CRREL REPORT 76-29

Failure of an ice bridge

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S.L. DenHartog, T. McFadden and L. Crook

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In order to verify current theoretical equations on ice bearing capacity, a heavily loaded truck was used to make successive passes over two ice bridges. Breakthrough occurred on one bridge with a vehicle weight of 53,630 lb (24,327 kg). The ice thickness was 17.5 in. (44.5 cm). This one test was in good agreement with the theoretical equations.

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FAILURE OF AN ICE BRIDGE

by

S.L. DenHartog, T. McFadden and L. Crook

INTRODUCTION

The ice cover of a lake or river has often simplified travel across these natural barriers. In the past century mechanization has led to heavier concentrated loads, requiring greater ice thickness and involving greater financial loss in case of ice failure. Numerous reports have been written on the subject of ice bearing capacity, some purely theoretical, some based upon field testing and some based upon collected accident reports. However, no report has been made of a controlled test under actual conditions which confirmed theoretical studies.

To fill this gap, three ice bridges were constructed on an Alaskan river in field expedient fashion, and two were tested to failure with a 10-wheel dump truck. Of primary interest was the performance of an ice bridge of minimum thickness in relation to predictive ice failure equations. Unfortunately, equipment breakdowns, mostly cold weather related, resulted in the loaded truck being repeatedly stopped and parked on the bridges. Equipment failures and time constraints also precluded testing of the third bridge.

LOCATION

Streams were inspected for a practical site location during the summer months. Accessibility, shallow river depth, bottom firmness, and mild flow velocity were the desirable stream characteristics to facilitate recovery of the test vehicle. The site selected was on the Chena River 200 yards (190 m) east of Ft. Wainwright runway 06. The maximum depth of the river was 5 ft (1.5 m), with a firm gravel bottom and an approximate flow rate of 1.6 ft/s (0.5 m/s).

The Chena River is a typical non-glacier-fed northern stream with sloping gravel bar banks and good access. Early winter temperatures fluctuate widely in the Fairbanks area, with air temperatures during November ranging between 52° (12°C) and –40°F (–40°C). However, ice cover on the river can be reliably expected to form during this month, allowing testing before the bitter temperatures of December set in.

TEST PROCEDURE

Since damage to the truck was anticipated, a 5-ton dump truck from the Ft. Wainwright surplus yard was used. The truck was winched across the bridge so that no driver was required in the

Testing on the second bridge was more successful, and failure occurred when the rear wheels of the truck dropped through the ice about 30 ft from the bank on the return trip of the third crossing (Fig. 2). The actual failure was not sudden, although deflection (as shown in Appendix Table A9) was large. The bridge had cracked audibly on previous crossings but there was little audible cracking with breakthrough. This bridge had been partially flooded during the previous night when a thickness measurement was made, and this water layer had not entirely frozen at the time of the test. Air temperatures during the testing were in the $-22°$ to $-31°$F ($-30°$ to $-35°$C), range, contributing to the difficulties and equipment failures.

LOADING

Loads were placed upon the bed of the surplus dump truck with a short boom crane. Six different loading combinations of steel and concrete blocks were used. The empty truck was weighed and found to have the following axle reactions:

Front axle	7.2 kips (3270 kg)
Middle axle	5.9 kips (2680 kg)
Rear axle	5.1 kips (2310 kg).

The steel and concrete blocks were of uniform dimensions. The weight of the concrete blocks averaged 5.10 kips (2313 kg), and the weight of the steel blocks averaged 0.96 kips (430 kg).

With the aid of Figures 3 and 4 the individual axle reactions were computed for each loading and are given in Table I. The total weight of the loaded truck varied from 38.6 to 53.6 kips (17,500 to 24,300 kg).

Figure 3. Fully loaded truck.

SITE PREPARATION AND BRIDGE CONSTRUCTION

The 47th Engineer Company (Construction) of Ft. Wainwright, Alaska, volunteered to build the test bridges as a training exercise. Construction was begun on 7 November 1974, with the surveyors of the 47th Engineer Company staking the bridge locations. In an effort to control flooding, 1 × 8 in. (25 × 200 mm) side boards were placed on edge 7 ft (2.1 m) from each side of the bridge centerlines, and secured with slush. Snow was shoveled along the sides of the boards and then soaked with river water from 5-gallon pails. Scrub spruce trees, of approximately 1 in. (25 mm) diameter and 6 ft (1.8 m) length, previously cut by CRREL personnel, were used for reinforcement (Fig. 5). The harvest of the 675 trees required about 50-55 manhours. Each spruce "rebar" was placed parallel to the centerline, with approximately 9 in. (23 cm) spacing on bridge 1 and 15 in. (38 cm) spacing on bridge 2. Approximately 1 ft (30 cm) of overlap was used between rows of rebars. Bridge 3 was left without reinforcing.

On Thursday, 7 November 1974, sideboards and reinforcements were laid out on bridge 1 over 2 in. (5 cm) of partially packed snow, and the bridge was lightly flooded. No work was done on Friday, Saturday or Sunday, 8, 9 and 10 November. Temperatures dropped over the weekend to as low as −27°F (−33°C), but warmed again by Monday, with 5 in. (13 cm) of new snow falling Monday and Tuesday (Table II). On Monday, 11 November, the 47th Engineer Company installed the 1 × 8 in. sideboards for bridges 2 and 3. On Tuesday they removed the fresh snow from bridges 2 and 3 with a snowblower, although simply walking down the snow prior to the next flooding would have been easier and just as effective. Spruce rebars were placed on bridge 2 and then both bridges 2 and 3 were flooded. On Wednesday morning all three bridges were flooded again. No further flooding was done until Monday, 18 November, because of warm weather.

Table II. Weather observations at International Airport, Fairbanks, Alaska.

Date Nov 74	*High temp (°F)*	*Low temp (°F)*	*Snowfall (in.)*
7	10	3	T
8	6	3	1.2
9	7	−22	0.8
10	6	−27	0.3
11	22	6	3.6
12	33	16	1.5
13	28	8	0
14	30	8	2.1
15	23	12	2.4
16	12	−15	T
17	−7	−21	T
18	−13	−27	T
19	−16	−27	T
20	−15	−29	T
21	4	−25	0.1
22	10	−3	0.3
23	3	−10	1.4
24	−1	−7	3.8

Two major problems were noted in the flooding operation. First, warm weather, inadequately sealed sideboards, and excessive initial flooding caused slow leakage under the sideboards. This leakage allowed air pockets to form under $^1/_8$ to $^1/_4$ in. (3 to 6 mm) of skim ice. This was especially noticeable when bridge 1 was flooded without removing 4-5 in. (11 cm) of fresh snow, resulting in a $^1/_4$ to $^3/_4$ in. (6 to 19 mm) ice sheet suspended over numerous air pockets where the snow had melted and run out under the sideboards. These thin ice covers were broken by walking along the bridges. (In subsequent tests, it is recommended that no sideboards be used; instead the water should be allowed to "feather out" at the edges of the bridge.) The second problem encountered was that initial light flooding was inadequate to sufficiently secure the spruce rebars to the ice surface. Subsequent flooding was inadvertently excessive, causing the rebars to loosen, float free, and be significantly displaced by the hydraulic force of the pumped stream (see Fig. 6). This phenomenon was a problem especially at bridge 2, where final flooding incompletely covered the rebars in many places.

The remainder of the week continued with mild temperatures and more snow, thereby discouraging further work. The weekend once again brought low temperatures, and Monday morning (18 November) was cold. Snow from the previous week was shoveled from the bridges in preparation for further flooding; however, early darkness, cold temperatures, and a faulty pump prevented Monday afternoon flooding. At this time no more than 2 in. of ice had been added to the surface. On Tuesday morning (19 November) the ice thickness was measured, and it was decided that the existing 14- to 16-in. (35 to 40 cm) ice was thick enough for testing. The sequence of freezing events, however, had left the reinforcing in the top half of the ice bridge, most of it within 2 in. (5 cm) of the surface.

DEFLECTION MEASUREMENTS

Deflection of the ice under load was measured with the use of a Zeiss level, stationed approximately 100 ft (30 m) upstream on grounded ice, and a survey rod fastened to the bed of the truck. Each increased loading compressed the truck's springs and lowered the height of the rod; therefore, measurements were later taken on a firm, flat, snowfree surface to determine a rod height for each loading. The correction required for this effect was less than $^1/_2$ in. (13 mm) from the smallest to greatest loading. A summary of deflection data is tabulated in the Appendix.

CONCLUSIONS

The test performed yielded a very limited amount of data, but some interesting observations should be reported. Using Nevel's (1968) computer program for the first crack on an infinite ice sheet with an assumed ice strength of 142 psi (10 kg/cm^2), we determined a required ice thickness of 22.3 in. (57 cm) for the 53,630 lb (24,327 kg) load. These calculations, which are based upon the stress under each wheel, show that the maximum stress occurs under the inner wheels of the middle axle, as might be expected. With actual failure at 17.5 in. (44.5 cm) the computer program gives a stress at failure of 214 psi or 15 kg/cm^2. However, the tests were not on an infinite ice sheet, but rather on a narrow river, with the bridge supported by grounding near shore as well as by flotation. Nevel (1972) has adapted his original program for this case. The new program* gives a stress at failure of 220 psi (15.5 kg/cm^2 for a 53,630 lb load, not appreciably higher and well within the range of our ability to predict ice strength.

Nevel (1972) has also made calculations for ultimate failure of a floating infinite ice sheet, based on the observation that failure takes place by the breaking of wedge tips formed by radial and subsequent circumferential cracks. Using his equation 1 and Table I for the rear set of 4 wheels on one

* The theory is based upon unreinforced ice, while bridge 2 (where failure finally occurred) was somewhat reinforced. The influence of this reinforcement is unknown.

APPENDIX. TEST DATA

Table AI. Preload profile, bridges 2 and 3.

Station (ft)	*13 Nov 74 elev (ft)*	*22 Nov 74 elev (ft)*	*23 Nov 74 elev (ft)*	*Ice thickness (in.) 21 Nov 74*	*Ice thickness (in.) 22 Nov 74*
			Bridge 2		
0+25	98.16	97.84	97.82		15½
0+50	98.10	97.83	97.82		16
0+75	98.18	97.91	97.91		18
1+00	98.20	98.09	98.08		24
			Bridge 3		
0+25	98.06	No later date preload		18	
0+50	98.00	profile taken.		17	18
0+75	98.02			18½	
1+00	98.06			25	

Table AII. Post load profile, bridge 3.*

Station (ft)	*Elevation (ft)*	*Deflection† (ft)*
0+25	97.01	–0.48
0+37	96.84	–0.53
0+50	97.26	–0.14
0+75	97.66	–0.18
1+00	97.77	–0.07

* No post load profile was done for bridge 2.

† Deflection from profile of 1st forward loading.

Table AV. Deflection data, bridge 3.

Loading 3

Front axle reaction = 10.6 k

Middle axle reaction = 17.7 k

Rear axle reaction = 15.4 k

Station (ft)	*Stop time (min)*	*Ice elev (ft)*	*Deflection* (ft)*	*Remarks*
Ahead				
0+25		97.09	-0.40	3″ water on bridge (0+25 to 0+50) @ start of loading
0+30		96.96	-0.43	
0+37		97.01	-0.37	
0+45		97.09	-0.30	
0+50		97.22	-0.18	Truck off bridge and up onto berm @ 0+50. Truck then reversed and pulled back onto bridge @ 0+45. Once back onto bridge truck again pulled ahead.
Back				
0+45		97.08	-0.31	
0+45		97.05	-0.34	
Ahead				
0+55		97.11	-0.30	
0+55	1	97.10	-0.31	Delay due to faulty steering.
0+55	5	97.10	-0.31	
0+55	7	97.08	-0.33	
0+55	10	97.07	-0.34	
0+55	16	97.05	-0.36	
0+58		97.08	-0.34	Truck off bridge again.
0+58	7	97.07	-0.35	Begin return.
Back				
0+50		97.00	-0.40	
0+40		96.88	-0.50	
0+37		96.73	-0.65	
0+30		96.71	-0.68	
0+25		96.81	-0.68	

* Deflection from profile of 1st forward crossing of bridge 3.

Table AVIII. Deflection data, bridge 2.

Loading 2

Front axle reaction = 11.0 k
Middle axle reaction = 20.1 k
Rear axle reaction = 17.4 k

Station (ft)	*Stop time*	*Ice elev (ft)*	*Deflection* (ft)*	*Remarks*
Ahead				
0+25		97.17	-0.65	
0+37		97.18	-0.64	
0+50		97.22	-0.60	
0+62		97.35	-0.52	Truck rolled onto berm and thereby
0+75		97.65	-0.26	elevated the rod side of truck (0+62)
0+87		97.88	-0.12	
1+00		97.92	-0.16	
Back				
0+87		97.82	-0.18	
0+75		97.53	-0.38	
0+62		97.25	-0.61	Truck rolled back onto bridge from
0+50		97.14	-0.68	berm
0+37		97.00	-0.82	
0+25		97.10	-0.72	

* Deflections from preload profile 23 Nov 1974.

Table AIX. Deflection data, bridge 2.

Loading 3

Front axle reaction = 12.6 k
Middle axle reaction = 21.9 k
Rear axle reaction = 19.1 k

Station (ft)	*Stop time*	*Ice elev (ft)*	*Deflection* (ft)*	*Remarks*
Ahead				
0+25		96.92	-0.90	Ice dry
0+30		96.79		Elevation @ failure
			-1.03	
				Failure occurred within 10-15 seconds of stopping

* Deflections from preload profile 23 Nov 1974.