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Crowd Induced Deflection of Dow's Lake Ice Cover During Winterlude Festival - 1985

by N.K. Sinha

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Résumé

Ce document décrit la réponse de la couche de glace flottante de 0,6 m d'épaisseur qui recouvrait un petit lac lorsque 60 000 spectateurs se sont rassemblés pour assister à un concert sur des estrades montées sur la glace. Afin de contrôler et d'évaluer la sécurité, on a enregistré en permanence le fléchissement et la déformation superficielle de la couverture de glace devant les estrades. Les données illustrent l'effet du mouvement d'une foule sur la déformation de la couche de glace et montrent combien il importe que les organisateurs préparent minutieusement les événements et assurent la maîtrise de la foule. Cet aspect de la question, pourtant extrêmement important, est souvent négligé dans les documents techniques.

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CROWD INDUCED DEFLECTION OF DOW'S LAKE ICE COVER DURING WINTERLUDE FESTIVAL — 1985

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Abstract

The response of a 0.6 m thick floating ice cover in a small lake is described, when 60,000 spectators gathered to witness a concert on stages built on the ice. To monitor and evaluate safety, deflection and surface strain of the ice cover were recorded continuously in front of the stages. The data illustrates the effect of crowd movement on the deformation of the ice cover and emphasizes the importance of careful planning of events, as well as crowd control by the organizers. This side of the story, in spite of its extreme importance, is often neglected in a technical paper.

Introduction

"Winterlude weaves its magic for 60,000" was the front page headline of Ottawa's newspaper "The Citizen" on Saturday, February 2, 1985. This headline was followed by a paragraph: "Skating, dancing, singing and clapping, an estimated 60,000 people celebrated the opening of the seventh annual Winterlude Friday night (Feb. 1) at Dow's Lake. Stretching out along the Rideau Canal, filling the terrace of the Dow's Lake Pavilion, standing on picnic tables, crouching around camp fires, they cheered brightly-coloured fireworks leaving clouds of smoke in the clear sub-zero air."

It was the largest crowd ever on the ice cover of Dow's Lake for the opening night ceremony of the ten-day long annual winter festival in Ottawa called "Winterlude". It was a family night - babies were snugly wrapped up in sleighs; children skating hand-in-hand with their brothers, sisters, friends, parents and grandparents. They danced around the 101 snow sculptures and clapped in rhythm to the tunes coming from huge and powerful speakers beside the two grandstands (Fig. 1) built on the ice cover - and the ice cover responded in harmony with the mass motion.

In the midst of the crowd there was a number of people whose duty it was to patrol the ice cover and monitor the condition of the ice in case it failed. One of the most strategic and vulnerable spots was the area in front of the grandstands where the load of spectators was maximum. At this site the deflection and surface strain of the ice cover was monitored continuously. This paper describes several aspects of the monitoring programs, the severe constraints of carrying out such investigations, and the results of the observations. The study brings out several factors on the response of an ice cover when it is used by a crowd, without any control of their movements, which is different from when it is used for transportation (1) or for parking cars under full control of the load distribution, as described by Meneley (2).

Background

The National Capital Commission (NCC) is responsible for the maintenance of Canada's Federal Government properties in the nation's capital. The Commission also manages and maintains the Rideau Canal, which flows through the core of the city, under a program for the development and improvement of the National Capital Region of Ottawa-Hull. For the last 12 years, a 7.8 km long and 30-70 m wide section of the canal has been used by the NCC to make a public ice skating rink. This rink has become the centre of public activities in Ottawa for about two months every winter.

The success of the rink and the popularity of the area led NCC to organize - since the winter of 1979 - a ten day long annual festival known as "Winterlude". It is held in the first two weeks of February. An important part of this festival is the snow sculpture competition and the exhibition of the sculptures on the floating ice cover of Dow's Lake which was originally constructed as a reservoir for the canal. This lake is about 800 m long and 300 m wide. On the average the water depth is maintained at about 3 m during the summer. Experience taught the organizers to limit the size, shape and the mass of the sculptures, and to distribute these loads on the ice cover. The result was a physically safe and artistically pleasant Dow's Lake ice complex containing the sculpture exhibition area, "Ice Dream", public skating path, and a number of ice hockey and figure skating rinks shown in Fig. 2 representing a small section of the complex.

The study to be reported here was undertaken in 1985 with one week's notice when the Winterlude organizers expressed their concern about the safety of the ice cover on Dow's Lake, particularly when a very large crowd was anticipated for opening night.

Opening Night Ceremony - Location

It was decided by the authorities to celebrate the Winterlude-1985 opening night ceremony in the 100 m x 100 m area in front of the newly constructed Dow's Lake Pavilion and adjacent to the "Ice Dream", as can be seen on the left-hand side of Fig. 2.

Two stages, each with dimensions of 20 m x 30 m were constructed on the ice cover (Fig. 2). Two scaffolded towers, with a base of 3 m x 3 m, were constructed 20 m in front of each of these stages for mounting the stage lights. These structures were about 5 m high and contained a platform for the operators of the lights and television cameras. The spaces below these platforms were thought to be ideal for instrumenting the ice because the

Figure 1 Crowd on Dow's Lake ice cover during the Winterlude opening night ceremony, Feb. 1, 1985 (Courtesy of Ottawa Citizen)

scaffolding could provide the necessary protection from the crowd. These two positions were designated as the measuring stations 1 and 2 as indicated in Fig. 2. The tower associated with Station 1 can be seen on the right hand side in Fig. 1.

Instrumentation

It was decided to record continuously the surface strain of the ice cover at the two stations. This choice was prompted by the fact that strain gauges designed earlier for ice (3), involving direct-current displacement transducers (DCDT), were available and that the operational people were reluctant to allow anything, such as drilling holes, that might affect general use of the ice cover.

Interpretation of strain, however, is difficult if both mechanically and thermally induced strain are present at the same time. This problem became more than an academic concern during the few days prior to the opening night. The sky was relatively clear and the weather office was forecasting a clear week. There were large differences between the maximum (≈-8°C) and the minimum (-18°C) temperature as illustrated in Fig. 3 which contains various information collected by the operational group (the gaps represent weekends). Since the ceremony was to take place during the evening, when the rate of change of air temperature could be substantial, particularly for a clear evening following a bright sunny day, there could be significant thermally induced strain in the ice cover.

The above arguments were sufficient to convince the authorities to allow examination of alternate methods of measuring the ice response. Accordingly, it was decided to measure the deflection of the ice sheet as well. This decision was taken only two days before the ceremony. A team of surveyors was promptly selected. Several sites and targets were identified the next day and practice measurements by a NCC survey team were conducted using an apparently secluded spot on the balcony of the pavilion as a reference point for installation of a theodolite. An imaginary crowd and absence of daylight was assumed during this practice. This exercise led to the reduction in the number of sites to three (Fig. 2) that could be surveyed with the necessary accuracy of 1 or 2 mm. Stations 1 and 2 correspond to the two light towers to be constructed; Station 3 represents a spot marked on the ice for parking a hot air balloon. Since surveying would give only discrete measurements, it was realized that a continuous recording of the deflection was necessary. Accordingly, permission was obtained to

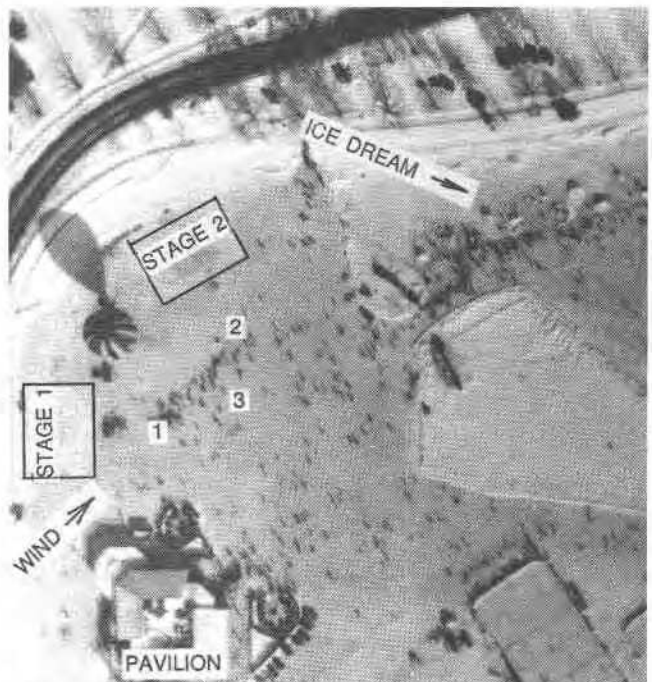

Figure 2

Aerial photo taken on February 2 at 11:00 a.m. shows the ice cover 12 hours after the opening night ceremony.

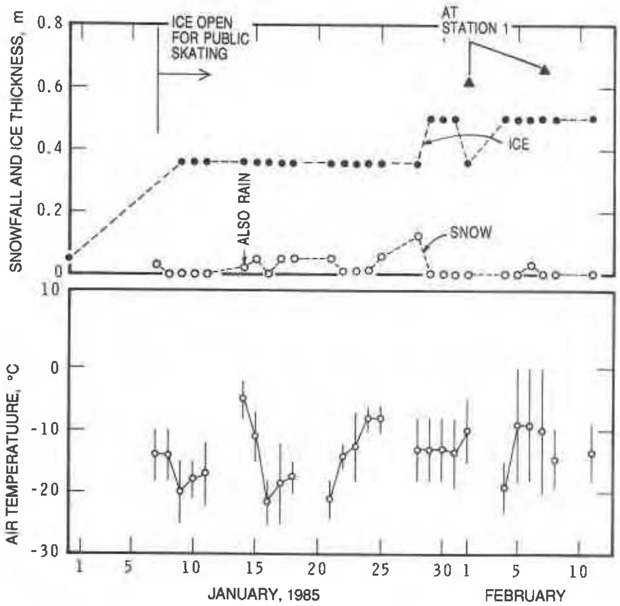

Figure 3

Histories of air temperature, snowfall and ice growth recorded at Dow's Lake

drill two holes in the ice at Stations 1 and 2. A simple device (Fig. 4) was designed and fabricated quickly using available materials in the laboratory. This device consisted of a 4 cm diameter aluminium tube, long enough to be driven into the soil at the lake bottom and an adjustable collar for mounting the barrel (coils, etc.) of a DCDT type displacement gauge. The tube, kept free from freezing into the ice cover, provided the reference point. A core, free to move inside the barrel, supported by a flat plate frozen to the ice surface moved vertically along with the ice cover. In this way, the absolute displacement of the ice cover with respect to the lake bottom could be recorded.

It was discovered, at the time of installation of the instruments, that the requested provision of a 110 V A.C. supply line required for the recorders and the data logger had been overlooked by the electricians. It was too late to supply the electrical line safely to the middle of the ice cover because of the complexity of the entire program. For this reason, small portable generators were obtained. However, when the generators were started the entertainers found the noise objectionable. Since one of the strip chart recorders could be operated on a 12 V battery, it was decided to use it with a car battery and to concentrate on the measurements at one station. Accordingly, Station 1 near Stage 1 was chosen after determining that the major activities of the evening program would be carried out on this stage.

An ice core, 76 mm in diameter, was taken from the central area at Station 1 for laboratory analysis of its structure at a later date. The ice thickness was 0.62 m and water depth below the ice was 1.55 m. The hole in the ice was used to install the deflection gauge (Fig. 5). The strain gauge, with a gauge length of 150 mm, was installed by freezing it onto the ice surface at a distance of 1 m from the hole, to avoid any localized deformation around the hole. Water and ice surface temperatures were measured with a thermistor probe.

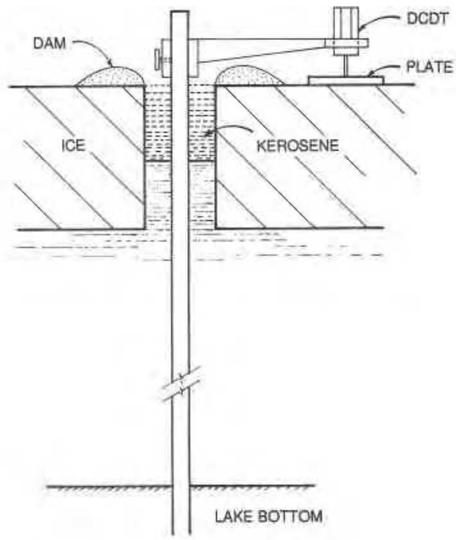

Figure 4

Displacement gauge and the mounting arrangement for recording the deflection of the ice cover

Figure 5

Ice deflection gauge after installation

At 6:30 pm the measuring system was fully operational and the surveyors were ready. Only half a dozen skaters were on the ice at that time so the initial no load readings were taken. The freeboard of the ice cover (depth of water level below the ice surface) was 0.06 m. There was a breeze 6-7 km/hr at an azimuth of 270° to 310° (Fig. 2), the air temperature was about -6°C and the ice surface and water temperatures were -3.5°C and 0.6°C, respectively. About a litre of kerosene was poured in the hole in the hope of preventing icing so that the reference metal tube would remain completely free from the ice sheet. However, in the later part of the evening icing occurred below the kerosene layer and it was necessary to break the ice from time to time as can be seen in Fig. 5; the photograph was taken at about 9 p.m.

Results

A description of the ice at Station 1 is given in Fig. 6. It was 0.62 m in thickness (h_i) and consisted of 0.16 m (h_{si}) fine-grained, randomly oriented snow ice including about 20 mm of flooded layers at the top, with average density ρ_{si} = 875 kg m^{-3} and 0.46 m (h_{cl}) of clear, large columnar-grained ice with the c-axis of the grains in the vertical direction and density of ρ_{cl} = 918 kg m^{-3}. Structural details of the top 450 mm of the ice cover showing all the interfaces can be seen in Fig. 6, which represents 0.5 mm thick vertical thin sections, prepared by the double-microtome technique (4) and observed under crossed polarized light. If ρ_w is the density of water and h_w is the equivalent water displacement, then

$$h_w = (\rho_{si}\, h_{si} + \rho_{cl}\, h_{cl})/\rho_w \qquad (1)$$

which gives h_w = 0.562 m for ρ_w = 1000 kg m^{-3} and the other values given above.

For a freely floating ice cover of uniform thickness, the freeboard is defined by

$$h_f = h_i - h_w \qquad (2)$$

This gives a freeboard of 0.058 m for the ice cover in question, which agrees extremely well with the measured value of 0.06 m. Such a good agreement indicates how flat and uniform the ice cover was at the entertainment square.

As can be seen in Fig. 3. the ice thickness measured at Station 1 on Feb. 1 (triangle) is significantly greater than the thickness (circle) reported by the operational people. It is rather intriguing to see only two thicknesses reported: 0.36 m or 0.50 m. Since the weather was cold and the sky was clear ice should have grown daily. This behaviour was confirmed 6 days later when the author found the ice thickness to be 0.67 m at the spot where the strain gauge was installed. Note that the operational personnel still reported a thickness of 0.5 m (Fig. 3). The reasons for this discrepancy were not determined.

Recordings made of the deflection of the ice cover and its surface strain are presented in Figure 7. Since human beings and their motions were the primary driving forces it is thought that the response of the ice cover should be described together with the description of the crowd and its movement, otherwise the data may not be meaningful. An effort is made in the following paragraphs.

The crowd started to gather rather quickly after 6:50 p.m. in the sculpture exhibition area, "Ice Dream" (Fig. 2). Since the grandstands were in the dark, the entertainment square attracted very few people. Exactly at 7:00 p.m., on Stage 1, in conjunction with sudden flood lights and thunderous sound through the powerful speakers, the Master of Ceremonies entered. It should be mentioned here that this type of entertainment strategy was detrimental to the integrity of the ice cover. The sound level was sufficiently high to induce a high level of seismic response in the ice cover. The vibrations of the ice cover could be felt at this time and there was a feeling that it also induced cracking activity in the ice cover. Studies on acoustic emission in ice provide ample evidence that small but rapid change in the strain does indeed crack and damage the ice (5).

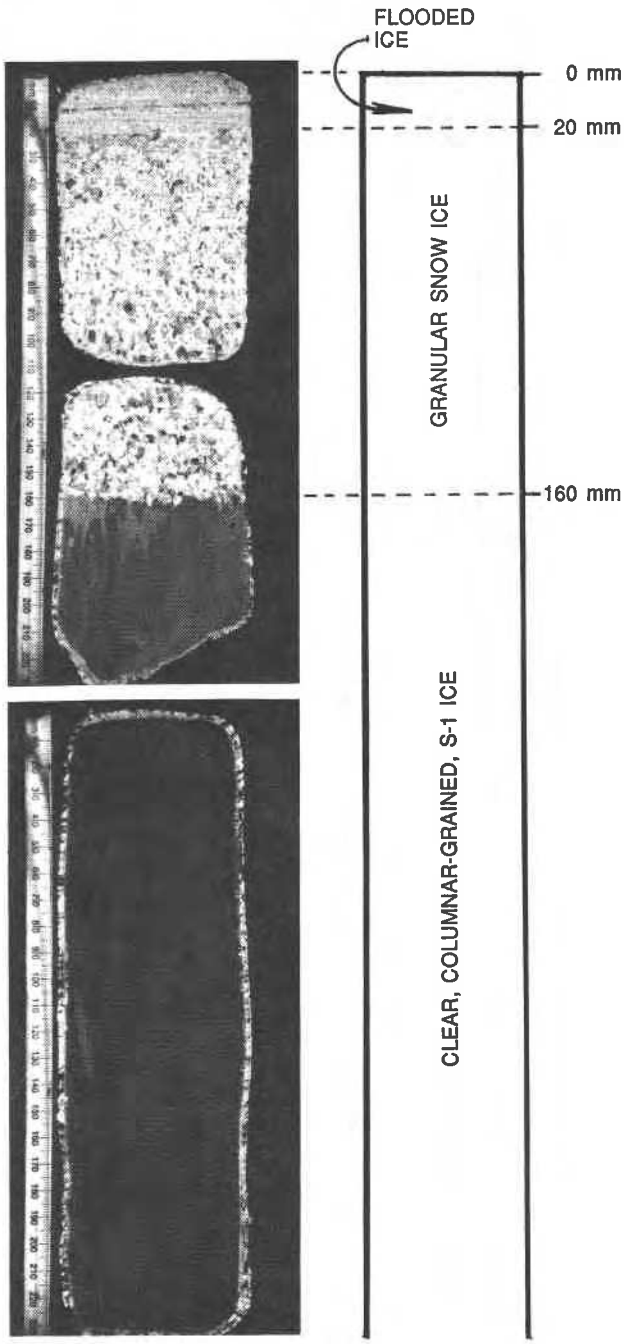

Figure 6 Structure of Dow's Lake ice

Within about 15 minutes a crowd of about 1000 gathered around Station 1 mostly in front of Stage 1. The initial event was the prize distribution and program announcement ceremony which lasted for half an hour. On the average, the deflection at Station 1 reached a value of about 17 mm. Confirmation of this deflection measurement came from the survey team reporting a value of 18 mm (Fig. 7); the bar indicates the error of measurement. At the same time they reported little deformation at Stations 2 and 3. There was practically no one around Station 2 and only a few people around 3.

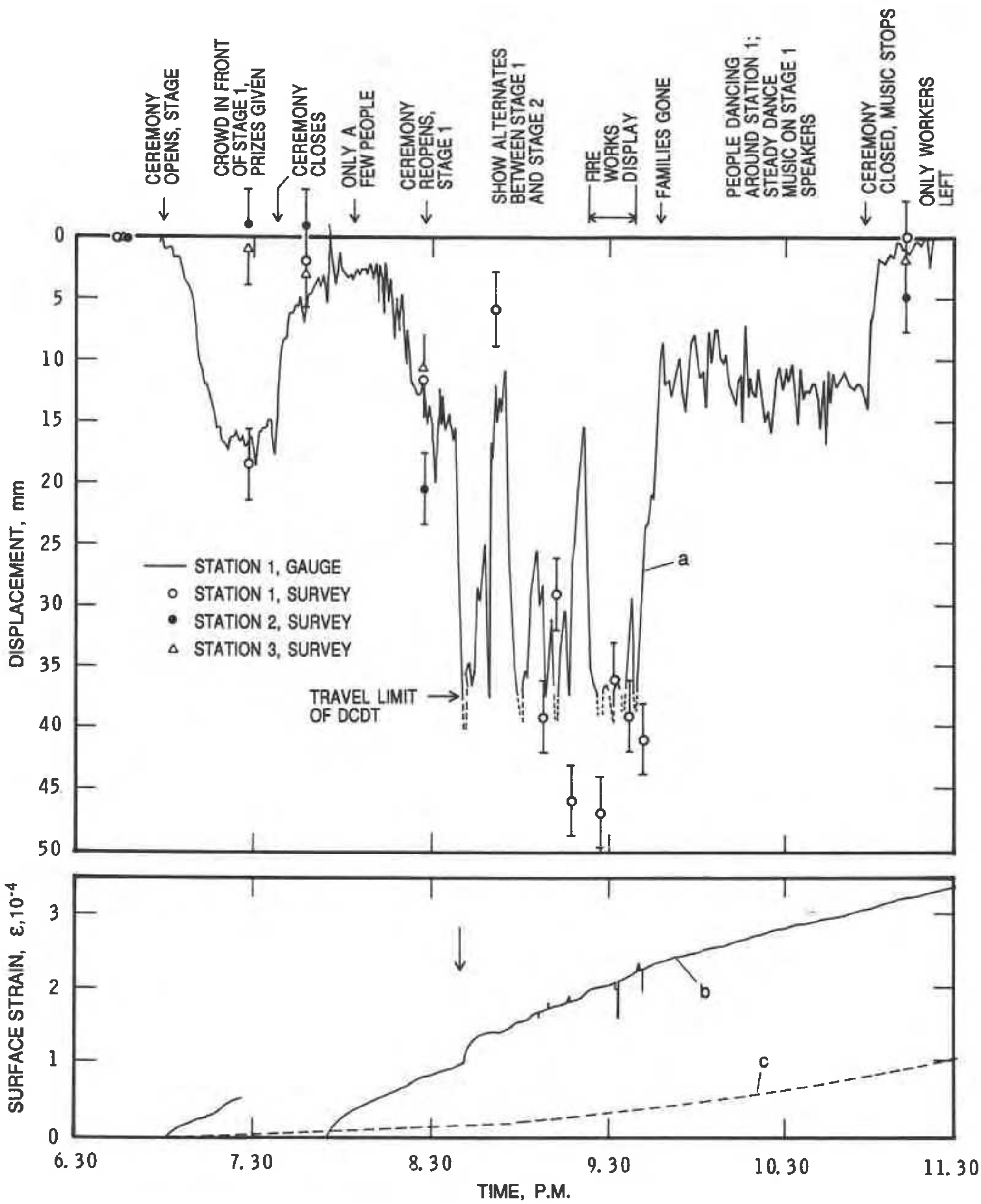

Figure 7 Dow's Lake ice deflection and surface strain during the 1985 Winterlude opening night ceremony

The surface strain also indicated a change during the period of crowd gathering and it was, as expected, compressive in sign (Fig. 7). However, when the strain reached a value of 5×10^{-5} at about 7:25 p.m., an enthusiastic child on skates lost his grip on the ice and managed to kick the strain gauge off the surface after sliding in a horizontal position that allowed his body to pass under the horizontal bars installed for stopping the crowd. This type of manoeuvre was not anticipated. Fortunately the gauge was not damaged.

The prize distribution ceremony was over by 7:40 p.m. Soon after this Stage 1 went into darkness. Within 10 minutes most of the crowd went back to the "Ice Dream" and, as can be seen in Fig. 7, the ice cover around Station 1 recovered most of its deflection. This lull in the crowd movement provided the opportunity to reinstall the strain gauge back on the ice surface. The simple exercise of mounting the gauge in the ice, however, proved difficult under the prevailing conditions. It took some time before a cup of water could be obtained for freezing the gauge. The hole in the ice, now full of kerosene, could not be used as the source of water without a hose.

Commencing at ten minutes after 8 p.m. there was a steady increase in the number of people on the entire ice cover, providing an interesting observation on how individuals try to maintain space between each other. It was noted that individuals maintained a distance of about 1.5 to 2 m between each other. This in fact distributed the load more or less evenly, which was certainly beneficial. The MC entered Stage 1 at 8:20 p.m., followed by a spotlight, and announced the imminent opening of the evening ceremony. This helped in the acceleration of crowd build-up in the entertainment square and an increasing rate in the deflection at Station 1. Finally at 8:30 p.m. the show opened. At this time the deflections at all the stations were essentially the same (Fig. 7) giving an indication that the crowd was evenly distributed, similar to the parking of cars on ice described in (2), and the entire square was acting as a buoyant slab. This conclusion was supported by the fact that the surface strain did not show any rapid change (Curve b, Fig. 7).

The attention of the people was diverted to Stage 2 at 8:32 p.m., when floodlights lit up that area and a big band started to play. Immediately some of the crowd moved in that direction and this reduced the deflection at Station 1. The band played for 5 minutes. As soon as the band finished playing, Stage 1 became the centre of attraction, especially for the children. This event led to a sudden rush of people, mainly children, towards Station 1 causing a rapid depression in the ice cover exceeding momentarily the travel limit of the displacement gauge (Fig. 7). There was certainly a localized depression around Station 1 during this time (8:40 p.m.) as evidenced by a rapid change in the surface strain (Fig. 7). Unfortunately, the surveyors were unable to take any reading because people were everywhere including the corner of the deck of the pavilion (see Fig. 2), where the theodolite was mounted. Monitoring the deflections at locations 2 and 3 was also abandoned after this time.

The attraction was diverted to Stage 2 at 8:52 p.m., when a fake 'Michael Jackson' appeared and started "lip syncing" and dancing, with the associated blinding lights and deafening music, "Thriller". For six minutes the crowd depressed that ice zone while elevating the area near Station 1. Fireworks started at 9:30 and for 20 minutes the display of lights, colours and explosion of fireworks froze the crowd to wherever they stood as can be seen in Fig. 1.

After the fireworks concluded at 9:45 p.m., about 70% of the crowd left the ice, which took only about five minutes, consequently the ice cover rebounded significantly (Fig. 7). Both the stages were darkened at this time and dance music was played from Stage 1 speakers. A fair number of people were dancing during this period. The dancing was stopped at exactly 11 p.m. and the ceremony was closed. Within a few minutes the crowd disappeared leaving only the workers. The ice cover came back exactly where it was before the ceremony began.

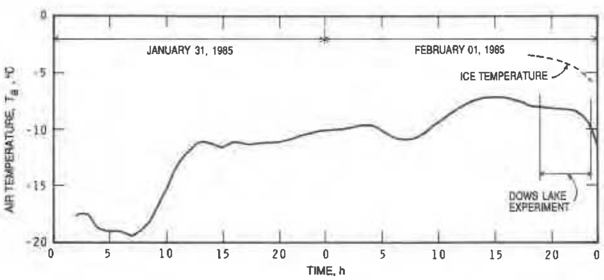

Figure 8

Air temperature recorded at the Ottawa International Airport and the ice surface temperature measured at Station 1, Dow's Lake

Discussion

Although there was no permanent deformation in the ice that could be measured, cracking activity did occur, especially when the crowd moved rapidly. Several cracks occurred during the fireworks and may have been associated with the shock waves from the exploding fireworks. This cracking activity can be seen as events (spikes) in the strain history recorded during the evening (curve "b" Fig. 7). Examination of this strain history in conjunction with the deflection history supports the hypothesis that the measured strain consisted of thermally induced and load induced components. Since the strain gauge used was practically insensitive to temperature changes of a few degrees, the contraction of the ice surface may be thought to be the major contributor to the measured strain. During the entire evening the ice surface temperature dropped by about 2°C. This can be seen in Fig. 8, which also shows the hourly air temperature recorded by the Weather Office at the Ottawa airport, 10 km south of Dow's Lake. Though the ice was significantly warmer than the air, similarities are worth noting in the general characteristics of the ice surface temperatures at Dow's Lake and the air temperature at the airport. Incidentally the wind was from the west and there was no crowd upstream of the measurement location (Fig. 2). Moreover, the vast open spaces of the Experimental Farm are situated upstream. Perhaps this explains why the temperature recorded at the airport bore such a close, almost one-to-one, correspondence with the changes in the ice surface temperature recorded at the Dow's Lake during the evening hours.

An estimation of thermal strain, ε_T, at the surface level of the ice cover is shown as curve "c" in Fig. 7, where

$$\varepsilon_T = \alpha \delta T \tag{3}$$

in which $\alpha = 5 \times 10^{-5}$ °C^{-1} (6) is the coefficient of linear thermal expansion and δT is the change in surface temperature.

A comparison of the measured surface strain and the calculated thermally induced contraction of the ice surface, as shown in Fig. 7, indicates that the change in the measured strain after about 10 p.m., was primarily caused by the cooling effect of the air temperature. Further evidence of this conclusion may be drawn from the fact that the measured surface strain is compressive (ie., indicating ice contraction) and the slope of the curves b and c in Fig. 7 are almost identical particularly in the later part of the evening. This simple correspondence, however, cannot be extended to the early period in the evening.

The most obvious increment in the recorded strain, which occurred at about 8:40 p.m. (Fig. 7), was certainly associated with the big crowd movement at that time. A rough estimation of the load induced strain can be made by subtracting the calculated thermal contraction from the measured deformation. The mechanically induced strain, associated with this crowd motion, was therefore in the range of about 1×10^{-4}. It was rather small, but large enough to give clear indication that the ice cover was locally deflected in addition to the depression due to the buoyancy effect. If the ice cover was tilted or depressed uniformly as a buoyant plate, there should not have been any surface strain. Moreover, this strain level is sufficient for the initiation of cracks (5) and the sounds of cracking could actually be heard at this time.

Strain measurements also show that the deformation of the ice sheet is complex and does not follow the simple laws of elasticity. This complex behaviour can be seen, particularly in the lack of an immediate strain recovery corresponding to the rapid reduction in the measured displacement, at about 8:50 p.m., when a large part of the crowd moved away towards Stage 2. The lack of a quick response in the surface strain can be explained by the fact that the delayed elastic strain and its delayed recovery together with the memory effect play major roles in the deformation processes of ice bodies (7). Ice not only shows elastic deformation, but also exhibits delayed elastic or time dependent recoverable response. Laboratory studies on this subject (3) indicated clearly that the interpretation of the strain field in ice is indeed very difficult if not impossible without detailed information on the load and loading history. In the present case it is complicated further by the variability in the load distribution and the thermal effect.

The only time the crowd was stationary and fairly dispersed was during the fireworks display, at about 9:30 p.m., for a period of 20 minutes. Examination of Fig. 7 shows that the displacement was about 40 mm during this period. Assuming this to be completely due to the loss in buoyancy (h_w), the number of people, N, per unit area, can be estimated by

$$N = \rho_w h_w / P \tag{4}$$

where P is the average mass of a person. If it is assumed further that P = 70 kg, then a displacement of 40 mm gives a crowd density N = 0.57 m^{-2} or a crowd of 17,500 at the entertainment square of 100 m x 100 m. This estimation is on the high side because of the neglect of local depression. A person experienced in crowd control estimated the crowd to be about 10,000 in that area. Some justification for this estimation also comes from a series of photographs of the crowd taken from the top of the tower at the station 1. One of these photographs is shown in Fig. 9.

Acknowledgement

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Figure 9 A small portion of the crowd on the ice cover during the fireworks display

Conclusions

To ensure safety for large crowds on an ice cover, deflection of the ice sheet should be monitored continuously either by standard surveying methods or by an electronic system. These methods provide the absolute displacement of the ice cover with respect to a fixed reference point such as a benchmark on the shore or the bottom of the body of water. The surveying technique is probably the most appropriate technique from the practical as well as economical point of view. Although an electronic system provides more information, it requires special equipment and is limited to shallow water bodies because of the use of rods or tubes anchored to the bottom; the anchoring could be a problem in many situations.

Measurement of the surface strains are useful only in conjunction with the measurement of the deflections. Strain data alone are difficult to measure and difficult to interpret.

As long as the ice cover is intact and in good condition without any cracks, it can support a crowd large enough to produce deflection up to about the free board of the ice cover. Entertainment methods, normally used with surprising elements, should be constrained to avoid any rapid movement of the crowd. Rapid change in the strain induces cracking activity and damages the ice.

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