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DYNAMIC STRENGTH AND ACCUMULATED PLASTIC STRAIN DEVELOPMENT LAWS AND MODELS OF THE REMOLDED RED CLAY UNDER LONG-TERM CYCLIC LOADS: LABORATORY TEST RESULTS

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ABSTRACT

The dynamic strength and accumulated plastic strain are two important parameters for evaluating the dynamic response of soil. As a special clay, the remolded red clay is often used as the high speed railway subgrade filling, but studies on its dynamic characteristics are few. For a thorough analysis of the suitability of the remolded red clay as the subgrade filling, a series of long-term cyclic load triaxial test under different load histories are carried out. Considering the influence of compactness, confining pressure, consolidation ratio, vibration frequency and dynamic load to the remolded red clay dynamic property, the tests obtain the development curves of the dynamic strength and accumulated plastic strain under different test conditions. Then, through curve fitting method, two different hyperbolic models respectively for the dynamic strength and accumulated plastic strain are built, which can match the test datum well. By applying the dynamic strength model, the critical dynamic strength of the remolded red clay are gained. Meanwhile, for providing basic datum and reference for relevant projects, all key parameters for the dynamic strength and accumulated plastic strain of the remolded red clay are given in the paper.

Keywords: remolded red clay; dynamic property;dynamic strength; accumulated plastic strain

INTRODUCTION

As a special soil, the red clay is widely distributed in southwest and south central areas of China. Through simple treatment, the remolded red clay is often used as the high speed railway subgrade filler. Therefore, whether the high speed railway subgrade filled with remolded red clay meets the relevant requirements is an urgent research topic.

As the base of the high speed railway, the subgrade is the key for ensuring the high speed railway safety operation. Numerous studies [1,2,3,4] show that on one hand the dynamic load caused by the high speed train run aggravates the vibration of the high speed railway subgrade and directly undermines the dynamic stability of the subgrade, on the other hand under long term dynamic load the subgrade dynamic strength would be cumulatively weakened and the plastic strain would be accumulated, which also influences the subgrade stability gradually. Thus, for the high speed railway engineering, the dynamic characteristics of the subgrade filler are the key to influence the engineering stability. As a result, research on the development laws and the describing models of the remolded red clay dynamic strength and accumulated plastic strain under long term cyclic loads has an important significance for evaluating the suitability of the remolded red clay as the high speed railway subgrade filler.

Due to the rare studies on the dynamic properties of the remolded red clay which directly influence the stability of the high speed railway subgrade, a series of cyclic dynamic triaxial tests under different load histories and dynamic load have been carried out, which focus on the development laws of the remolded red clay dynamic strength and accumulated plastic strain under different dynamic loads and obtain their description models. The research achievements have a certain academic value and engineering application value.

DYNAMIC TRIAXIAL TEST OF THE REMOLDED RED CLAY

BRIEF INTRODUCTION OF THE DYNAMIC TRIAXIAL APPARATUS

The dynamic triaxial test used the computer-controlled electro-hydraulic servo dynamic triaxial test system SDT-10. The test system can provide a maximal axial dynamic load of 10kN. The triaxial pressure cell can bear a maximal confining pressure of 1 MPa. The precision of the deformation sensor is better than 0.5%. The precision of the tested strain can reach 10-4. The sample size is Φ39.1*80mm. The provided axial and lateral exciting frequency is 0~5Hz. The provided wave can be sine wave, triangular wave, square wave, trapezoidal wave and user-defined wave and the controlling type can be stress-controlled or strain-controlled.

TEST PROGRAM

The soil sample used in this paper is obtained in the area around the interurban railway from Wuhan to Xianning and is remolded soil, whose physical properties can refer to the front work of the authors [5].

For comprehensive analyzing the developmental and various regulations of the accumulated plastic strain and dynamic strength of the remolded red clay under different long term cyclic loads, the applied dynamic load amplitude remaines unchanged. The test procedure is that firstly different load histories were applied on the remolded red clay sample and then different cyclic loads were applied. In the test procedure, the dynamic mechanical properties of the testing soil sample impacted by different load histories were monitored. The tests are stress-controlled.

The tests considered four factors such as compactness, confining pressure, consolidation ratio and vibration frequency. The specific test programs are shown in tab. 1.

Tab. 1 Short-time dynamic triaxial test program

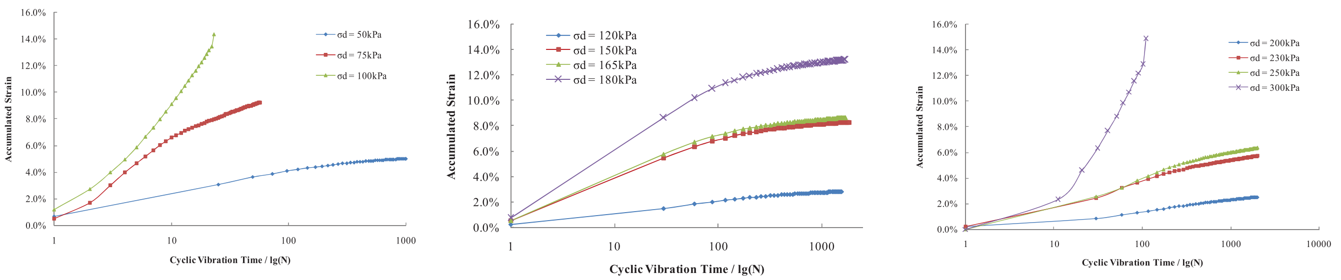
Test ID	Influencing Factors			
	Compactness	Confining Pressure	Consolidation Ratio	Vibration Frequency
DT1-1 DT1-2 DT1-3	0.80 0.85 0.95	50	4.0	1Hz
DT2-1 DT2-2 DT2-3	0.8	25 50 100	3.0/4.0	1Hz
DT3-1 DT3-2 DT3-3	0.8	50	1.0 2.0 3.0	1Hz
DT4-1 DT4-2 DT4-3	0.8	50	3.0	1Hz 2Hz 5Hz

TEST RESULTS AND ANALYSIS

DEVELOPMENT AND MODEL FOR THE ACCUMULATED PLASTIC STRAIN

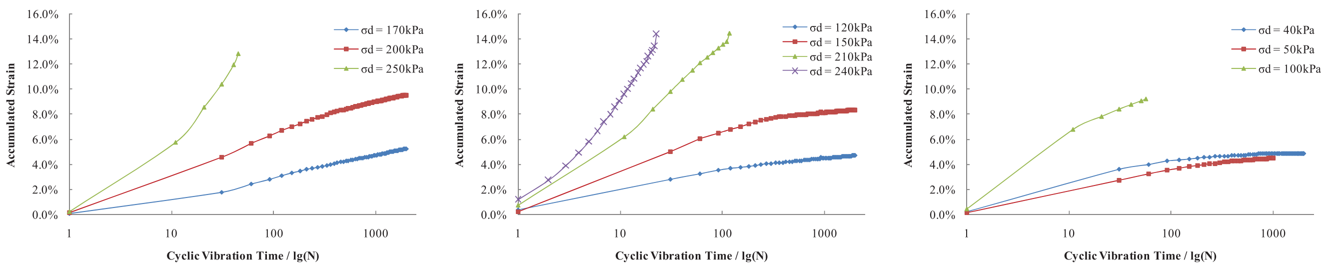
TEST CURVES OF ACCUMULATED PLASTIC STRAIN

Through dealing with the test datum, several accumulated plastic strain curves under different load histories are obtained as shown in Fig.1~4.



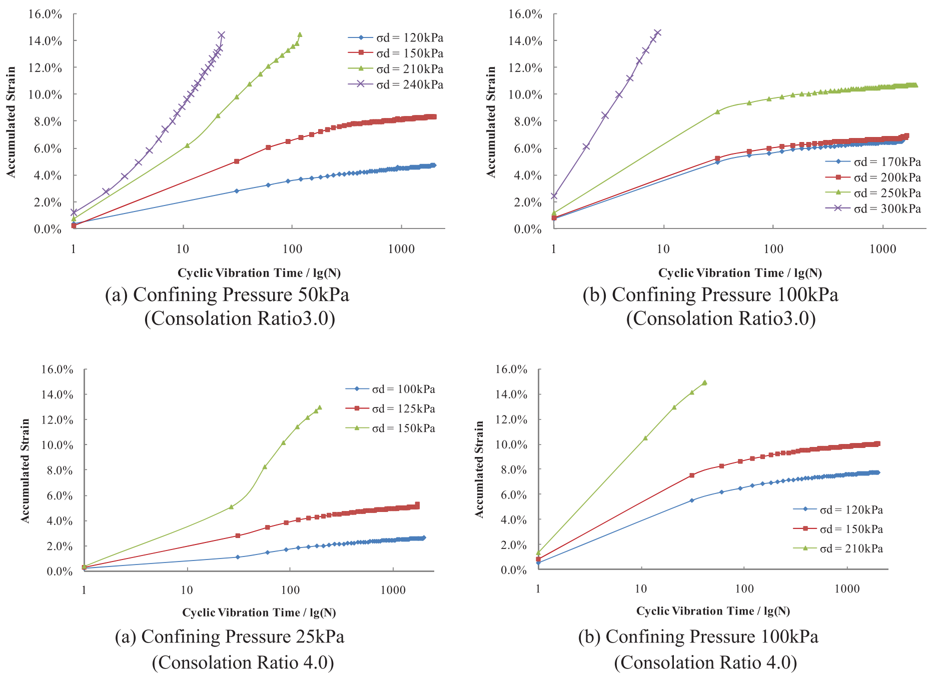
(a) Compactness 0.8 (b) Compactness 0.85 (c) Compactness 0.9

Fig.1 Accumulated strain curves under different compactness (k_c=4.0, σ_3=50kPa, f=1Hz)



(a) Consolation Ratio 2.0 (b) Consolation Ratio 3.0 (c) Consdation Ratio 4.0

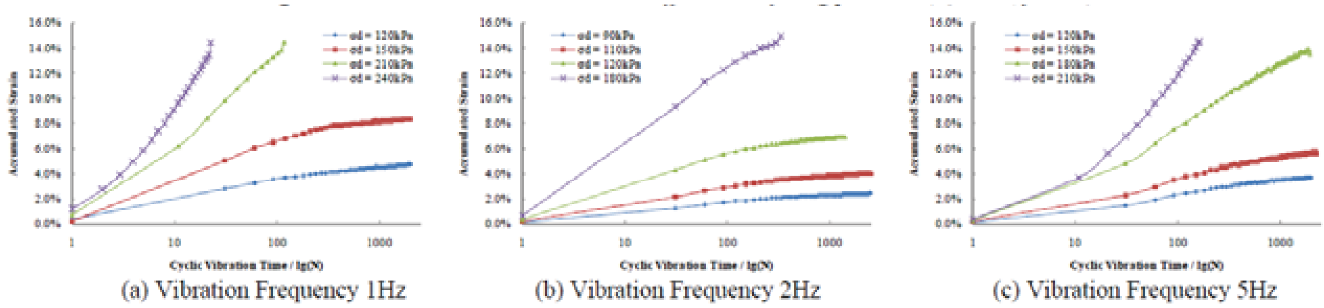
Fig.2 Accumulated strain curves under different consolation ratio (λ_c=0.80, σ_3=50kPa, f=1Hz)



(a) Confining Pressure 50kPa (Consolation Ratio3.0) (b) Confining Pressure 100kPa (Consolation Ratio3.0)

(a) Confining Pressure 25kPa (Consolation Ratio 4.0) (b) Confining Pressure 100kPa (Consolation Ratio 4.0)

Fig.3 Accumulated strain curves under different confining pressure (λ_c=0.80, f=1Hz)



(a) Vibration Frequency 1Hz (b) Vibration Frequency 2Hz (c) Vibration Frequency 5Hz

Fig.4 Accumulated strain curves under different vibration frequency (λ_c=0.80, σ_3=50kPa, kc=3.0)

From fig. 1~4, it is known that under relatively small dynamic load, the accumulated plastic strain of the remolded red clay develops rapidly in the initial loading stage and as time goes on, it stabilizes gradually due to the compaction of the soil; under relatively large dynamic load, the accumulated plastic strain develops rapidly yet the same in the initial loading stage, but its developing rate is still large in the later loading stage and even under larger dynamic load, the developing rates in all the loading stages are the same and the soil damage in a short time.

MODEL ANALYSIS OF THE ACCUMULATED PLASTIC STRAIN

From the developing curves of the accumulated plastic strain of the remolded red clay, it is known that they can be roughly divided into three types: (1) stable type curve; (2) damage type curve; (3) developmental type curve, which are shown in fig. 5.

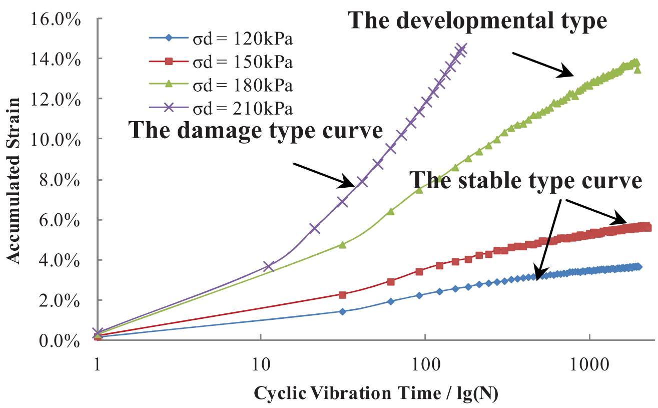


Fig.5 Typical curves of the remolded red clay

As for the describing model of the accumulated plastic strain, there are several proposed models such as the Monismith model [6] and semi-logarithmic model put forward by Stewrat and CAI [7,8] etc. But from analysis, it is known that the proposed models mentioned above cannot fit the accumulated plastic strain curve well because they usually aim at a certain type curve, for example, the models are divergent in the late stage, which cannot reflect the stable type curve. In addition, the fitting effect of these models on the developmental type and damage type curves is also unsatisfactory. As a consequence, a new model is proposed in this research to reflect the development of the remodel red clay accumulated plastic strain.

$$\varepsilon_p = (aN^b)/(1+cN^b)$$

Where, ε_p is accumulated plastic strain; N is vibration time; a, b, c are model parameters.

From eqn. above, it is known that when the vibration time N tends to infinity, the accumulated plastic ε_p is equal to a/c, which mean ε_p tends to a certain value; the shape of the ε_p curve can be reflected by adjusting the parameter b; and the parameter c can reflect the vibration time when ε_p tends to a certain value.

DEVELOPMENT AND MODEL FOR THE DYNAMIC STRENGTH

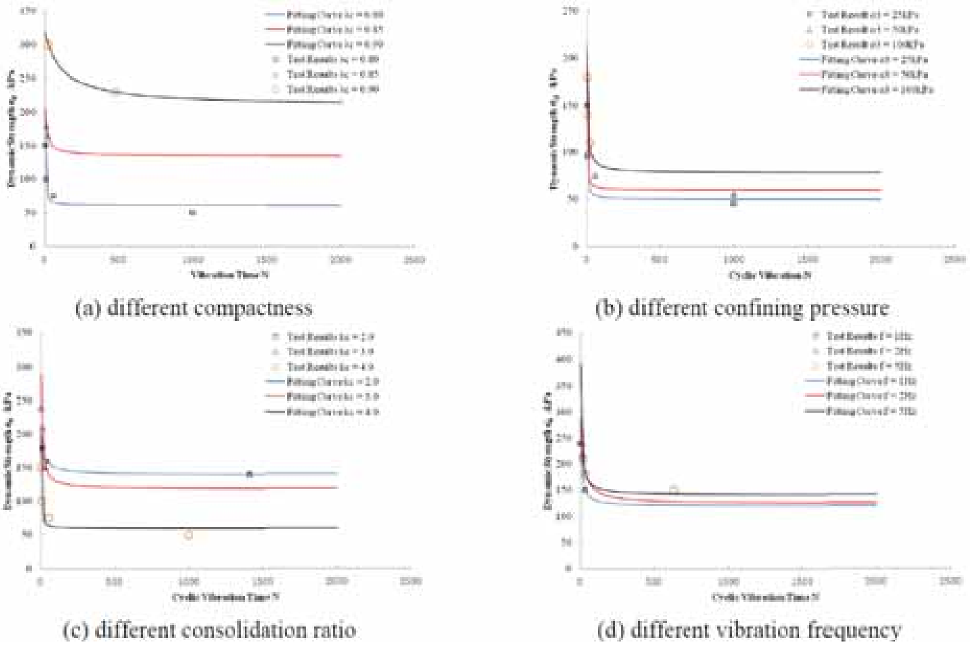
TEST CURVES OF THE DYNAMIC STRENGTH

The soil dynamic strength is different due to the loading rate and cyclic impacting effect of the dynamic stress. It is usually understood to be the stress when the strain reaches a certain damage criterion under some impacting vibration times of the dynamic load [9]. Here, the definition of the dynamic strength means that it is changeable under different conditions. In addition, the dynamic strength is closely related to the cyclic vibration time and the damage criteria. Therefore, how to determine the damage strain is important for discussing the soil dynamic stress.

According to vast researches [10,11,12], the criteria of the dynamic strength are usually divided into three categories: the first criterion is strain; the second criterion is inflection point of the accumulated strain curve; the third criterion is liquefaction. From analysis, it is known that the third criterion is definitely not suitable for clay and the second criterion mainly aims at the saturated soft clay and do not goes for stiff clay. As a consequence, the first criterion is used as the criterion to determine the dynamic strength of stiff clay. For the traffic engineering such as high speed railway, in pursuit of safety and comfort, the subgrade deformation is asked for being less than a certain value in the engineering design and there are requirements for the settlement of the first year, which demand that the dynamic strength criterion must be safe and conservative. Therefore, the criterion for determining dynamic strength in this research is when the accumulated plastic strain reaches 5%.

Fig. 6(a)~6(d) gives the dynamic strength varieties of the remolded red clay under different conditions. It is known that under different test conditions the soil dynamic strength σd decreases in a nonlinear rule with the vibration time. Under effect of relatively large dynamic stress, the soil damage rapidly and along with the decrease of the dynamic load, the damage vibration time gradually increases.

In addition, from the figures it is also known that the soil dynamic strength is improved when the compactness, confining pressure of the soil and the vibration frequency of the dynamic stress is enhanced. But the relation between the consolidation ratio and the dynamic strength is adverse to the other influencing factors. On the other hand, different factors have different effect on the soil dynamic strength. For example, the improvement effect of the soil compactness on the soil dynamic strength is especially apparent, but the influencing effects of other factors are relatively weaker. All these regulations describe the influence of the load histories to the dynamic strength of the remolded red clay.



(a) different compactness (b) different confining pressure

(c) different consolidation ratio (d) different vibration frequency

Fig.6 The remolded red clay dynamic strength and the model fitting effects

THE DYNAMIC STRENGTH VARIETY MODEL AND CRITICAL DYNAMIC STRENGTH

The dynamic strength is an important dynamic parameter of soil under dynamic load to reflect whether the soil damage, therefore, research on variety of the soil dynamic strength has a great significance. In addition, from the analysis above, when the dynamic stress decrease, the vibration time when the soil damage increase and as a consequence, when the dynamic stress is less than a certain value, which is called critical strength σcr defined by Health[13] and demonstrated by many researcher [9,10,11,12,14,15], the soil cannot damage forever. σcr can be gained by the dynamic strength model as following:

$$\sigma_d = c\left(1 - \frac{N}{a + bN}\right)$$

The fitting effects and parameters are shown in Fig.6(a)~6(d). It is known that the fitting effect is well and the square of correlation coefficients reach more than 0.95.

From fig. 6(a)~6(d), it is known that the dynamic strength tends to stable when decreasing to a certain level, which means under this level of the dynamic load, the needed failure vibration time tends to infinity, but the accumulated plastic strain is forever smaller than 5%. This phenomenon demonstrates the existence of the critical dynamic strength σcr from the point of test yet.

The critical dynamic strength of the remolded red clay under different load histories can be gained and can be calculated by the following equation:

$$\sigma_{cr} = 1003.48\lambda_c - 41.43k_c + 0.33\sigma_3 + 8.996f - 597.6$$

CONCLUSION

Through a large number of cyclic dynamic triaxial tests under different load histories and dynamic load, the development laws of the remolded red clay dynamic strength and accumulated plastic strain were studied in detail and on this base their description models were obtained. The main conclusions are as follows:

1. Load histories have a great effect on the dynamic properties of the remolded red clay, but different load histories have different influencing laws. By improving the compactness, confining pressure and vibration frequency, the soil ability to resist external load is improved which lead that the accumulated plastic strain development is slowed down and the soil critical dynamic strength is improved, but due to the influence of the nature and state of the soil itself, the effects of compactness and confining pressure are more obvious. On the contrary, the accumulated plastic strain is accelerated to develop and the critical dynamic strength is lowered by improving the consolidation ratio because it causes relatively large partial stress and promotes the development of the local damage in soil.
2. The dynamic strength and accumulated plastic strain of the remolded red clay can be well described by the models proposed in this paper. The models can reflect the three different test curves at the same time and has a high correlation coefficient with the test datum. At the same time, the empire equation for the critical dynamic strength of the remolded red clay is also given. All these models can provide basic datum and reference for the related engineering.
3. For the high speed railway engineering, in pursuit of safety and comfort, the criterion for determining dynamic strength is suggested to be when the accumulated plastic strain reaches 5%.

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