Snow Consolidation Properties by using Mechanical Press Machine

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Abstract: This study develops high-speed snow compressor (HSSC) to assist the snow disposal at aging and depopulation marginal society by reducing the disposal volume. The snow consolidation density by using square cross-section pressure vessel and mechanical press machine was investigated for obtaining newly fundamental data. Also, back pressure on the inner lateral wall of the pressure vessel was investigated to confirm an occurrence of ununiform deformation of the snow or not. Some tests for different geometry conditions of \(H/W = 0.5, 1.1,\) and \(1.7\) were performed to investigate the geometry effects on the snow consolidation properties, respectively. Here parameter \(H\) and \(W\) show the height and width of the pressure vessel, respectively. By the result, it was found that the snow was easily consolidated by lower axial formation pressure compared with cases by using a hydraulic press machine. Moreover, the snow consolidation properties by using a mechanical press machine were almost the same for \(H/W = 0.5, 1.1\) and \(1.7\). And the occurrence of large impulsive force at the bottom dead center was observed, but the excessive large force is not related to increase the snow compaction density was found quantitatively.

Keywords: Aging society issue, Snow disposal, Depopulation, Dynamic deformation, Impulsive force

1. Introduction

Recently depopulation and labor shortage problem with aging society progress have become big issue in Japan. The authors investigate some procedures to assist snow disposal at marginal society for long time as one of the issues [1]-[3]. By field work result it was found that there are many elderly people who are over 80 years old cannot perform snow removal work by themselves, and some healthy elderly people who are from 60 to 70 years old helped or performed snow removal work of those elderly people houses. And it was found that they have the problem to transport huge amount of snow to dispose it at snow removal work. Therefor authors develop the HSSC to assist the snow disposal of elderly person by reducing its volume. And it was found that they have the problem to transport huge amount of snow to dispose it at snow removal work. Therefor authors develop the HSSC to assist the snow disposal of elderly person by reducing its volume.

By literature survey, in past years, some researchers have researched dynamics and statics mechanics on natural science of snow. Some international collaborate reaches are performing. Especially Schweizer et al. are leading advanced fundamental science researches for long time [4]-[14]. It is fairly and clearly elucidated the nature science phenomena of mechanical properties of the snow and snow avalanche by their devoted and consecutive accomplishment, they have given fracture criterion of the snow as most important information by both of theoretical and experimental investigations. Furthermore, some researchers have investigated snow consolidation procedures [15]-[19]. Their result are widely variety by reason of the experimental condition difference, and the snow consolidation mechanism is not clear yet. And moreover, some researchers have investigated the snow or dry ice extrusion process [20]-[22]. Snow extrusion process is new topic on both of fundamental science research and applied engineering, and it has not been studied enough at all.

And almost above described snow consolidation research were performed under quasi-static state. Recently, in advanced nature science research related to snow is shifted to dynamic mechanics research. But there are not enough fundamental snow consolidation data on dynamics. Therefore, in previous report, authors investigated dynamic snow consolidation properties by using mechanical press machine [2][3]. And by the results, it was doubt that the snow consolidation deformation is not uniform deformation which was assumed by some researchers for long time. Therefore, it needs more additional tests to confirm that. In this research, snow consolidation properties by using mechanical press machine were investigated. And result of that the mechanical press machine under position control was able to increase the compression column density compared with that of using hydraulic hand press machine is shown as follows. And quantitative result which of the impulsive force caused by crosshead inertia at bottom dead center was not
mainly factor of increasing snow compression column density is shown follows.

2. Schematic Explanation of Proposed HSSC

Schematic illustrations of present and proposed snow removal works are shown in Fig. 1 [1]∼[3]. In present process the snow removal work is performed by human-intensive power or the small agricultural wheel loader. The carrying load efficiency is about from 20 to 30 % at best. But in proposed process some snow will be consolidated completely into the ice column by HSSC. And it will be carried onto the truck bed in order. It is thought that as result the carrying load efficiency will increase by 200 to 300 %.

Schematic illustration of proposed HSSC is shown in Fig. 2 [1]∼[3]. The machine will be set on wheel or crawler vehicle housing corresponding to snow removal work condition. Authors investigate relation between axial formation pressure and back pressure on pressure vessel lateral wall during snow consolidation formation to ensure integrity of the compression pressure vessel.

The supposed HSSC will have Bang-Bang or automatic motion control system to compress huge amount of snow synchronized with human intensive snow removal work operation [3]. Schematic illustration of human collaborative HSSC with automatic compression system is shown in Fig. 3. Authors have thought that there are a few demand for private snow removal work in present, but in future social demand to conduct private snow removal work would be rapidly increased by reason of increasing single household by aging and depopulation society.

In previous research results [1]∼[3] shown that large formation force is needed to consolidate huge amount of snow into the compacted small ice column. Therefore, the developing proposed machine needs to generate large formation force. By the way, it is known that general mechanical press machine was able to a larger formation force by a small torque by using wedge effect of ball screw. Therefore, it will be possible to reduce the proposed machine weight by using a mechanical press mechanism. In the paper the Bang-Bang motion control of the mechanical press machine was simulated by using universal material testing machine for investigating snow consolidation properties. Even though in usually usage of the universal testing machine without overload protector is not adapted to some material compression tests including sudden its stop at bottom dead center, because of unexpected excessive impulsive force by machine’s inertia. But it was intentionally applied to the snow consolidation test to simulate the material compression under Bang-Bang motion control. Those testing procedures are described followings chapter.

3. Experimental Procedure of Snow Consolidation by using Mechanical Press Machine

Schematic illustration of square cross section snow consolidation pressure vessel [2] are shown in Fig. 4. The pressure vessel was made by milling and wire-cut electrical discharge machining from JIS S45C steel bulk material. The pressure vessel has square cross section and 12 small pressure sensors at lateral wall. The apparatus consist of some load cell censors: Kyowa Electronic Instruments
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Figure 5: Schematic illustration of snow consolidation testing by using mechanical press.

Co., Ltd., PS-70KDM2, and strain amplifier: Turtle Industry Co., Ltd., TUSB-S01LC2Z with sampling frequency of $f = 100$ Hz. The special small load cell sensor was made by special material having temperature compensation function, therefore user has not need to consider temperature effect on strain measurement. Those compressive tools were kept temperature at range of $T = 0 - 7 \, ^\circ\text{C}$ before the snow consolidation test by cooling, and the snow melting during the tests is able to neglect was confirmed by pretest, it has good agreements with previous reports [1] [2]. The gap clearance between pressure vessel dies and platens is almost 0.5mm, and air in the pressure vessel dies can release via the gap clearance.

Schematic illustration of snow consolidation testing by using mechanical press is shown in Fig. 5. A mechanical universal material testing machine: Shimadzu Corp. Autograph X 10 with trapezium position and motion control software was used to simulate the mechanical press motion. The pressure vessel shown Fig. 4 was set on center of the bed of the machine. By interview to Shimadzu Corp engineer, it was confirmed that the apparatus can completely take control of the position and formation force during control mode. In general usage of the machine can control the formation force until the crosshead motion halt. But in the paper, crosshead was intentionally sudden halted when axial formation pressure reached up to commanding pressure value, to simulate the material compression deformation under Bang-Bang motion control.

Schematic illustration of snow consolidation test is shown in Fig. 6. The snow consolidation pressure vessel and the under platen are set as shown in Fig. 6(a). Then, shaving ice imitating snow were filled into the pressure vessel up to its upper rim as shown in Fig. 6(b). Then the movable upper platen was set on the tapped snow as shown in Fig. 6(c). The dies were closed by the upper and under platens and the pressure vessel. Then the snow was consolidated in the pressure vessel by one stroke. In the snow consolidation test, the axial formation force, back pressure of the lateral wall of the pressure vessel and crosshead position were measured during the test. And after the compaction density at each crosshead position during those continuously test was evaluated by back calculation based on the record data. And results were organized by dimension ratio of $H/W = 0.5, 1.1$ and $1.7$. Here, parameter $H$ shows initial filling snow height as shown in Fig. 6(b), and constant $W$ shows represent width of the pressure vessel described above as shown in Fig. 4(a). In the test, some steel tool was set below the under platen to adjust initial filling snow height $H$, and after the height setup the adjust tool was took away, and the under platen was setup on the ground again.

The experiment apparatus photograph is shown in Fig. 7. During snow consolidation test, the applied axial formation force was measured and it was displaying on the Autograph’s jog controller as shown in Fig. 7(a). And the formation forces was recorded, and stress relaxation was evaluated by using 30 Hz video camera as shown in Fig. 7(b). And the lateral back pressure on the compression pressure vessel lateral wall was simultaneously measured by using the 12 sensors as shown in Fig. 7(c)(d).

In those tests, unexpected excessive formation force was observed when the mechanical machine reached bottom dead center and halted its motion. But the compressive axial formation force changed rapidly, therefore the Autograph was not able to display clearly the formation force with low sampling frequency $f = 100$ Hz. And the camera was also not able to capture the dramatic formation force.
change with \( f = 30 \) Hz. Therefore, the excessive formation force and displacement of the crosshead at the sudden motion halt was evaluated by using external load cell and analog position measurement apparatus. The experiment was performed by \( f = 1000 \) Hz sampling frequency, but it was thought that the sampling frequency would be enough to use the experiment by considering following described obtained result. External load cell: Tokyosokki Kenkyujo TCLK-50kNA, and dynamic strain amplifier: Tokyosokki Kenkyujo DA-16A were used to evaluate axial formation force, and external analog position measurement: Midori precision LP200F-C was used to evaluate crosshead’s position. Those apparatus were connected to personal computer: Iiyama corp. Style Infinity, via A/D converter board: Interface corp. LPC-361316. But unfortunately, the load cell was not waterproof type. Therefore, the excessive formation force was only investigated by compressing the load cell directly just for reference. The load cell was set under at a distance of 1.5 mm from the compressive formation tool, and then it was compressed directly at dry condition in the experiment.

4. One Stroke Snow Consolidation Formation Result

One stroke snow consolidation formation tests were performed for dimension ratio \( H/W = 0.5, 1.1 \) and 1.7. The relation among axial formation or back pressure and testing time of \( H/W = 1.1 \) as an example is shown in Fig. 8. The formation pressure \( p_z \) was given up to \( p_z = 3.0 \) MPa. The back pressure occurred at only \( S_p = 5 \) mm. And both of axial formation and back pressures shown stress relaxation after those pressures reached up to its peak value. And it was found that the back pressure occurred partially at lateral wall among its height direction. And those occurred almost near the bottom of the pressure vessel. It has good repeatability with previous report [2], and it is opposing to some author’s assumption as uniform snow consolidation deformation at low strain rate regime \( \dot{\varepsilon} \leq 10^{-3} s^{-1} \) [15][16]. It was clear that that the snow deformed un-uniformly at high strain rate regime \( \dot{\varepsilon} > 10^{-3} s^{-1} \) as this research.

Moreover, unexpected excessive back pressure occurred in some case. The relation among axial formation or unexpected excessive back pressure and testing time of \( H/W = 1.1 \) is shown in Fig. 9 as a typical example. The back pressure of \( S_p = 5 \) mm became over commanding formation pressure \( p_z = 3.0 \) MPa, and it reached up to 4.22 MPa. The statistical data of back pressure for each \( H/W \) were investigated. Statistical data of back pressure for \( H/W = 0.5, 1.1 \) and 1.7 are shown in Table 1. The tests were 10 times performed at each experimental condition. In almost 90 % test, the maximum back pressure was occurred only at \( S_p = 5 \) mm. And in almost 20 % of the tests, back pressure became larger than commanding axial formation pressure.

Table 1: Statistical data of back pressure for \( H/W = 0.5, 1.1 \) and 1.7.

| Pressure vessel dimensions ratio \( H/W \) | 0.5 | 1.1 | 1.7 | Total |
|------------------------------------------|----|----|----|------|
| Trial number of times.                   | 10 | 10 | 10 | 30   |
| Number of times when the maximum back pressure occurred at \( S_p = 5 \) mm. | 8  | 10 | 10 | 28 (90.3%) |
| Number of times when the back pressure became larger the axial formation pressure. | 2  | 2  | 2  | 6 (19.4%) |
| Maximum value in measured back pressure / MPa | 3.82 | 4.22 | 3.67 | 1.41 (141%) |
5. Snow Consolidation Properties of Mechanical and Hydraulic Press Deformation

Then relation between average snow density $\rho$ of the compacted ice column and axial formation pressure $p_z$ were investigated. The relation between snow compaction density and axial formation pressure for $H/W = 1.1$ is shown in Fig. 10 as example. In all of results for $H/W = 0.5, 1.1, 1.6$ have almost same relation curves trend. And it has good repeatability of previous reported results [1][2], therefore, other detail results were omitted here.

Then the relations between snow compaction density and axial formation pressure on previous and present research results were compared. The relations between snow compaction density and axial formation pressure for present and previous reported results are shown in Fig. 11 [1]. Here, paint white one is showing the present one stroke snow consolidation formation results by using mechanical press machine. And paint black one is showing the previous reported incremental snow consolidation formation results by using hand hydraulic press machine [1]. Those experimental curves data are much different. In the incremental formation group, the relation was strongly affected of the compression pressure vessel’s dimension ratio. But on the other, the one stroke formation group shown almost same relation curves, and those relations were not affected by the dimension ratio effects. And all of data of using mechanical press machine is almost same with using hand hydraulic press machine of $H/W = 0.5, 1.1$. And it is easy to increase the snow compaction density by using mechanical press machine compared with hydraulic one even with same axial formation pressure. It was thought that the one stroke formation was performed under position control, but the incremental formation was performed under loading control, and it is one of the reasons of that the mechanical press machine has easy higher snow compaction density [23].

Schematic illustration of relations between axial formation pressure and elapsed time of previous and present reports are shown in Fig. 12. In previous report [1], hand hydraulic press machine was used to snow consolidation test. The rough relations are showing at left side of Fig. 12. In using hand hydraulic press machine, the axial formation pressure monotonically increased, and the elapsed time was for few minutes, and it needed some repeatable strokes. And the crosshead velocity dramatically changed from maximum value to zero. The crosshead velocity became zero when the axial formation pressure reaches up to maximum commanding value. And the force equilibrium occurred on quasi static condition, and there is no displacement, and there were no occurrence of work to more compressive de-
form the ice column. But the mechanical press machine was able to increase axial formation pressure with constant crosshead velocity in a matter of seconds and one stroke. And when the axial formation pressure reaches up to maximum commanding value, the crosshead was suddenly halted at maximum crosshead velocity. Therefore, there was maximum work to deform the ice column until immediately before halt the machine. And after reaching commanding force value, the inertia would be released as impulsive force including stress relaxation. The inertia is the reason of that the usage of mechanical press machine is easy to obtain ice column having higher snow compaction density compared with the usage of hydraulic press machine when same axial formation pressure was given.

6. Impulsive Force Effect on Snow Compaction Density

In described above, an occurrence of larger impulsive force immediately after its motion halt at bottom dead center by large crosshead’s inertia was feared. Therefore, more details of the impulsive force and the crosshead displacement were investigated. Relations between measured crosshead strokes and elapsed testing time are shown in Fig. 13. Measurement apparatus of mechanical press machine and external analog linear scale were used to the measurement test. Both measurement apparatus show that the press machine immediately moved at constant crosshead velocity after starting the test, and the machine immediately halted at the end of the test. It shows that the press machine has precisely position control ability. It was quantitatively cleared that the driving screw of the machine did not rotate, and the crosshead position did not also move. And it was found that the crosshead inertia after its motion halt is not related to increase or decrease of the compaction ice density. The Fig. 13 is an example of some tests, and same trend have been observed at another experiments.

Relations between axial formation force and experimental elapsed testing time are shown in Fig. 14. It shows force value of the mechanical press machine’s and external load cell. The testing machine halted during $\Delta t_1 = 0.03$ sec after reaching the axial formation force value up to commanding force of 2512 N, but the absolute value of the axial formation force value became larger $F_z = 4,500$ N, and it became 1.6 times larger than commanding force value. In the test, the press machine recognized the halted signal by itself, and halted its data recording too. But in fact, the inertia was not released completely, and then, it was released arbitrarily. And absolute value of the axial formation force increased rapidly up to almost 8,000 N, and it became almost 3 times large compared with the demanding force value of the test. The elapsed testing time after recognition of the machine halt signal to its real motion halt is almost 0.20 sec. And it was quantitatively cleared that unexpected impulsive force was very large. Therefore it was thought that the mechanical press machine for snow consolidation process has to need a general overload protector mechanism to avoid fracture of the machine at bottom dead center, or it needs motion control system based on measurement force data. Of course Shimadzu Corp. Autograph X 10 has such function with optional software, even though in this report, irregular usage was intentionally performed to simulate the mechanical press process.

The relation between measured and commanding compressive forces are shown in Fig. 15. Impulsive force were occurred at all of those test. And the data spread is small and good repeatability is found. And it has trend of that absolute value of the excessive impulsive compressive force became large with increase of absolute value of commanding compressive force.

7. Conclusion

In this research, snow consolidation properties by using mechanical press machine were investigated. And effect of impulsive force caused by crosshead inertia on increase of
snow compaction density was also investigated. As results, it was found that followings.

1) Unexpected excessive back pressure occurred in some case. And the back pressure of \( S_p = 5 \text{ mm} \) over commanding formation pressure \( p_z = 3.0 \text{ MPa} \), and it reaches up to 4.22 MPa.

2) The statistical data of back pressure for each \( H/W \) were investigated. In 90 % of tests, the maximum back pressure was occurred only at \( S_p = 5 \text{ mm} \). And in 20 % of the tests, back pressure became larger than commanding axial formation pressure.

3) The inertia during cross head motion is the reason of that the usage of mechanical press machine is easy to obtain higher snow compaction density compared with the usage of hydraulic press machine when same axial formation pressure was given.

4) Unexpected high impulsive force at dead bottom of the center after crosshead motion halt is not related to increase or decrease of the snow compaction density.

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