SHEAR STRENGTH OF FRESH SNOW

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(*Received* 13 *Feb.*, 67, *Revised* 23 *Nov.*, 67)

The paper reports a new apparatus for determining the cohesion, '*C*' and friction ϕ for fresh snow. The values of '*C*' and ϕ are measured under different conditions of snow with different grouser plates, values of which are found to be *0·11 lb/sq* in and 40° respectively.

During the trials of snow crossing chains[1], it was observed that the physical properties of snow changes with time, temperature and pressure. The same changes were noted during the studies of frictional properties of pneumatic rubber tyres of snow[2] and bearing capacity of snow[3]. From the knowledge of soil mechanics, it has been assumed that the soil strength may be determined as a function of friction ϕ, cohesion 'C' and density γ. Bekker[4] has also pointed out that snow may be considered as another type of cohesive and/or frictional mass. Though this assumption due to the everchanging properties of snow may not be quite correct but as far as the present studies are concerned with regard to the performance of snow vehicles, may be very useful. In the case of snow, the variability of cohesion '*C*' and friction ϕ is more complex because of the snow metamorphosis[5] which causes the state of stress-strain relationship to depend on temperature and the rate of load applications. Therefore it was essential to investigate these constants at different temperature loads and density so that these may by correlated with the vehicle mobility over snow.

METHOD

An apparatus, as shown in Fig. 1 for determination of the values of friction ϕ and cohesion '*C*', was designed and fabricated at Defence Laboratory, Jodhpur and was installed at Field Laboratory, Gulmarg in November 1963. It consists of a tray '*T*' (5′×14″×8″) fitted with ball-bearings '*B*' so that it could move forward and backward

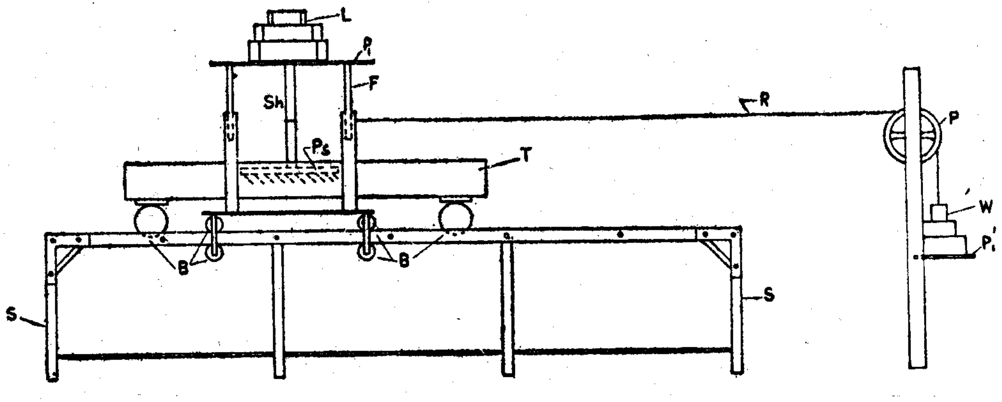

Fig. 1—Block diagram of the apparatus for determination of the angle of friction ϕ and cohesion '*C*'.

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on a rigid iron stand '*S*' without offering any appreciable resistance to motion. During the time of snow fall, the tray was placed in the open to collect fresh undisturbed snow and observations were taken when it was filled completely. On the other days, it was filled with snow taken from outside with help of a spade. The different sizes of grouser plates were constructed. The grouser height was kept 1″ and the distance between the two grousers was also 1″. The grouser plate 'Ps' was attached to a central shaft '*Sh*' of a frame 'F' which rested on ball-bearings '*B*' rolling on the iron stand '*S*'. The arrangement was made in such a way that the load which was placed on the frame '*F*', was borne by the central shaft '*Sh*' and thereby the grouser plate '*Ps*' which was resting on the snow surface. The frame '*F*' was pulled horizontally with a rope '*R*' passing over a pulley '*P*' fitted with bal-bearings. After loading the frame and waiting for about 5 minutes, weights were added to the pan in steps of 1 kg. On each addition of weight in the pan there was a slight movement of the plate from its position. Weights were increased in steps till the failure condition *i.e.* when the snow was unable to keep the plate in position and the plate begins to move from its position at least ten inches. Each observation was taken under similar conditions, several times and the mean value was recorded. The horizontal force which moved the grouser plate forward was taken as '*H*' the shearing force and the load '*L*' which was placed on a pan '*P*' was noted as '*L*' the vertical load. The observations were made at different loads with different sizes of grouser plates at varying conditions of snow.

MEASUREMENTS OF DENSITY

The experimental arrangement was the same as described earlier[2]. Four aluminium cubical containers having inner side of 10 cm open at the top were constructed. The containers were weighed empty and were kept outside during the snow fall and when filled, were weighed again. The density of snow was calculated as the difference in weight divided by volume. On the days when it was not snowing, the containers were filled with

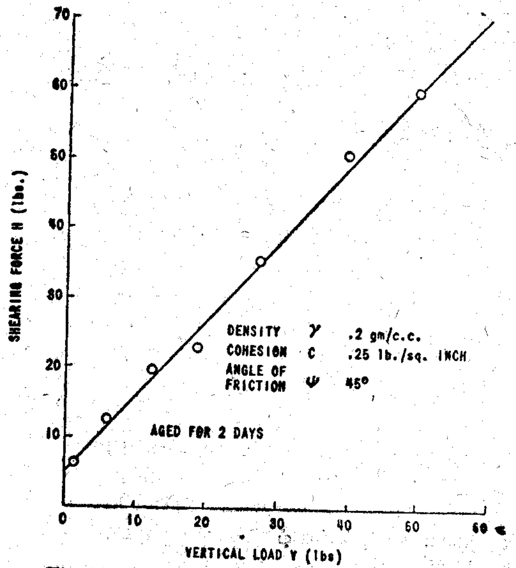

Fig. ″2—Shearing force for the spuded plate size 4″× 4 plotted against load at temp. —3·5°C.

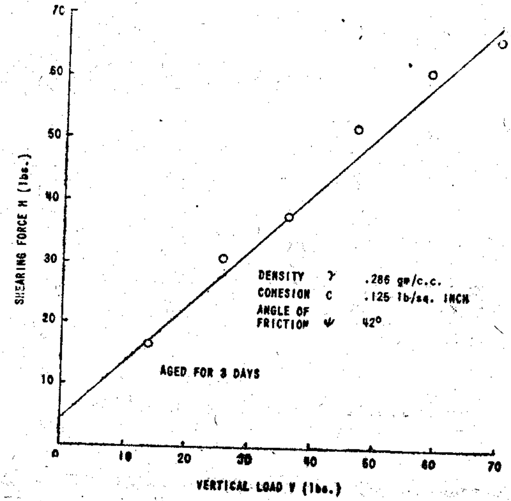

Fig. 3—Shearing force for the spuded plate size 6″×6″ plotted against load at temp. —9°C.

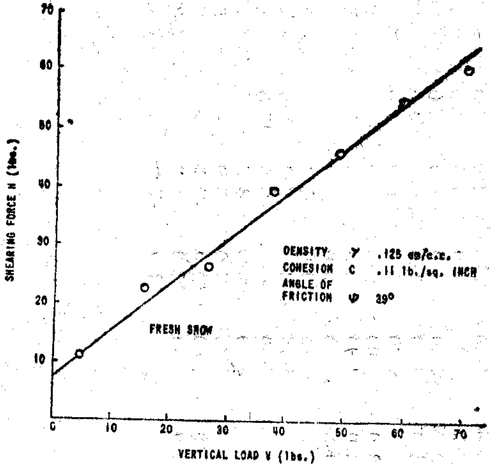

Fig. 4—Shearing force for the spuded plate size 8″×8″plotted against load at temp. —5°C

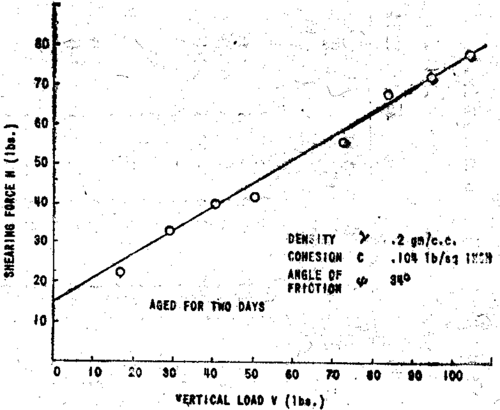

Fig. 5—Shearing force for the spuded plate size 9″×36″ plotted against load at temp. —3·5°C

snow removed gently from outside (surface). Each value is the mean of several observations.

METEOROLOGICAL CONDITIONS

The meteorological data in respect of maximum, minimum temperature, snow fall and snow depth for the period December 1963 to March 1964 are tabulated in Table 1. It is observed that the winters at Gulmarg are very severe. The month of January is very cold when the maximum temperature was recorded below zero for 17 days and minimum was recorded 23°C below zero. Maximum snow fall was recorded 30 inches in a day and the maximum depth of snow goes up to 7 feet. During the winter, Gulmarg is free from the high winds, days and nights are very calm and quite. The entire work was carried out under the natural conditions. There was not much variation in the room temperature because it was open from all sides and the temperature was checked during the observation. The details of the climate of Gulmarg have been published elsewhere.

RESULTS AND DISCUSSIONS

The observations for the spuded plates having dimensions 4″×4″, 6″×6″, 8″×8″ and 9″×36″ with spud height 1″ and spaced 1″ apart are shown graphically in Figs. 2 to 5 respectively. It is seen that the horizontal force is directly proportional to the vertical load.

From these curves, the values of friction ϕ and cohesion 'C' are determined and tabulated in Table 2. It is interesting to note that the values of 'C' and ϕ decrease as the area of the grouser plates increases. The values of C, ϕ and density of snow are compared at different temperatures having the same grouser plate in Table 3. It is observed from Fig. 4 & 6 that these values incrase as the temperature of the snow surface decreases. The experiments made on the shear strength of snow indicate that the theoretical function $H=CS+V \tan \phi$ is satisfied for the low loads investigated. Various type of snow designated in Table 2 produce almost a straight line relationship between 'τ', the shearing stress and, σ the normal stress which relates to pressures between 1 and 3 pounds/sq. inches. Thus it is possible to determine the snow strength in any specific case. As has been mentioned earlier that the physical properties of snow depend on the temperature and

TABLE 3

MAXIMUM-MINIMUM TEMPERATURES AND SNOW FALLS AT GULMARG DURING THE PERIOD FROM DECEMBER 1963 TO MARCH 1964

Date	December 1963 Temperatures (° C) Max.	December 1963 Temperatures (° C) Min.	December 1963 Snow Fall (Inch)	December 1963 Snow Depth (Feet)	January 1964 Temperature (° C) Max.	January 1964 Temperature (° C) Min.	January 1964 Snow Fall (Inch)	January 1964 Snow Depth (Feet)	February 1964 Temperature (° C) Max.	February 1964 Temperature (° C) Min.	February 1964 Snow Fall (Inch)	February 1964 Snow Depth (Feet)	March 1964 Temperature (° C) Max.	March 1964 Temperature (° C) Min.	March 1964 Snow Fall (Inch)	March 1964 Snow Depth (Feet)
1	2·0	—8·0	4·0	1·25	—3·5	—14·0		2·75	0·0	—21·5		5·0	5·0	—7·0		5·5
2	4·5	—10·0		1·20	—0·5	—14·0		2·70	1·5	—17·5		4·75	2·0	—8·5	9·0	5·6
3	7·5	—10·0		1·20	—1·5	—10·0	6·0	3·00	0·0	—21·0		4·75	4·5	—2·0	24·0	6·5
4	5·0	—8·5	6·0	1·25	—0·5	—11·5		3·00	1·0	—20·0		4·50	3·0	—10·5	12·0	7·0
5	8·5	—8·0		1·00	—2·0	—9·0	8·0	3·50	0·0	—13·5	9·0	5·00	1·5	—9·0	4·0	6·5
6	7·0	—7·0		0·80	—1·0	—4·5	8·0	4·00	4·5	—12·5		4·75	4·5	—12·5	1·5	6·0
7	5·0	—4·5		0·75	1·0	—1·5	30·0	5·25	4·0	—14·0		4·70	8·5	—10·5		5·75
8	8·0	—5·5		0·60	1·5	—1·0	24·0	6·00	1·5	—11·0		4·40	7·5	—8·5		5·60
9	7·0	—7·0		0·50	3·0	—7·0	3·0	5·75	3·0	—11·5	8·0	4·50	6·0	—3·0		6·50
10	8·0	—5·5	5·0	0·75	0·5	—15·0		5·25	1·0	—14·0		4·42	1·5	—4·0	24·0	6·50
11	1·5	—4·5	2·0	0·75	4·5	—13·0	9·0	6·00	—1·0	—15·0		4·40	7·0	—5·5	6·0	5·90
12	1·0	—4·5	7·0	1·40	—1·0	—19·0	2·0	5·50	2·5	—13·0		4·33	9·0	—6·0		5·60
13	—2·0	—5·0	30·0	2·50	—1·5	—18·0	4·0	5·50	5·0	—10·0		4·25	12·0	—7·0		5·25
14	—2·5	—10·0	2·0	2·50	—4·0	—19·0		5·25	2·0	—7·0	4·0	4·30	9·0	—6·0		5·00
15	—2·5	—11·0		2·25	—1·5	—15·0		5·25	3·0	—3·5	3·0	4·40	8·5	—2·0	6·0	4·80
16	—3·0	—11·0	4·0	2·25	—1·0	—19·5		5·00	2·0	—6·5	3·0	4·25	6·0	0·0	4·0	4·75
17	—1·0	—14·0		2·00	1·0	—15·5	5·0	5·40	1·5	—3·0	30·0	6·00	8·0	—4·0	6·0	4·80
18	—4·0	—15·0		2·00	0·0	—19·0		5·25	2·0	—2·0	4·0	6·10	1·0	—2·0	20·0	5·80
19	—4·0	—16·0	6·0	2·25	—6·0	—20·0		4·75	5·5	—14·0		5·60	4·0	0·0	4·0	5·80
20	—5·5	—16·5		2·00	—4·0	—14·5	15·0	5·75	3·5	—8·0	12·0	6·00	4·5	0·0		5·25
21	—1·5	—16·5		1·75	—2·5	—8·0	6·0	6·00	2·0	—4·0	3·0	6·00	6·5	—5·5		5·00
22	—3·0	—18·0		1·75	—3·0	—12·5	18·0	7·00	3·0	—7·0	10·5	6·30	9·0	—7·0		4·82
23	—6·0	—17·0		1·70	2·0	—21·5		6·50	3·5	—10·0		6·15	10·0	—1·0		4·60
24	—6·0	—17·0		1·60	4·0	—21·5		5·75	7·5	—14·0		5·75	2·5	0·0	3·0	4·50
25	—6·0	—17·0	3·0	1·75	3·0	—23·0	4·0	5·75	4·5	—15·0		5·60	6·5	0·0	12·0	4·67
26	1·0	—15·0		1·75	2·5	—21·0		5·50	4·5	—13·5		5·40	9·0	4·5		4·60
27	4·0	—12·5		1·70	2·5	—21·5		5·40	6·0	—12·0		5·15	9·0	—5·0		4·50
28	2·0	—10·0		1·60	3·5	—22·0		5·25	3·0	—10·5	8·0	5·50	14·0	—4·0		4·30
29	0·0	—6·5	3·0	1·75	2·0	—21·5		5·10	4·0	—6·0	12·0	6·00	12·0	—4·5		4·00
30	4·5	—6·0	18·0	3·00	—0·5	—22·0		5·00					10·0	—3·0		3·75
31	0·0	—11·0		2·75	1·5	—21·5		4·75								

pressure[8], therefore, taking these values for practical purposes, it is always better to adopt the average values of coefficients which would cover the field of oversnow vehicle operation.

Figure 6 shows the variation of 'H' with 'V' at temperature —8°C. It is seen that the relation $H \sim V$ is not a straight line and it does not satisfy the equation $H = CS + V \tan \phi$, where 'S' is the area of the grouser plate. Though out of six sets of observations, only one set shows the deviation from the above equation but this cannot be neglected because such deviations have been noted by the earlier workers also. Haefele[8] has shown that the shearing strength of snow is a function of at least three independent factors, time, pressure and temperature. If temperature is kept constant and a fresh snow is subjected to pressure it undergoes a disruption of its structure which is followed by a decrease in 'τ' indicated by *AB* in Fig. 6. When the pressure is further increased, an increase in τ will be observed.

TABLE 2

Values of Cohesion 'C', friction ϕ and density of snow γ

Date	temp. (°C)	γ (gm/cc)	Plate size (in. x in.)	C lb/sq in	ϕ°	Snow conditions
20-2-64	—3·5	·200	4″×4″	·250	45	Aged for two days
24-12-63	—9·0	·286	6″×6″	·125	42	Aged for three days
19-12-63	—5·0	·125	8″×8″	·110	39	Fresh snow
20-2-64	—3·5	·200	9″×36″	·104	34	Aged for 2 days

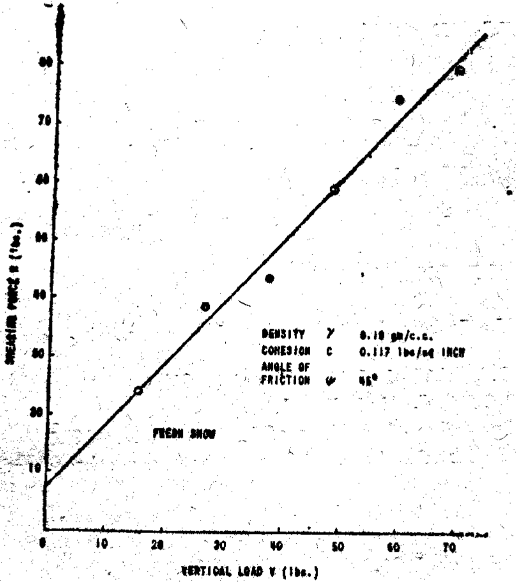

Fig. 6—Shearing force for the spuded plate size 8″×8″ plotted against load at temp. —11°C

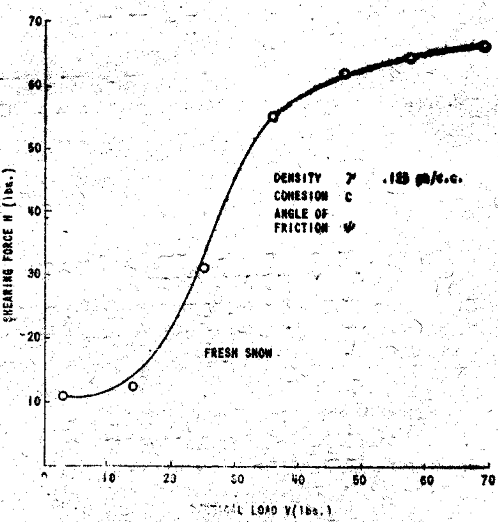

Fig. 7—Shearing force for the spuded plate size 6″×6″ plotted against load at temp. —8°C

TABLE 3

Comparison of the values C, ϕ and γ at different temperatures (Plate size 8″×8″)

Date	Temp. (°C)	γ gm/cc	C lb/sq in	ϕ°	Snow conditions
19-12-63	—5·0	·125	·110	39	Fresh
23-12-63	—11·0	·190	·117	45	Aged for two days

This may be treated as the effect of compaction and changes in snow structure, expressed by the line *BC*. Further compression leads to the changing of snow into ice. It may be mentioned here that the process described by the portion *AB* has little practical importance from the point of view of vehicle operation, because it refers to very low pressures which can never be attained in the vehicle design *F*.

From the present results the safe value of cohesion '*C*' may be taken as 0·11 lb/sq inch and the friction ϕ=40°. Bekker[8] has also determined these values and has taken the cohesion, C=1 lb/sq inch and friction ϕ=40°. The value of cohesion C=1 lb/sq inch seems to be too high and at least for the fresh snow which falls in the month of December to February at Gulmarg, the value 0·11 lb/sq inch would be more suitable.

CONCLUSION

1. *H* is directly proportional to *V*.
2. The value of friction ϕ for fresh snow is found to be 40°.
3. The value of cohesion *C* for fresh snow is found to be 0·11 lb/sq inch.

ACKNOWLEDGEMENT

Thanks are due to Dr. V. Ranganathan, Deputy Chief Scientist and Dr. H. Nath, Director of Research Laboratories for suggesting the problem and guidance during the work. Thanks are also due to Dr. M.P. Murgai, Assistant Director and Dr. Kartar Singh, Director, Defence Science Laboratory, Delhi for their suggestions and criticism during the course of preparing the manuscript.

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