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EXPERIMENTAL ANALYSIS OF DYNAMIC MECHANICAL PROPERTIES FOR ARTIFICIALLY FROZEN CLAY BY THE SPLIT HOPKINSON PRESSURE BAR

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A device for impact compression experiments is the split Hopkinson pressure bar with a refrigerating attemperator. Data for incident and reflected waves are obtained by the measuring technique with strain gauges, and data for transmitted waves are obtained by the measuring technique with semiconductor gauges. Static compression tests of frozen clay are conducted at an identical temperature and different strain rates of 0.001 *and* 0.01 $\sec^{-1}$*. Dynamic stress-strain curves are obtained at strain rates of* 360–1470 $\sec^{-1}$*. The low and high temperatures correspond to high and low strain rates, respectively. It is shown that both the temperature and strain rate affect the frozen soil deformation process. Different dynamic stress-strain curves obtained at the same temperature but different strain rates are found to converge. The test results indicate that frozen soil has both temperature-brittleness and impact-brittleness.*

Key words: *frozen clay, dynamic properties, split Hopkinson pressure bar.*

Introduction. The mechanical research on frozen soil is a young science. At present, the experimental research on frozen soil is mainly focused on static mechanics [1, 2]. The dynamic mechanical research is mostly carried out at low frequencies or small amplitudes of the waves. In solving problems associated with digging in frozen soil, however, it is urgent to understand its mechanical behavior under impact loads. The Sandia National Laboratory has performed some research on the dynamic mechanical behavior of perennial frozen soil in Alaska [3].

The experiment described in the paper addresses the dynamic mechanical behavior of frozen soil, discussing the effects of strain rates and temperature. A split Hopkinson pressure bar (SHPB) test of frozen clay is performed at different temperatures and different strain rates. Static compression tests of frozen clay were conducted at the same temperatures at different strain rates with a DCS-5000 material test machine (Japan).

1. Experiment Scheme. Frozen clay samples collected from a certain shaft at a depth of 220–225 m in the Anhui province were considered. Its dry density was 1710 kg/m^3, and its moisture content was 21.42%. The samples 34 mm in diameter and 18 mm long were frozen in metal moulds for 24 h. Then, the moulds were removed, and the samples were frozen for the next 24 h at the same temperature, prepared for dynamic and static experiments.

The device for the impact compression experiment was the split Hopkinson pressure bar 37 mm in diameter with a refrigerating attemperator (Figs. 1 and 2). The pressure bar was made of aluminum. The data for the incident and reflected waves were obtained by the measuring technique with strain gauges. As the wave impedance of frozen soil is very low and the signal of the transmitted wave is still weak, semiconductor strain gauges were installed on the transmission bar to collect the signal of the transmitted wave.

The SHPB test was carried out at seven different low temperatures $T_0 = -5, -7, -10, -12, -15, -17$, and -20°C, and with four different strain rates $\dot\varepsilon$ for each value of T_0 (Table 1). The static experiment, to be compared with the impact compression experiment, was performed at $\dot\varepsilon = 0.001$ and 0.01 $\sec^{-1}$.

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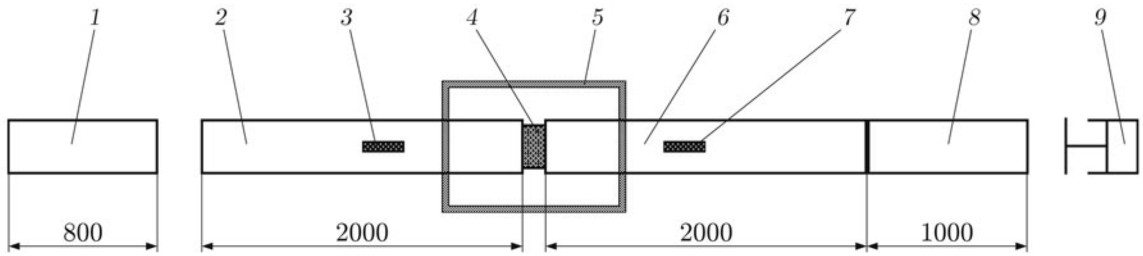

Fig. 1. Sketch of the SHPB system used for the frozen soil test: 1) striker bar; 2) incident bar; 3) strain gauges; 4) frozen soil sample; 5) low-temperature enclosure; 6) transmission bar; 7) semiconductor strain gauges; 8) output bar; 9) buffer.

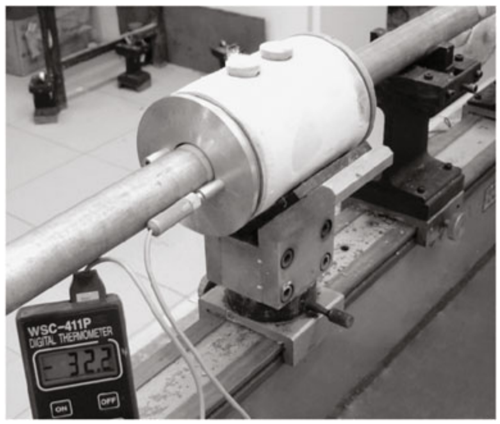

Fig. 2. Split Hopkinson pressure bar with a refrigerating attemperator.

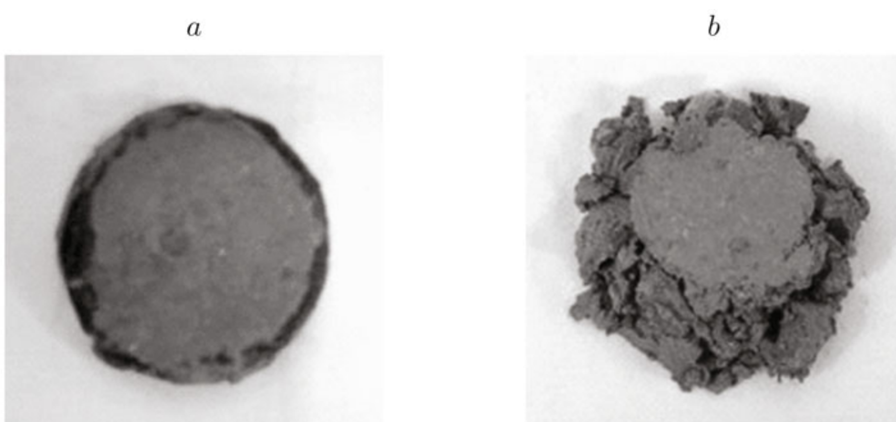

Fig. 3. Samples after compression experiments: (a) static compression at $T_0 = -20°$C; (b) dynamic compression at $T_0 = -7°$C and $\dot{\varepsilon} = 300$ sec^{-1}.

2. Experimental Analysis. The sample photographs taken after static and dynamic impact compression experiments are shown in Fig. 3.

Figures 4 and 5 show the stress as a function of the strain at different temperatures and strain rates. It is seen in Fig. 4 that the stress increases with decreasing temperature at the same strain rate $\dot{\varepsilon}$. The temperature exerts a significant effect on the static and dynamic mechanical behavior of frozen soil. It follows from Fig. 5 that the stress increases with increasing strain rate at the same temperature. The strain rate exerts a significant effect on the static and dynamic mechanical behavior of frozen soil.

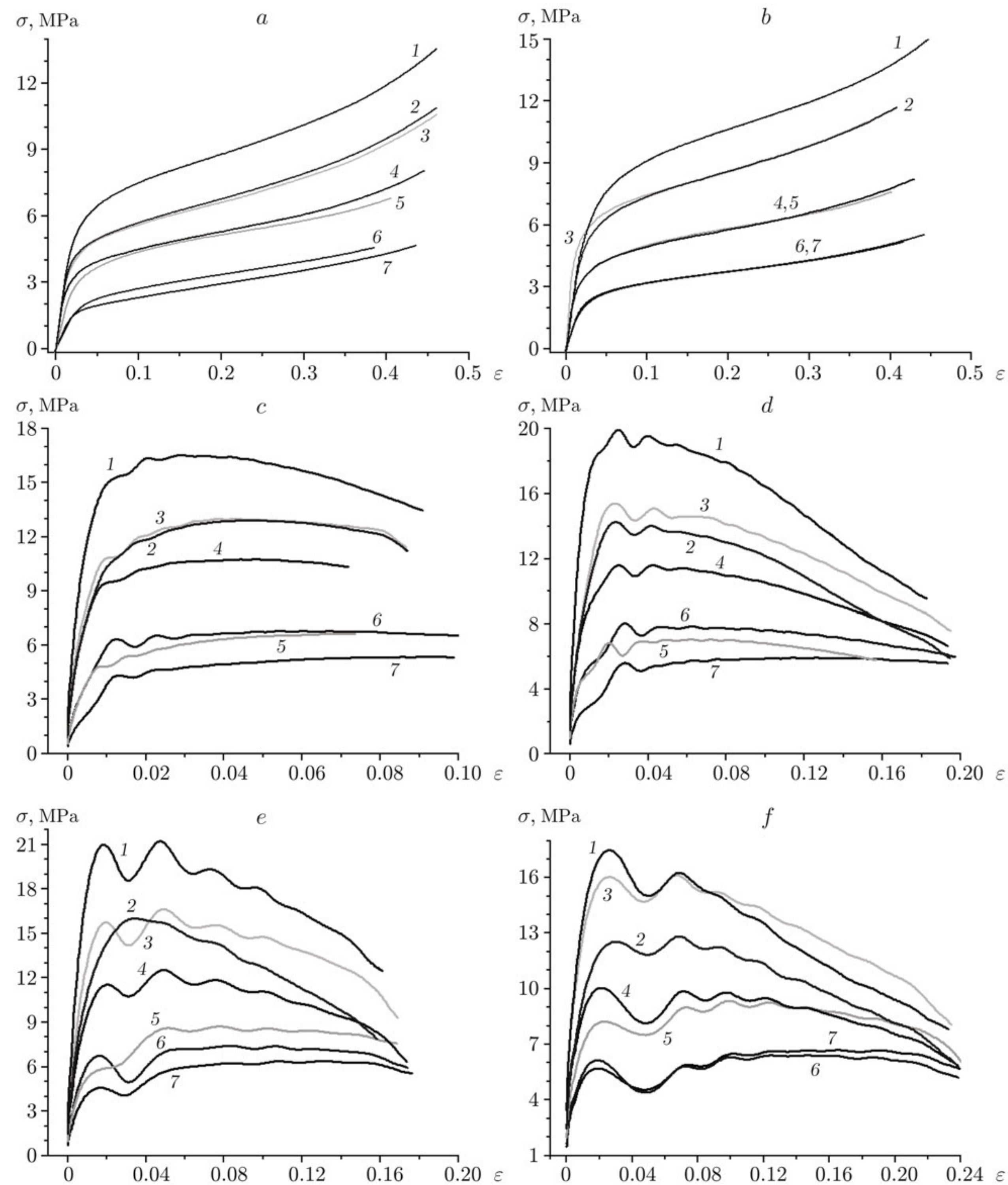

Fig. 4. Stress–strain curves at strain rates $\dot{\varepsilon} = 0.001$ (a); 0.01 (b), 300 (c), 600 (d), 1050 (e), and 1450 $\sec^{-1}$ (f) and temperatures $T_0 = -20$ (1), -17 (2), -15 (3), -12 (4), -10 (5), -7 (6), and -5°C (7).

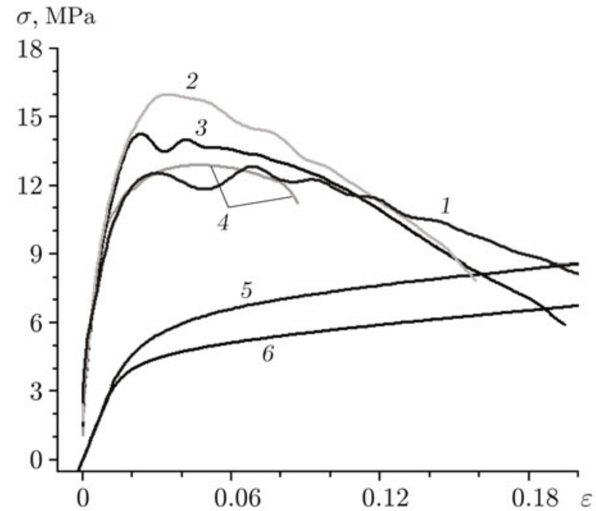

Fig. 5. Stress–strain curves at $T_0 = -17°$C and rates $\dot{\varepsilon} = 1445$ (1), 1028 (2), 622 (3), 284 (4), 0.01 (5), and $= 0.001$ sec^{-1} (6).

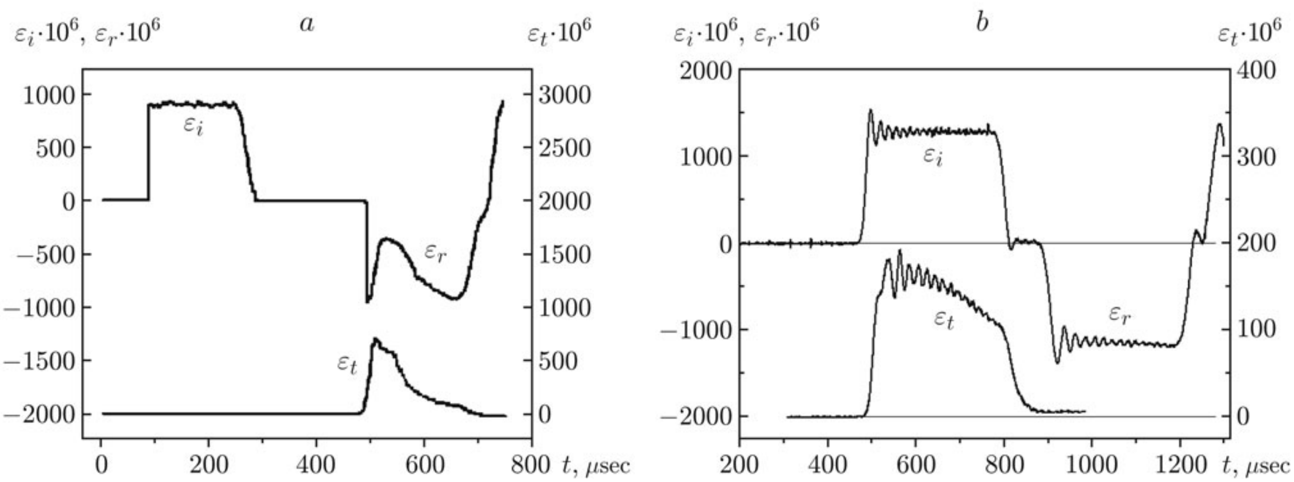

Fig. 6. Strain curves in the incident (ε_i), reflected (ε_r), and transmitted (ε_t) waves: (a) granite [4]; (b) frozen soil.

These dependences show that frozen soil has a time-temperature equivalent property. Low test temperatures correspond to high strain rates, and, vice versa, high temperatures correspond to low strain rates. Figure 4 shows that the dynamic stress–strain curves obtained at the same strain rate but at different temperatures converge. The higher the strain rate, the more obviously the curves converge, approaching the curve corresponding to the highest temperature.

Figure 5 shows that the dynamic stress–strain curves obtained at the same temperature but at different strain rates also converge. The lower the test temperature, the more obviously the curves converge. The curves converge to the curve corresponding to the lowest strain rate. The converging phenomenon occurs because breakdown of the samples plays an unimportant role in their carrying capacity. The converging phenomenon also reflects the instability of frozen soil. The instability cannot appear under quasi-static conditions (see Figs. 4a and 4b), but it is manifested under dynamic conditions. The experimental results show that frozen soil has both temperature-brittleness and impact-brittleness, which reflect the time-temperature equivalence property of frozen soil.

The stress–strain curves in Figs. 4 and 5 display obvious oscillations, which are enhanced with a decrease in temperature or an increase in strain rate. These oscillation are induced by the temperature-brittleness and

TABLE 1

Average Strain Rates under Dynamic Loading at Different Temperatures

T_0, °C	$\dot{\varepsilon}$, $\sec^{-1}$
−5	350, 660, 1080, 1470
−7	350, 650, 1060, 1450
−10	260, 540, 1100, 1470
−12	270, 630, 1050, 1450
−15	260, 620, 1020, 1430
−17	280, 620, 1030, 1440
−20	300, 590, 980, 1440

impact-brittleness of frozen soil, rather than by two-dimensional effects caused by propagation of elastic waves in finite-diameter bars. To demonstrate these conclusions, impact compression experiments were performed with soft materials, such as polyurethane foam cement and foam aluminum, under the same experimental conditions. The profiles for the transmitted waves are smooth. The profiles of the transmitted waves obtained in impact compression tests of frozen soil display oscillations responsible for the oscillations on the dynamic stress–strain curves.

The brittleness of frozen soil is much smaller than that of rock [4]. The latter will collapse even in experiments under quasi-static compression conditions (Fig. 6). Rock collapses abruptly and frozen soil slowly, but frozen soil collapses more quickly with decreasing temperature or increasing strain rate. The amplitude and period of oscillations of the transmitted waves increase.

Conclusions. Frozen soil samples were investigated at different temperatures and strain rates with the use of the split Hopkinson pressure bar. Both the test temperature and the strain rate affect the frozen soil properties under dynamic loading. Moreover, the temperature and strain rate exert a significant effect on the stress–strain dependences. This fact reflects the time–temperature equivalence property of frozen soil. The time–temperature equivalence property of frozen soil is caused by its temperature-brittleness and impact-brittleness.

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REFERENCES

1. Xu Xueyan, Zhong Congli, Chen Yaming, and Zhang Jiayi, "Research on dynamic characters of frozen soil and determination of its parameters," *Chinese J. Geotech. Eng.*, **5**, No. 20. 77–81 (1998).
2. Zhao Shuping, Zhu Yuanlin, He Pin, and Yang Chengsong, "Recent progress and suggestion in the research on dynamic response of frozen soil," *J. Glaciology Geocryology*, **5**, No. 24. 681–686 (2002).
3. Moo Y. Lee, A. Fossum, L. S. Costin, and D. Bronowski, "Frozen soil material testing and constitutive modeling," Report No. SAND2002-0524, Sandia National Laboratory, USA (2002).
4. Liu Jianfei, Hu Shisheng, Hu Yuanyu, and Zhao Jian, "Research on dynamic compressive testing and mechanics properties of granite," *Chinese J. Rock Mech. Engng*, **19**, No. 5. 618–621 (2000).