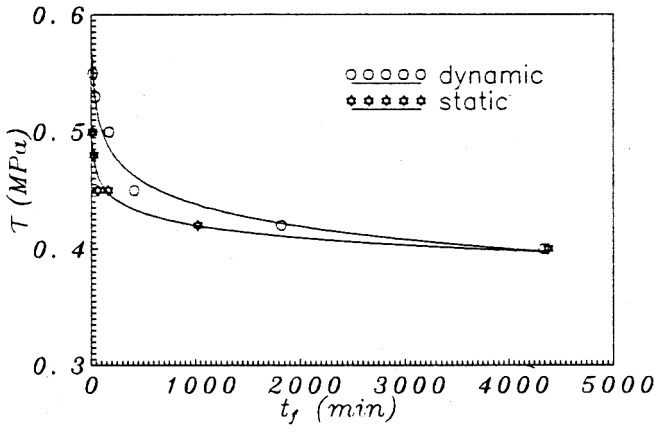
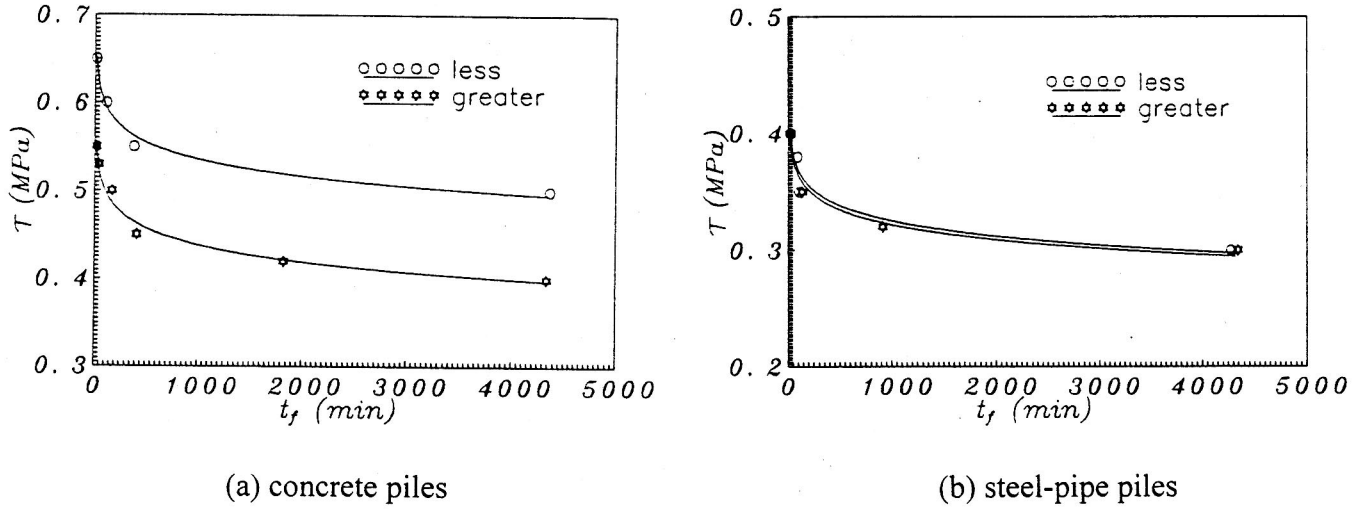


Figure 7. Long-term adfreeze strength curves of concrete piles under different types of load.



(a) concrete piles

(b) steel-pipe piles

Figure 8. Long-term adfreeze strength curves under different rigidity of pile foundations; (a) concrete piles; (b) steel-pipe piles.

piles is higher than that of steel-pipe piles. This indicates that the surface roughness of the model piles has an obvious effect on the adfreeze strength: the rougher the pile surface, the higher the adfreeze strength. So an effective way to increase the adfreeze strength is to increase the roughness of the pile surface.

Type of Loading

Figure 7 shows two long-term adfreeze strength curves for concrete piles under dynamic loading (f=5Hz) and static loading, in which all the other test conditions are the same (W=20%, T=-5°C). In this figure we see that both of the adfreeze strengths decrease with elapsed time, but the rapidity of decrease is different. During the initial period of loading, the adfreeze strength under dynamic loading is higher than that under static loading. With longer-term loading, the adfreeze strength under dynamic loading becomes less than that under static loading. This indicates that the failure mechanism of adfreeze strength between dynamic loading and static loading is different. Under static loading, the process of pile settlement might be related to rheological processes in frozen soil, but under dynamic loading, it might be more related to the fatigue process of the frozen soil structures. We must pay close attention to this problem when designing pile foundations under dynamic loading.

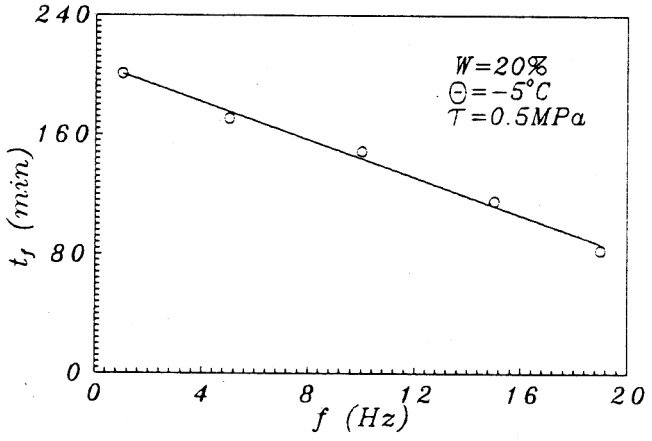


Figure 9. Failure time of adfreeze strength versus frequency of dynamic loads.

Rigidity of Pile Foundation

Figures 8a and 8b show the effect of the rigidity of pile foundation on the adfreeze strength under dynamic loading. In these tests, the rigidity of the pile foundation was changed by changing the rigidity of steel plate under the soil samples and it was measured at 18 kN/mm and 21 kN/mm respectively. Figure 8a indicates that the rigidity of the pile foundation has an obvious effect on the adfreeze strength of concrete piles: the greater the rigidity, the lower the adfreeze strength. But, Figure 8b indicates that the change of rigidity has little effect on the adfreeze strength of steel-pipe piles.

Frequency of Dynamic Load

Figure 9 shows the effect of frequency of dynamic loading on the failure time of adfreeze strength of concrete piles. In this figure we can see that the failure time of adfreeze strength decreases linearly with increasing frequency of dynamic loading. This indicates that the adfreeze strength of concrete piles decreases with the increase of frequency under dynamic loading.

Conclusions

1. The temperature of frozen soil has a significant effect on the adfreeze strength of model piles under dynamic loading: the lower the temperature, the higher the adfreeze strength.

2. As the moisture content of frozen soil approaches its saturation value, the adfreeze strength of model piles under dynamic loading reaches a maximum.

3. The roughness of the pile surface has an obvious effect on the adfreeze strength of model piles: the

rougher the pile surface, the higher the adfreeze strength.

4. During an initial period of loading, the adfreeze strength under dynamic loading is higher than that under static loading. During longer-term loading, the adfreeze strength under dynamic loading becomes less than that under static loading.

5. Under dynamic loading, the rigidity of the pile foundation has an obvious effect on the adfreeze strength of concrete piles: the greater the rigidity, the lower the adfreeze strength. However, this effect is not obvious on the adfreeze strength of steel-pipe piles.

6. In the range of 1-20 Hz, the adfreeze strength of concrete piles decreases linearly with the increasing frequency of dynamic loads.

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