Journal of Glaciology, Vol. 32, No. 112, 1986

COMPARISON OF EXPERIMENTAL AND COMPUTER MODELING OF SNOW-BLOCK IMPACT ON STRUCTURES

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ABSTRACT. Data from experimental tests of snow-block impact against vertical barriers are used to establish values of parameters in order to computer-model the impact mechanics. The results show that total impulse, impact force, and duration of impact can be modeled by accurate specification of the kinematic viscosity in the fluid representation. In modeling the highly transient impact, kinematic viscosity of the material is determined to vary linearly with the impact velocity. This non-physical condition is attributed to lack of accountability of compressibility effects in the computer model, and reduces modeling to an empirical approach. A biviscous modeling of the impact process is in near correspondence to linear viscous modeling, due to dominant importance of block momentum on impact rather than fluidity of material in the impact region.

RÉSUMÉ. *Comparaison entre l'expérience et la modélisation calculée de l'impact de blocs de neige sur les structures.* Des impacts expérimentaux de blocs de neige sur des barrières verticales ont été utilisés pour établir les paramètres d'un modèle d'ordinateur simulant la mécanique des impacts. Les résultats montrent que la poussée totale, la force et la durée de l'impact peuvent être modélisées par des spécifications précises de la viscosité cinématique dans le fluide représenté. En modélisant l'impact instantané, on constate que la vitesse de l'impact varie linéairement avec la viscosité cinématique du matériel. Cette condition non-physique est attribuée au défaut de prise en compte des effets de compressibilité dans le modèle d'ordinateur, et réduit la modélisation à une approche empirique. Une modélisation bivisqueuse de processus d'impact est en correspondance proche avec une modélisation visqueuse linéaire, en raison de l'importance dominante du moment du bloc sur l'impact par rapport à la fluidité du matériel dans la région de l'impact.

ZUSAMMENFASSUNG. *Vergleich zwischen experimenteller und rechnerischer Modellbildung des Aufpralls von Schneeblöcken auf Bauwerke.* Werte aus experimentellen Untersuchungen des Aufpralls von Schneeblöcken auf vertikale Hindernisse wurden zur Ableitung von Parametern für ein Computer-Modell des Aufprallmechanismus herangezogen. Die Ergebnisse zeigen, dass der Gesamtimpuls, die Aufprallkraft und -dauer durch genaue Spezifizierung der kinematischen Viskosität in der Darstellung als Flüssigkeit modelliert werden können. Bei der Modellierung des äusserst flüchtigen Aufprallvorganges wird davon ausgegangen, dass die kinematische Viskosität des Materials sich liear mit der Aufprallgeschwindigkeit ändert. Diese nicht-physikalische Bedingung geht zu Lasten des Fehlers eines Ausdrucks für die Wirkung der Komprimierbarkeit im Computer-Modell und beschränkt die Modellierung auf eine empirische Näherung. Ein biviskoses Modell des Aufprallvorganges kommt dem linear viskosen sehr nahe, vor allem wegen der beherrschenden Bedeutung des Blockmoments beim Aufprall gegenüber dem flüssigen Zustand des Materials in der Aufprallzone.

INTRODUCTION

The close proximity between buildings in urban areas in Japan in high snowfall regions creates problems of snow slides from roofs that impact the walls of adjacent structures. The problem has recently been investigated experimentally to evaluate force and total impulse on vertical barriers caused by impacting snow blocks (Nakamura and others, 1981). The block impacts cover a range of impact speeds, angles of contact, and block sizes. Data from these tests include time variation of the transient impact force, and the total impulse normal to the barrier, for each configuration of block geometry and kinematics involved.

Timewise, in a parallel program with the experimental work, analytical capability has been under development to model snow flow and impact by computer simulation of the processes (Pedersen and others, 1979). The computer program, SMAC (Simplified Marker and Cell Code), developed by Amsden and Harlow (1970), uses a finite-difference formulation of the two-dimensional Navier–Stokes equations to model transient, viscous fluid flow. In the process of finding the range of kinematic viscosity and surface-friction coefficients of the material representation, the program was found to model snow-block impact. Verification of the computer formulation has been singularly lacking, and the opportunity to compare the experimental work on barrier impact with computer modeling of the phenomenon is warranted. The purpose of this paper is to show the comparison of results between the experimental and computer modeling of snow-block impact.

EXPERIMENTAL PROGRAM

The experimental set-up included a variable-slope roof-like structure, load-cell instrumented vertical barriers, and film and hard-line recording equipment. To vary speeds and angles of impact, the roof angle and the distance between barrier and roof were varied (Fig. 1). Natural dry snowfall on the roof was allowed to metamorphose to desired density and depth. Upon tipping the roof, the snow

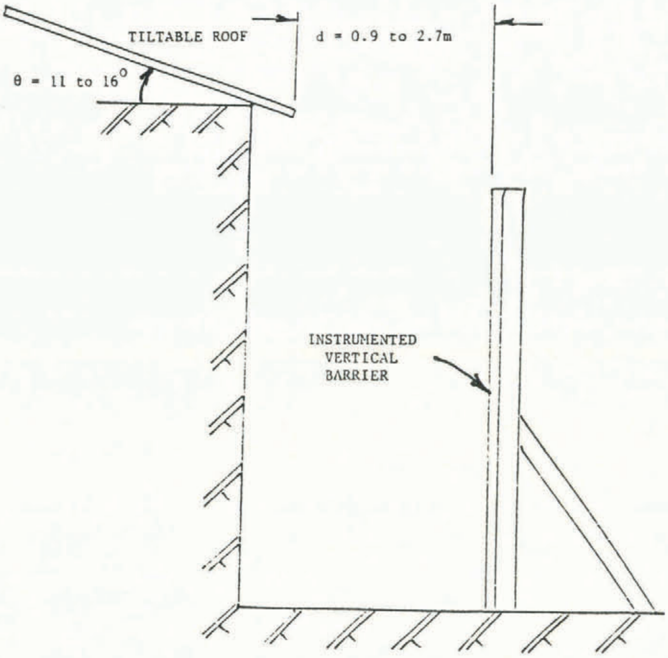

Fig. 1. Roof and vertical barrier geometry and dimensions.

mass slid from the roof, broke into natural blocks of different lengths and impacted the snow barrier. Each barrier consisted of 12 panels sized 1.0 m wide and 0.3 m high mounted on two horizontal load cells. Three different sets of experiments were performed, the first using 14 blocks, and the second and third using 11 blocks each. For each block tested, continuous time history of normal force on each panel was recorded. From this, reduced data included total impulse, maximum force, and time duration of the impact. One block impact from each of the three sets of experiments was computer modeled. Experimental data from these three tests are summarized in Table I. Typical time sequence of impact of a snow block against a barrier is shown in Figure 2a, with a corresponding computer-simulated impact shown in Figure 2b. From Figure 2 is it noted that the impact occurs on the corner of each block. Thus, the crushed area continuously increases as the impact advances, which makes the impact process continuously transient. This condition is different from previous work on snow impact in which a near-steady loading condition followed an initial transient response. Thus, this experimental set-up represents a different test condition on numerical modeling of the impact process.

Other recent work on snow-block impact is that by Perla and others (1978) of normal impact of cylindrical blocks upon force-measuring targets. This type of impact is also a continuous transient process but distinct from the tests by Nakamura and others; those by Perla and others involved fragmentation of the blocks after initial impact.

TABLE I. EXPERIMENTAL SNOW-BLOCK IMPACT DATA

Case No.	*Block mass*	*Block dimensions* *Length*	*Height*	*Width*	*Block density*	*Impact velocity*	*Impact angle**	*Max. impact force*	*Total time duration*	*Total impulse*
	kg	m	m	m	kg/m^3	m/s	degrees	N	s	N.s
I	101	0.65	0.38	1.00	410	5.6	36	3850	0.170	275
II	91	0.67	0.33	1.00	410	4.4	59	2040	0.290	250
III	92	0.65	0.43	1.00	330	6.3	44	8830	0.200	450

*Measured from vertical.

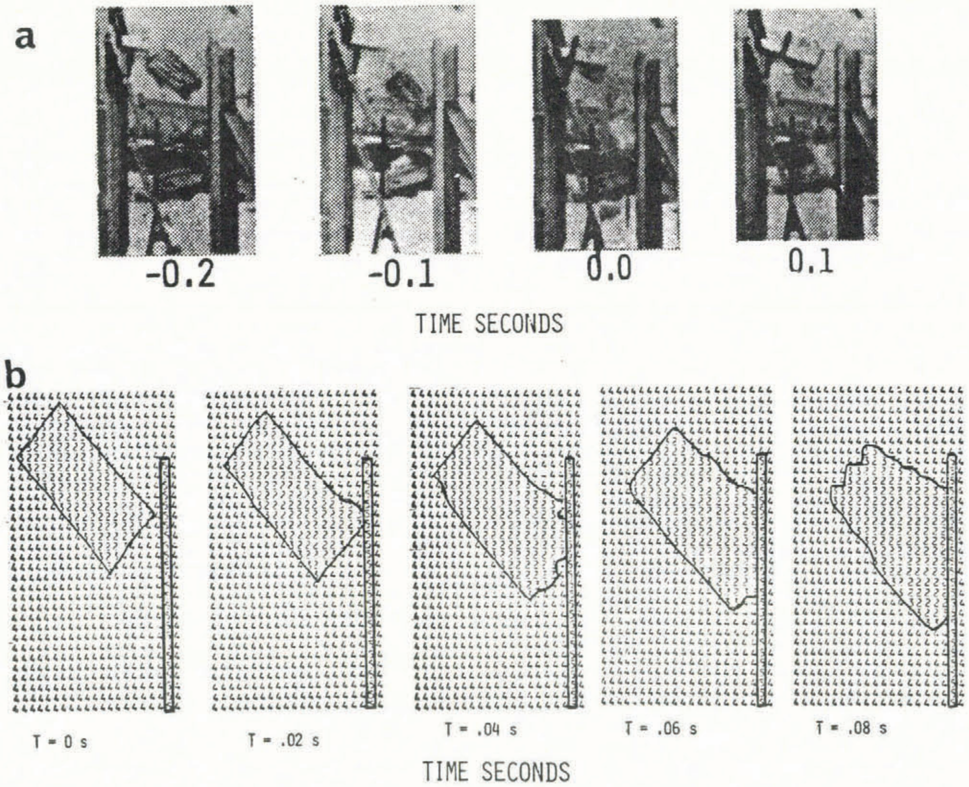

Fig. 2. (a) Physical, and (b) computer-simulated impact of a snow block against a vertical barrier.

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This process of fragmentation adds complexity to computer modeling of impact but may be representable if experimental data on fragment formation are measured.

COMPUTER MODEL

The basic problem in computer-modeling block impact was two-fold, namely, the selection of the geometry and the determination of the physical constants. Establishing a value for the kinematic viscosity to represent the material during impact was the primary task in computer evaluations. The other physical parameter, surface friction, was investigated by specifying a range of conditions from no-slip, partial-slip to free-slip at the boundary between the snow block and the barrier. In the finite-difference representation of the problem, a grid dimension $\delta_x = 0.025$ m proved adequate in modeling the three physical cases. This was verified by repeated computer runs varying δ_x and comparing the results. After establishing values for viscosity, ν, further numerical work was done to evaluate fitting a biviscous material representation to the impact problem.

PRIMARY EXPERIMENTAL AND COMPUTER RESULTS

Comparison between the experimental and computer-predicted force versus time-into-impact for the three blocks of cases I, II, and III are summarized in Figures 3, 4, and 5, respectively. The smooth dashed lines are the experimental curves, while the stepped dashed lines are the computer-generated curves. The discontinuities of the computer response show the effect of discretization, both spatially and timewise, the result of finite-differencing continuous functions. This effect could be reduced by using smaller cell dimensions and smaller time increments. In contrast, the smoothness of the experimental curves indicates damping sufficient to suppress local transient behavior characteristic of impact phenomena. It is likely that the actual transient response is somewhere between the experimental and computer results. Looking at the overall response during the entire impact, the results show an adequate duplication of average force and total impulse, which is the area under the curves, if kinematic viscosity $\nu = 0.1–0.5\ \mathrm{m^2\,s^{-1}}$ for the three cases. This is a large variation in viscosity for a relatively small variation in impact velocity. In fact, plotting the viscosity versus the normal component of the impact velocities (Fig. 6) shows a near-linear increase in viscosity with increase in velocity for the three cases. This degree of variation in viscosity is unlikely to be physically correct and suggests that, for this configuration of impact, local compressibility effects may have significant importance on the impact-force production. Thus, in computer modeling without material compressibility, the viscosity is adjusting in order to match peak force of compact. This variation in viscosity apparently does not affect the duration of impact from that of the experimental results, as the two sets of results are in agreement.

A second variable in these tests is the snow-block density. For case III, corresponding to the largest normal impact velocity, the block density is 20% less than that of cases I and II (Table I). What effect this change has on impact force cannot be singled out from the test results; however, linearity would imply a 20% effect based on momentum considerations. Another possible variable is temperature; however, all tests were performed on one overcast day (29 February 1980) with snow temperature at 0°C, and ambient temperature ranging from 5.1° to 7.3°C. Thus, temperature change between tests is small; however, water content in the snow was not measured.

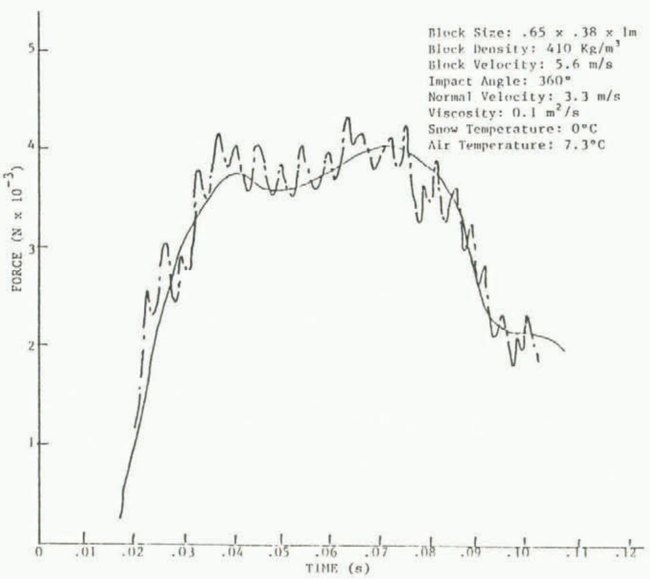

Fig. 3. Normal impact force versus time, case I.

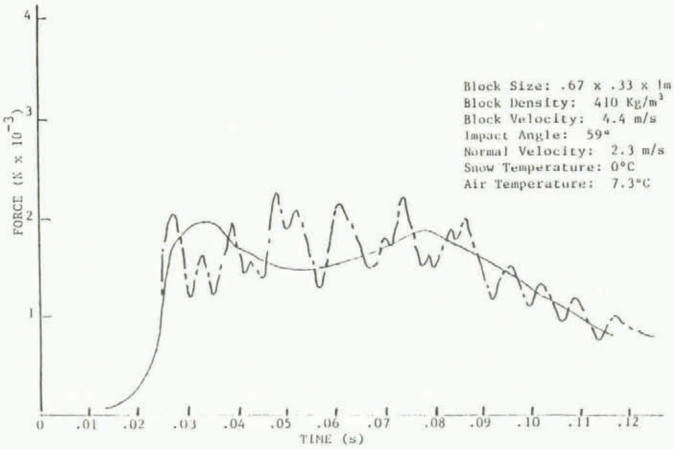

Fig. 4. Normal impact force versus time, case II.

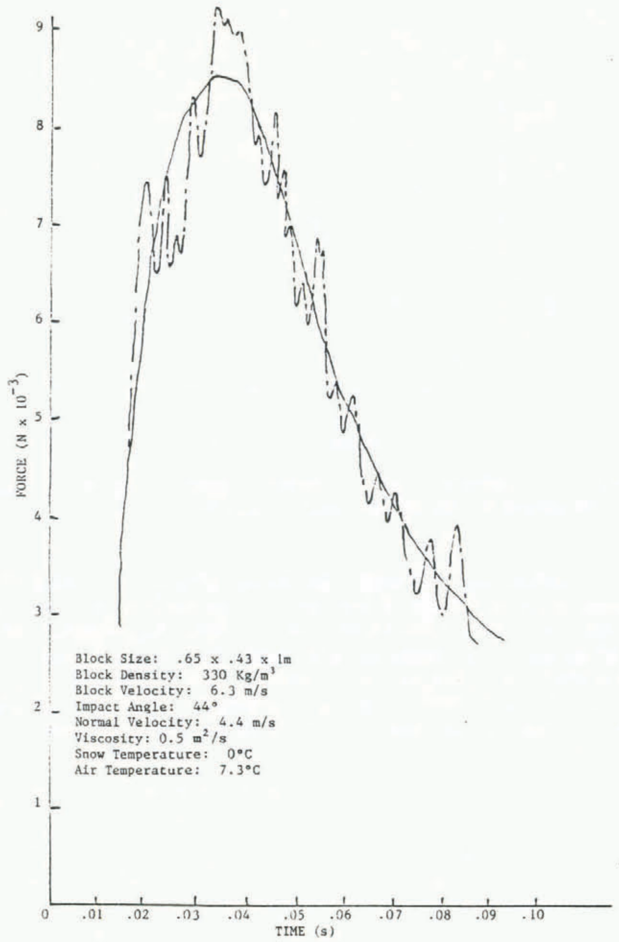

Fig. 5. Normal impact force versus time, case III.

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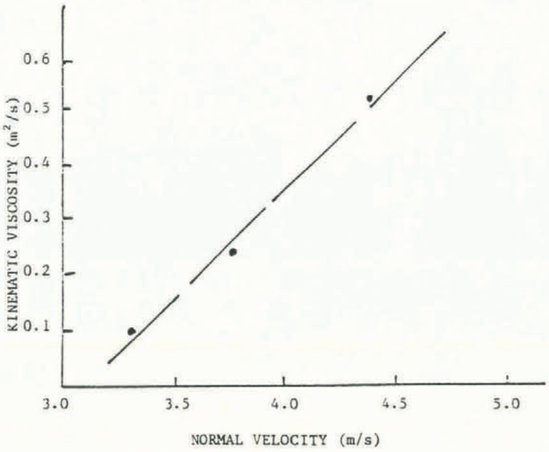

Fig. 6. Variation in kinematic viscosity versus normal component of the block-impact velocity.

Comparison between the experimental and computed total impulse for the three cases is summarized in Table II. The per cent differences between the experimental and computed total impulses are small for cases I and III, wherein by adjusting the viscosity, the force–time curves were brought into near correspondence. This procedure, when applied to case II, produced a close fit over the interval of time comparison in Figure 4. However, tail-off of the experimental curve was inordinately slow compared to the other cases and gave a larger total impulse than what was obtained from the computer simulation. Reasons for this are not apparent from review of cine film of the experimental block impact, although block fracturing upon impact is a possibility.

Results of varying surface friction between the block and the barrier showed no variation in total impulse or shape of the impulse curve. The only difference was that in the case of the free-slip surface condition the block displaced vertically downward more than for the other cases. Data were not sufficiently detailed to allow choice of one boundary condition over another.

Other parameters of potential importance relative to impact include effects of temperature on snow-block properties, elasticity of the structure impacted, and effect on impact characteristics due to higher impact velocities. Tests performed to date have been carried out holding temperature constant near 0°C. Elasticity of the impacted structure shows up on the results obtained in this paper. Computer modeling was carried out with a rigid wall, whereas the experimental results include flexibility of the load cells and the physical barrier involved. The difference in the two cases appears to be restricted to a steeper initial force build-up in the computed responses, which have negligible effect on the total impulses (Figs 3, 4, and 5).

BIVISCOUS MATERIAL REPRESENTATION

A biviscous representation (Dent and Lang, 1983) of the block material was attempted to determine whether more accurate modeling could be obtained. In the case of flowing snow, a biviscous model, which includes an approximation of low-stress material locking, produces a better model of snow flow than does a linear viscous model. In the case of block impact, material next to the barrier is at high stress, while material in the trailing part is at low stress (locked) as the impact process advances. Results of the biviscous representation indicated that impact force was not highly dependent upon the large deformation occurring at the barrier but more a function of the deformation of the low-stress regions. The apparent reason for this is that the dominant mechanism for force production during the impact is from the momentum of the trailing, slowly deforming material, which was equally effective in both the single and biviscous models. This does not preclude differences that might be detected in more highly controlled experiments.

CONCLUSIONS

Computer modeling of snow-block impact using a viscous fluid model has been demonstrated to be feasible in duplicating the force–time variation of the impact. However, a parameter of inordinate sensitivity was found to be the kinematic viscosity in relation to impact velocity. This dependency is likely to be non-physical, so that in predicting total impulse, current computer modeling is strongly empirical. To correct this by incorporating compressibility effects (and perhaps elasticity effects) is a complex material and programming problem.

A second observation of material behavior was obtained from impact analysis using a biviscous representation of the block material. In this case a strong correlation was noted between the impact force generated and the momentum of the material in the trailing section of the block during impact. In contrast, the influence on impact force by the highly stressed material next to the barrier was small. The result of this was a reduction to near correspondance between the single and biviscous models.

TABLE II. EXPERIMENTAL AND COMPUTED TOTAL IMPULSE

Case No.	*Block mass*	*Impact velocity*	*Impact angle*	*Total impulse experimental*	*Total impulse duration*	*Total impulse computed*	*Total impulse*	*Viscosity*
	kg	m/s	degrees	N.s	s	N.s	% diff.	m^2/s
I	101	5.6	36	275	0.09	240	4.2	0.1
II	91	4.4	59	250	0.10	162	35.2	0.2
III	92	6.6	44	450	0.09	400	11.1	0.5

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MS. received 21 April 1983 and in revised form 31 July 1984