NRC Publications Archive Archives des publications du CNRC

Flexural strength and fracture toughness of sea ice

Timco, G. W.; Frederking, R. M. W.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Cold Regions Science and Technology, 8, 1, pp. 35-41, 1983-08

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=f7885656-1323-4fed-ac88-d88c010a7bd4>
<https://publications-cnrc.canada.ca/fra/voir/objet/?id=f7885656-1323-4fed-ac88-d88c010a7bd4>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

Ser
TH1
N21d

p. 1146
c. 2

BLDG

10517

National Research
Council Canada

Conseil national
de recherches Canada

FLEXURAL STRENGTH AND FRACTURE TOUGHNESS OF SEA ICE

by G.W. Timco and R.M.W. Frederking

ANALYZED

Reprinted from
Cold Regions Science and Technology
Vol. 8 (1983)
p. 35 - 41

DBR Paper No. 1146
Division of Building Research

Price \$1.00

OTTAWA

NRCC 22788

Canada

4193058

RÉSUMÉ

On a effectué au milieu de l'hiver des expériences sur la résistance à la flexion et à la rupture de la glace qui se trouvait dans des champs de débris autour de l'île de Tarsiut dans la mer de Beaufort. Les essais comprenaient la détermination de la structure des cristaux, de la salinité et de la densité de la glace, et de la résistance à la flexion et à la rupture d'une petite poutre de glace. La résistance à la flexion était comprise entre 0,6 à 1,0 MPa et la résistance à la rupture entre 100 et 140 kPa·m². Les deux caractéristiques dépendaient du volume d'eau salée à l'état liquide et de sa profondeur dans la couche de glace. En comparant ces résultats à ceux obtenus avec de la glace d'eau douce à fins cristaux, et pour des charges comparables, on a observé que la résistance à la flexion de la glace d'eau de mer était bien plus faible que celle de la glace d'eau douce tandis que la résistance à la rupture de la glace d'eau de mer était plus élevée.

CISTI / ICIST

3 1809 00210 2926

FLEXURAL STRENGTH AND FRACTURE TOUGHNESS OF SEA ICE

G.W. Timco

Hydraulics Laboratory, Division of Mechanical Engineering, National Research Council of Canada, Ottawa, Ontario K1A 0R6 (Canada)

and R.M.W. Frederking

Geotechnical Section, Division of Building Research, National Research Council of Canada, Ottawa, Ontario K1A 0R6 (Canada)

(Received October 8, 1982; accepted in revised form November 2, 1982)

ABSTRACT

A series of mid-winter experiments were carried out on the ice in the rubble field around Tarsiut Island in the Beaufort Sea. The tests included grain structure determinations, salinity and density of the ice, small beam flexural strength and fracture toughness. Typical values for flexural strength and fracture toughness were 0.6–1.0 MPa and 100–140 kPa m^{1/2} respectively. Both properties were dependent on brine volume and depth in the ice sheet. In comparing these results with identical tests on fine-grained freshwater ice it was found that for comparable loading conditions, the strength of the sea ice was significantly lower than the strength of the freshwater ice, whereas the fracture toughness of the sea ice was higher than the fracture toughness of the freshwater ice.

by the grain type (granular or columnar), grain size and orientation, temperature, salinity (brine volume) of the ice, loading stress rate and loading strain rate. Several different types of experiments have to be performed in order to gain proper insight into the fracturing mechanisms and failure modes of the ice. Measurement of its mechanical properties even for a limited range of conditions, can provide valuable information.

In the present study, the salinity, density, grain structure, flexural strength and fracture toughness of ice from the Beaufort Sea were investigated. The same measurements had been made previously on fine-grained, columnar freshwater ice using the same test equipment (Timco and Frederking, 1982), allowing a comparison of the flexural strength and toughness of freshwater ice and sea ice for identical – although limited – range of conditions.

1. INTRODUCTION

With the current activity in the Beaufort Sea, it is necessary to have both a knowledge and an understanding of the mechanical properties and fracturing behaviour of sea ice. In particular, information of this type is necessary for both design calculations of ice forces on structures and bearing capacity determinations. Because sea ice is a complex mixture of ice, brine, solid salts and air which is never in a state of complete internal equilibrium, its properties are variable and dependent on several factors. The mechanical properties can be influenced

2. SAMPLE ACQUISITION AND PREPARATION

The present experiments were conducted during two separate field trips to the Beaufort Sea, January 5–15 and May 3–6 of 1982. The majority of the work reported relates to the tests performed during the January (mid-winter) trip. The results from the May trip were used to supplement and expand the results of the January trip. On both occasions, the ice was cut from a large rafted solid block of ice in the rubble field 40 m west of Tarsiut Island, a concrete-caisson-retained island in the Beaufort Sea. Using a chain saw, blocks of ice 45 cm long by 10

cm wide were cut through the full depth of the ice sheet. For handling purposes, these blocks were in turn cut into upper and lower halves. In addition, several horizontal and vertical cores were taken and used for detailed studies of the uniaxial compressive strength of the ice (Frederking and Timco, 1983). The ice pieces were placed in a plastic bag and packed in a cardboard box. The samples were transported to the heli-pad on the island and flown by helicopter (in an unheated compartment) to Tuktoyaktuk where they were transported to a small test laboratory which had been set up in the yard of the base camp of Dome Petroleum Ltd. At all times during cutting, transporting and storing during the January trip, the samples were at temperatures below -30°C . There was no evidence of any brine drainage from the samples. In the May trip, the samples were subjected to higher temperatures ($\approx -10^{\circ}\text{C}$) during these procedures. Although there was some brine drainage in this case (especially when trimming the samples), the salinities were not significantly different from the January ice.

In the lab, a small band saw was used to cut the ice blocks into pieces 45 cm $\times$ 10 cm $\times$ 6.5 cm thick. The long direction of the specimen was in the horizontal plane of the original ice sheet. In general, the top 5–6 cm of the ice block (fine snow ice) was cut off and discarded, and the ice block was then cut into 10 layers. Because each large block of ice was cut in half for ease of transportation and handling, no useable samples were obtained from layer 5.

3. STRUCTURE OF THE ICE

Vertical and horizontal thin sections were made using the "hot plate" technique on both trips. Figure 1 shows a composite of the ice as photographed through crossed polaroids. The structure of the ice is typical for sea ice from the Beaufort Sea. In the upper 2–3 cm, there is a layer of fine-grained snow ice. Below this, the grain size increases, but the ice remains granular with a gradual change to a columnar structure with depth. For this ice, the grains are columnar below a depth of 30 cm; however, distinct banding is evident along the length of the core. These banding features are fairly common in ice from the Beaufort Sea (Frederking and Timco, 1980), and would seem to occur as a result of periodic lateral

shifts of the ice cover during growth. Note the very strict columnar structure of the ice at depths of 30–50 cm and the abrupt change at ≈ 50 cm to a finer-grained mix of granular and columnar crystals. Below this, the ice becomes strictly columnar again. Note also the distinct preferred orientation of the azimuthal angle of the *c*-axis at a depth of 45 cm (as shown in the horizontal section at that depth). This preferred orientation is very well developed and this example clearly shows that this orientation can develop to a very ordered state within 10–12 cm of ice growth.

4. SALINITY AND DENSITY OF THE ICE

The salinity of the ice was determined with a YSI conductivity meter using melted samples from each layer from each block. This gives an indication of the salinity variations in both the vertical and horizontal directions. The salinity profile of the ice in January is shown in Table 1. In general, there is a higher salinity in the upper layer with a lower salinity, which is relatively independent of depth in the lower layers. This behaviour is typical for Beaufort Sea ice at that time of the year (Martin, 1979; Frederking and Timco, 1980). Horizontally, the salinity is reasonably consistent within the individual layers. This suggests that the ice tested in this program grew as a single piece under the same conditions.

The density was determined by carefully measuring the mass and dimensions of right-prisms of the ice which had been squared and shaped using a band-

TABLE 1
Salinity of the ice (‰)

Block depth range (cm)	Sample					
	1	2	3	4	5	6
0–5.0	–	–	–	–	–	–
5.0–11.5	7.0	5.9	6.7	6.1	5.6	5.6
11.5–18.0	5.2	4.6	4.7	4.6	4.8	5.0
18.0–24.5	4.8	5.5	5.0	5.0	5.1	4.9
24.5–31.0	4.9	4.1	4.3	4.4	4.5	4.6
31.0–37.5	–	–	–	–	–	–
37.5–44.0	4.1	3.6	4.4	4.2	4.1	3.8
44.0–50.5	4.3	3.9	4.6	4.5	4.5	4.1
50.5–57.0	4.2	3.7	3.7	4.1	3.8	3.8
57.0–63.5	4.7	4.8	3.6	4.7	4.8	4.3
63.5–70.0	2.8	4.2	–	3.8	4.8	4.5

Fig. 1. Composite of thin section photographs showing both vertical and horizontal profiles through the ice sheet. The grid is 1 cm on a side.

TABLE 2

Density of the ice

Sample	Width (cm)	Thickness (cm)	Length (cm)	Mass (g)	Density (g cm ⁻³)
1	5.24	5.75	19.20	511.4	0.884
2	5.83	5.31	18.99	531.1	0.903
3	5.98	5.15	19.09	537.3	0.914
4	5.70	5.35	19.10	528.5	0.907
5	5.79	5.24	19.10	522.5	0.902
6	5.29	5.12	19.10	472.2	0.913
Average					0.904 ±0.010

saw and planer. The results are presented in Table 2. The average density of the ice was 0.904 ± 0.010 g/cm³.

5. FLEXURAL STRENGTH OF THE ICE

Small scale tests using the 4-point loading configuration were used to measure the flexural strength of the ice. For these tests, the ice was trimmed into prism-shaped specimens and tested in a motorized 0.05 MN capacity compression tester using specially designed aluminum platens (Timco and Frederking, 1982). A 0.05 MN capacity load cell was used in conjunction with an *X*-time recorder to make load-time curves for each test. From these recordings, the maximum load at failure (P'), the time of failure (t_f) and the loading stress-rate ($\dot{\sigma}_f$) were determined. The time to failure for these tests ranged from 12 to 22 sec. The flexural strength was calculated using

$$\sigma_f = 3 P' l / w h^2 \quad (1)$$

where l is the distance between supports ($l = 10$ cm in this case), w is the width of the sample and h is the thickness of the sample. In all cases, the bottom of the sample (i.e. the bottom of each layer) was placed in tension. The compression tester was used at a nominal cross-head displacement rate of 4×10^{-2} mm s⁻¹. To ensure isothermal temperatures in the ice and to test the ice over a range of temperatures, the samples were cold-soaked overnight in freezers before testing. After testing, part of the sample was saved to determine the confined compressive strength of the ice (Timco and Frederking, 1983). The rest

was melted for salinity measurements. The brine volume (ν_b) of the ice was calculated from measured temperature and salinity values using the empirical relations of Frankenstein and Garner (1967).

The results of the flexure tests are shown as a function of depth at constant temperature in Fig. 2 and as a function of brine volume in Fig. 3. The results suggest that the flexural strength is higher in the upper region of the ice where the ice is granular. This is in spite of the fact that the ice had a higher salinity in the upper layer. In the lower layers, where there is either a columnar or a mixture of columnar and granular ice, the strength is slightly lower. In the granular region, $\sigma_f = 1.16$ MPa whereas in the lower columnar regions $\sigma_f = 0.86$ MPa at -20°C . These values at this cold temperature correspond to relatively low brine volumes (15‰). With increas-

Fig. 2. Flexural strength versus depth of the sample in the ice sheet for a temperature of -20°C .

Fig. 3. Flexural strength versus brine volume for columnar sea ice.

ing brine volume, for the columnar ice, there is a general decrease in flexural strength such that for brine volumes of 50‰, the flexural strength is 0.6 MPa. These values are significantly lower than those obtained by the authors on very fine grained freshwater ice using the same test setup. For this ice, $\sigma_f = 2.2$ MPa for a grain size of ≈ 1 mm, and $\sigma_f = 1.8$ MPa for a grain size of ≈ 3 mm (Timco and Frederking, 1982). For grain sizes comparable to the grain sizes of the sea ice, however, a flexural strength of 1 MPa is inferred from Michel's (1978) analysis of apparent flexural strength of 10 mm grain diameter freshwater ice. Keeping in mind these results for freshwater ice, it is interesting to note that an extrapolation of the data on sea ice to the $\nu_b = 0$ axis is in good agreement with the results on freshwater ice for grain sizes comparable to the grain size in the sea ice. This would suggest that the flexural strength of sea ice is controlled by the grain size and not the platelet size in the ice. Dykins (1967), on the other hand, reports from direct tension tests that there is no strong grain-size dependence in tensile-type failures for saline ice. Clearly, much more work is required in this area before this question can be unambiguously answered.

6. FRACTURE TOUGHNESS OF THE ICE

Fracture toughness (i.e. resistance to fracture by crack propagation), was measured using the 4-point loading method. Basically, the fracture toughness (K_{IC} or critical stress intensity factor) is a material property which determines the stress necessary to propagate a crack of a known size. The principle of the stress intensity factor approach is that at the onset of cracking of a material, the stress field near the crack tip is always the same, regardless of the geometry and loading configuration of the specimen. The fracture toughness is related to the strain energy release rate (G) by (for plane strain)

$$K_{IC}^2 = GE/(1 - \mu^2) \quad (2)$$

where E is Young's modulus and μ is Poisson's ratio (see Jayatilaka, 1979). For a purely brittle solid, G is twice the surface energy (γ) of the solid. To date, there have been a number of investigations of the fracture toughness of freshwater ice (Gold, 1963; Goodman and Tabor, 1978; Hamza and Muggeridge, 1979; Liu and Miller, 1979; Goodman, 1980; Miller,

1980) but only a few for sea ice (Vaudrey, 1977; Urabe et al., 1980; Urabe and Yoshitake, 1981a, 1981b). The results of the freshwater ice tests indicate that the fracture toughness decreases with increasing loading rate, increasing temperature and decreasing grain size. For sea ice, Vaudrey measured toughness values averaging 70 kPa m^{1/2} for brine volumes of 25–30‰. Urabe found that for ice temperatures of -2°C ($\nu_b = 120\%$), the fracture toughness was related to the sub-grain size in the ice.

Using the fracture mechanics approach, the determination of K_{IC} is a stress analysis problem which involves the applied stress, the loading geometry, the crack length and dimensions of the sample. The fracture toughness is given by Brown and Strawley (1966) for the 4-point loading configuration

$$K_{IC} = \frac{3 P' l}{wh^2} \sqrt{a} f(a/h) \quad (3)$$

where

$$f(a/h) = 1.99 - 2.47 (a/h) + 12.97 (a/h)^2 \\ - 23.17 (a/h)^3 + 24.80 (a/h)^4$$

and a is the length of a notch (≈ 1.2 cm) which was made in one of the 45 cm $\times$ 10 cm faces using the band saw. Since the notch (or "crack") must be sharp, the notch was sharpened using a surgeon's scalpel before inserting it into the press. The test conditions (temperature, loading rate, sample size and orientation, test setup, etc.) were identical to that for the flexure tests.

In performing fracture toughness tests, the results can be interpreted in terms of linear elastic fracture mechanics (LEFM), only if certain conditions are met. Namely, the region of plasticity at the tip of the crack must be confined to the tip and be much smaller than any geometric dimension of the sample, the crack must be sharp, and it must be significantly longer than any pre-existing flaw in the sample. In the present tests, since the sample is relatively small and the grain size relatively large, these conditions are not all met. If analyzed in terms of LEFM, this would tend to underestimate the value of K_{IC} . Recently, however, Urabe and Yoshitake (1981b) have compared results of small-beam and large-beam fracture toughness tests on sea ice and found that the small-beam tests give comparable results to the large-beam tests (which meet the above mentioned

conditions) if corrected using

$$(K_{IC})_{\text{corrected}} = \frac{\sqrt{a_e} f(a_e/h)}{\sqrt{a} f(a/h)} K_{IC} \quad (4)$$

where a_e is a corrected notch length (which is the sum of the notch length and sub-grain size in the region of the tip), $f(\cdot)$ is the function given in eqn. (3) and K_{IC} is the toughness value calculated using LEFM theory. All the test results reported here have been corrected using this equation. Depending upon the grain size, this correction increased the K_{IC} value by 9–43% from that calculated using simple LEFM theory. It should be noted that in all cases, the load–time curves for these tests were linear to failure indicating that the tests were performed in the elastic range of behaviour. The time to failure ranged from 9 to 15 sec. At failure, the load dropped abruptly to zero. In every case, the fracture plane was an extension of the saw-cut “crack”.

The test results are shown as a function of depth at constant temperature in Fig. 4, and as a function of brine volume for columnar ice in Fig. 5. The results indicate that the fracture toughness is relatively constant ($\approx 110 \text{ kPa m}^{1/2}$) in the granular region of the ice cover. With increasing depth to the columnar layer, the toughness of the ice increases. The strong brine volume dependence of the fracture toughness of the ice is clearly evident from Fig. 5. Included in this figure are the high brine volume results of Urabe and Yoshitake (1981a) for comparable grain size and loading rate. The results are in good agreement.

In Fig. 5, along the $v_b = 0$ axis, the fracture toughness values for freshwater ice are indicated for two different grain sizes. For fine-grained ($\approx 2 \text{ mm}$) freshwater ice (with a grain size slightly larger than the sub-grain (or platelet) width of sea ice), the toughness of the ice is $83 \text{ kPa m}^{1/2}$ for a comparable loading rate (Timco and Frederking, 1982). For larger grained (5–10 mm) freshwater ice (with a grain size comparable to the grain size sea ice), the toughness of the ice is $150\text{--}170 \text{ kPa m}^{1/2}$ for a comparable loading rate (Urabe and Yoshitake, 1981b). From Fig. 5, an extrapolation of the experimental data to the $v_b = 0$ axis is in good agreement with the larger-grained results for freshwater ice. Although this analysis would suggest that the toughness of the ice may be controlled by the grain size rather than the platelet size in the ice, a more rigorous experi-

Fig. 4. Fracture toughness versus depth of the sample in the ice sheet at a loading rate of $10 \text{ kPa m}^{1/2} \text{ s}^{-1}$ and a temperature of -20°C .

Fig. 5. Fracture toughness versus brine volume for columnar ice at a loading rate of $10 \text{ kPa m}^{1/2} \text{ s}^{-1}$.

ment would have to be performed to clarify unambiguously the structural factors which control the fracture toughness variations.

In fracture toughness tests on sea ice, the use of the small beam correction formula is clearly not desirable. Care should be used, therefore, in choosing the sample size for the test. The present data can be used to determine sample sizes which allow the use of the linear fracture mechanics approach in evaluating the tests. This would give more reliable results. Moreover, much more information could be obtained

by making detailed thin sections of the ice for *each* strength or toughness test. In this way, more accurate information on mechanical properties and fracture behaviour of sea ice would be obtained.

ACKNOWLEDGEMENTS

The authors would like to thank Gulf Canada and Dome Petroleum for the opportunity to perform these experiments. The logistics, transportation and accommodation support provided by these companies made this test programme possible. The assistance of D. Blanchet of Dome Petroleum in making the thin sections is gratefully acknowledged.

This paper is a joint contribution from the Divisions of Mechanical Engineering and Building Research, and is published with the approval of the Directors of the Divisions.

REFERENCES

- Brown, W.F. and Strawley, J.E. (1966), Plane strain crack toughness of high strength metallic materials. American Society for Testing and Materials (ASTM Special Technical Publication No. 410).
- Dykins, J.E. (1967), Tensile properties of sea ice grown in a confined system. In: H. Oura (Ed.), *Physics of Snow and Ice*, Bunyendo Printing Co., Japan, Vol. 1, pp. 523–537.
- Frankenstein, G.E. and Garner, R. (1967), Equations for determining the brine volume of sea ice from -0.5 to -22.9°C . *J. Glaciol.*, 6(48): 943–944.
- Frederking, R.M.W. and Timco, G.W. (1980), NRC ice property measurements during the Canmar Kigoriak trials in the Beaufort Sea, Winter 1979–80. NRC/DBR paper No. 947, Ottawa, Canada.
- Frederking, R.M.W. and Timco, G.W. (1983), Uniaxial compressive strength and deformation of Beaufort Sea ice. *Proc. POAC 83* (in press).
- Gold, L.W. (1963), Crack formation in ice plates by thermal shock. *Can. J. Phys.*, 41: 1712–1728.
- Goodman, D.J. and Tabor, D. (1978), Fracture toughness of ice: preliminary account of some new experiments. *J. Glaciol.*, 21(85): 651–660.
- Goodman, D.J. (1980), Critical stress intensity factor (K_{IC}) measurements at high loading rates for polycrystalline ice. In: P. Tryde (Ed.), *Physics and Mechanics of Ice*. Springer-Verlag, New York, pp. 129–146.
- Hamza, H. and Muggeridge, D.B. (1979), Plane strain fracture toughness (K_{IC}) of freshwater ice. In: *Proc. POAC 79*. Norwegian Inst. of Technology, Trondheim, Norway, Vol. 1, pp. 697–707.
- Jayatilaka, A. (1979), *Fracture of Engineering Brittle Materials*. Applied Science Publ. Ltd., London.
- Liu, H.W. and Miller, K.J. (1979), Fracture toughness of freshwater ice. *J. Glaciol.*, 22(86): 135–143.
- Martin, S. (1979), A field study of brine drainage and oil entrapment in first-year sea ice. *J. Glaciol.*, 22(88): 473–502.
- Miller, K.J. (1980), The application of fracture mechanics to ice problems. In P. Tryde (Ed.), *Physics and Mechanics of Ice*. Springer-Verlag, New York, pp. 265–277.
- Michel, B. (1978), *Ice Mechanics*. Les Presses de l'Universite Laval, Quebec, 499 pp.
- Timco, G.W. and Frederking, R.M.W. (1982), Comparative strengths of freshwater ice. *Cold Reg. Sci. Technol.*, 6: 21–27.
- Timco, G.W. and Frederking, R.M.W. (1983), Confined compressive strength of sea ice. *Proc. POAC 83* (in press).
- Urabe, N., Iwasaki, T. and Yoshitake, A. (1980), Fracture toughness of sea ice. *Cold Reg. Sci. Technol.*, 3: 29–37.
- Urabe, N. and Yoshitake, A. (1981a), Fracture toughness of sea ice – in situ measurement and its application. *Proc. POAC 81*. Quebec City, Canada, Vol. I, pp. 356–365.
- Urabe, N. and Yoshitake, A. (1981b), Strain rate dependent fracture toughness (K_{IC}) of pure ice and sea ice. *Proc. IAHR Symp. on Ice*. Quebec City, Canada, Vol. II, pp. 551–563.
- Vaudrey, K.D. (1977), *Ice engineering – study of related properties of floating ice sheets and summary of elastic and viscoelastic analyses*. Technical Report R860, Civil Engineering Lab., Port Hueneme, Calif., U.S.A.

This publication is being distributed by the Division of Building Research of the National Research Council of Canada. It should not be reproduced in whole or in part without permission of the original publisher. The Division would be glad to be of assistance in obtaining such permission.

Publications of the Division may be obtained by mailing the appropriate remittance (a Bank, Express, or Post Office Money Order, or a cheque, made payable to the Receiver General of Canada, credit NRC) to the National Research Council of Canada, Ottawa. KIA 0R6. Stamps are not acceptable.

A list of all publications of the Division is available and may be obtained from the Publications Section, Division of Building Research, National Research Council of Canada, Ottawa. KIA 0R6.