DNMI - RAPPORT

DET NORSKE METEOROLOGISKE INSTITUTT
POSTBOKS 320 BLINDERN 0314 OSLO 3
TELEFON : (02) 60 50 90

ISBN

RAPPORT NR.
KLIMA 30/86

DATO
18.06.86

TITTEL

EXTREME WIND AND WAVES AT THE INNER PART OF THE ROMSDALSFJORD
EXTREME WIND AT A HOLDING AREA NEAR BJØRNSUND LIGHT HOUSE

UTARBEIDET AV

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Norwegian Contractors

OPPDRAGSNR.

SAMMENDRAG This report is based on the author's graduate thesis. That work was carried out during 1976-1978, using data from 1975-1976. The wind conditions of the inner fjord region and their dependence of the coastal wind were discussed. Transfer coefficients from Ona to the inner fjord were established.

In this report, the extreme wind conditions at Ona are discussed, and extreme wind conditions at the inner part of the Romsdalfjord are estimated. The 100 years 1 min mean wind speed varies between 32 and 43 ms^{-1} along the fjord. Easterly wind is the strongest wind except at Isfjorden east of Åndalsnes, where westerly wind is the strongest. However, the wind speeds are lower there.

The 100 years significant wave height is estimated to 1.5m - 2.3m.

At a holding area just inside Bjørnsund light house, the extreme wind as defined above, is estimated to 39 ms^{-1} (SW-NW).

UNDERSKRIFT

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BJØRN AUNE
FAGSJEF

SUMMARY OF THE RESULTS

Extreme wind.

The table shows the extreme 1 min wind speeds (ms^{-1}) with return periods 2, 10, and 100 years at the area east of Åndalsnes (the Isfjorden area, A), the area within 1-2 km west of Åndalsnes (including Øra, B), and the area further out along the fjord (north of Innholmen, C). The extremes are given for different sectors. The extremes occur in the period september to april, and most likely at december - january.

sector	area	2 years	10 years	100 years
$30 - 80^{o}$	B	18	21	24
$30 - 110^{o}$	A	20	23	27
$90 - 140^{o}$	B	30	34	39
$30 - 140^{o}$	C	33	37	43
$120 - 220^{o}$	A	18	21	24
$150 - 220^{o}$	B	18	21	24
$150 - 220^{o}$	C	18	21	24
$230 - 290^{o}$	A	25	28	32
	B	25	28	32
	C	29	33	38
$300 - 20^{o}$	A	16	18	21
	B	16	18	21
	C	16	18	21

Extreme 1 min wind speeds (ms^{-1}) with return periods of 2, 10, and 100 years at the holding area near Bjørnsund light house:

Sector	2 years	10 years	100 years
$360 - 30^{o}$	20	25	30
$40 - 90^{o}$	15	20	25
$90 - 150^{o}$	20	23	27
$160 - 220^{o}$	20	25	30
$230 - 350^{o}$	30	34	39

Summer extremes.

The summer (may-august) extremes should be reduced to 2/3 of the extremes above.

Extreme wave heights.

Extreme wave heights with return periods of 2, 10, and 100 years at the three sites A, B, and C (Fig. 1) of the inner part of the Romsdalsfjord.

Area	Direction	2 years	10 years	100 years
A	W	0.9m	1.1m	1.5m
B	W	1.3m	1.6m	2.1m
C	W	1.4m	1.8m	2.2m
C	E	1.5m	1.9m	2.3m

Wave periods. There is not carried out any special analysis considering wave periods. However, common values during high wave heights (~ 2 m) are 5 - 6 s, while 3 - 4 s is a typical value for wave heights of ≤ 1 m.

I N N H O L D S F O R T E G N E L S E

1. INTRODUCTION

This report is an answer on a request from Norwegian Contractors concerning extreme wind and wave conditions at the inner part of the Romsdalsfjord and a holding area near Bjørnsund light house at the coast of Romsdal. The request is enclosed as Appendix 1.

2. SITE AND TOPOGRAPHY

2.1 Large scale and mesoscale topography.

The Romsdal area is situated on the western part of the Langfjella mountain chain. These mountains are quite complexe and have their largest horizontal and vertical extension south and southeast of the Romsdal area. However, the Romsdalen valley runs in a lower pass between Jotunheimen to southeast and Dovre/Rondane to northeast.

The Romsdalen valley runs to the Romsdalsfjord. On a mesoscale this fjord runs northwest - southeast.

2.2 Local topography.

The inner part of the Romsdalsfjord forms a 1 km deep and 2 km wide air channel. The mountain sides are rather steep. This part of the fjord is locally turned WSW - ENE (Fig. 1).

The holding area near Bjørnsund light house is open to the sector south through west to north (180^0 - 30^0). The island Gossen, situated at southwest, is rather flat and provides a rather poor shelter. However, the whole area is situated at some distance inside the outer coast-line.

3. WIND CONDITIONS

3.1 Previous investigations.

The wind conditions in the area have been studied by the author during episodes from autumn 1975 to autumn 1976. The main results from this study are presenteted in a report (1). The wole study can be found in a graduate thesis (2).

The work was concentrated on the general wind climate in the inner part of the fjord. Further on, the connection between the wind speed at the Romsdalsfjord and at the coast was studied. Some work concerning wind distribution between Øra, Åndalsnes, and the area north of Innholmen (Fig.1) was also done. However, extreme wind statistics were not applied. Some important statements may be drawn from (1) and (2):

A. Easterly winds prevail during winter and autumn in the inner part of the fjord. At Øra, Åndalsnes the local direction is ESE, while ENE prevails north of Innholmen. During strong easterly wind, the speed seems to be highest north of Innholmen. During moderate easterly winds, the wind "beam" may move north of this measuring site, and then be measured strongest at Øra.

B. Easterly winds are considerably stronger in the inner districts of the Romsdalfjord (Innholmen - Øra) than at the coastal area (Ona, Vigra), 20 to 50% higher wind speed in relation to Ona is usually measured. It seems that easterly to southerly wind crossing the passes through the Langfjella mountain chain northeast of Jotunheimen is forced down causing very high wind speeds (easterly) in the inner fjord area. The outer part of Romsdal seems to be located in a sheltered zone well protected by the Langfjella on a larger scale. For extreme wind conditions it may be reasonable to use the factor 1.4 when calculating the wind speed at Øra from the speed at Ona, being slightly conservative from the average value. The wind speed north of Innholmen seems to be some 10% higher than at Øra.

C. During summer the prevailing wind direction is westerly at the inner districts of the fjord. This is a sea breeze effect, the speed is then going up to 7 ms^{-1}. However, when the wind direction at the coast (all-year) is in the sector west to northwest, the wind speed of the inner fjord area usually blow up to 60% (Øra) of the speed at Ona sea light. However, there is some deviation from that average value. We therefore think it may be reasonable to use the factor 0.7 when estimating extreme wind at Øra, blowing along the fjord from westerly

direction, from the extremes valid at Ona. Again, the wind speed is highest north of Innholmen, some 20% higher than at Øra. The extreme cases are most likely to occur late autumn or early winter.

D. The very high and frequent wind speeds at the coast measured at southwesterly direction are partly induced by the large-scale topography. Probably, the wind speed at higher levels (>1000m) at the inner districts is also high in such situations. Such a high-level wind could probably be forced down some places, but this seems not to be the case at the Romsdalfjord. The topography seems not to be favourable for such conditions, and only occasionally some moderate to strong gusts may reach the fjord level.

E. The gust factor (max 3-5s speed to the 10 minute average) is found to be near 1.5 for wind blowing out from the inner fjord (easterly) as well as wind blowing into it (westerly). For southerly and northerly wind, the speed is considerably reduced, but the gust factor is estimated to 2.0.

3.2 Extreme wind conditions at the inner part of the Romsdalfjord.

For strong westerly wind at the inner part of the Romsdalsfjord to occur, the wind at the coast should be within the sector W to NW. Within those sectors, the 50 years extreme of the 10 min mean (10 min extreme) wind is found to 37 ms^{-1} at Utsira (3), 36 ms^{-1} at Hellisøy (4), 41 ms^{-1} at Nordøyan, and 36 ms^{-1} at Sklinna (5). It therefore seems reasonable to put the value 36 ms^{-1} to Ona. It should be remembered that the strongest wind there occurres in the sector SW to W.

The statements above give us an estimate for the 50 years 10 min westerly wind speed at the inner part of the Romsdalsfjord. This value is 0.7 . 36 ms^{-1} = 25 ms^{-1} . This estimate is valid at Øra, Åndalsnes. It seems reasonable to put this value to be representative for the fjord from 1 km west of Øra and eastwards to the end of the fjord. For the district north of Innholmen the estimate of some 20% higher wind speed give us 30 ms^{-1}.

For easterly and southeasterly winds, the coast south of the Stadt corner, and further along the coast of Trøndelag, is not representative for the coast of Møre and Romsdal which is sheltered towards those directions. However, we have an extreme wind analysis at the Vigra airport which tells us that the 50 years 10 min wind speed within easterly to southeasterly sector is 18 ms^{-1} (6). The area around Vigra should be representative for the area near Ona sea light, but the local wind speed shold be some higher at Ona due to the local conditions (surface wind less decelerated due to less

friction). If we put the value some 20% higher at Ona, the value 22 ms^{-1} should be accepted.

The discussions above now give us the value 1.4 . 22 ms^{-1} = 31 ms^{-1} as the 50 years 10 min value for easterly winds. This value is only representative for Øra and the area west of Åndalsnes and 1-2 km further out along the fjord. The speed north of Innholmen (10% higher) should then be 34 ms^{-1}. East of Åndalsnes, at the Isfjorden area, the wind speed is considerably lower, and should probably not exceed the value at Ona, 22 ms^{-1}.

For winds being perpendicular with the valley/fjord system the speed is reduced to some 40% of the coastal value (1). The 50 years 10 min value for southwesterly wind at Ona is probably 40 ms^{-1}. Hence, the cross-wind from south at the inner fjord should not exceed 16 ms^{-1}. Using 35 ms^{-1} as the extreme value at Ona in northerly to northeasterly sector, a value of 14 ms^{-1} should be valid for northerly cross winds at Øra. The values above should be valid within the whole part of the inner fjord.

Table 3.1

Estimated 50 years 10 min wind speed (ms^{-1}) at Ona, and the areas A (Isfjorden), B(Øra), and C(north of Innholmen) of the inner part of the Romsdalsfjord.

area	sector	wind speed	area	sector	wind speed	area	sector	wind speed	area	sector	wind speed
Ona	N-NE $340-60^0$	35	A	N $300-20^0$	14	B	N $300-20^0$	14	C	N $300-20^0$	14
	E-SE $70-160^0$	22		E $30-110^0$	22		NE $30-80^0$	16		E $30-110^0$	34
	S 170-200	30		S 120-220	16		E $90-140^0$	31		S 120-220	16
	SW-W 210-260	40		W 230-290	25		S 150-220	16		W 230-290	34
	W-NW 270-330	36					W 230-290	25			

3.3 Extension to 2, 10, and 100 years 1 min wind speed.

For extending to other return periods, we use the equation

$$v_{10}(n) = v_{10}(50y) \cdot (0.76 + 0.14 \log_{10} n) \quad (3.1),$$

taken from (7). Here n is the return period. The equation is valid for 3-5 s wind gusts. However, it is used here for 10 min mean wind speed, but it is believed that only minor errors come up by such an approximation. This give us $v_{10}(2y) = 0.80 \cdot v_{10}(50y)$; $v_{10}(10y) = 0.90 \cdot v_{10}(50y)$; and $v_{10}(100y) = 1.04 \cdot v_{10}(50y)$.

When discussing 1 min values, we use the formula

$$GF(1\ min) = 1 + 0.44(GF(4s) - 1) \quad (3.2),$$

to find the gust factor, $GF(\tau)$ for the gust period, τ; taken from (8). All gust factors refers to a 10 min mean time. We then obtain the 1 min wind speed by

$$v(1\ min) = v(10\ min) \cdot GF(1\ min) \quad (3.3).$$

When using the 3-5 s gust factor 1.5, we obtain

$$v(1\ min) = 1.22 \cdot v(10\ min) \quad (3.4),$$

and

$$v(1\ min) = 1.44 \cdot v(10\ min) \quad (3.5)$$

is valid for the 3-5s gust factor 2.0.

We are now able to put up a table giving the different wind speeds asked for.

Table 3.2

Extreme 1 min wind speeds (ms^{-1}) with return periods 2, 10, and 100 years at the area east of Åndalsnes (the Isfjorden area, A), the area within 1-2 km west of Åndalsnes (including Øra, B), and the area further out along the fjord (north of Innholmen, C). The extremes are given for different sectors. The extremes occur in the period september to april, and most likely at december - january.

sector	area	2 years	10 years	100 years
$30 - 80^{o}$	B	18	21	24
$30 - 110^{o}$	A	20	23	27
$90 - 140^{o}$	B	30	34	39
$30 - 140^{o}$	C	33	37	43
$120 - 220^{o}$	A	18	21	24
$150 - 220^{o}$	B	18	21	24
$150 - 220^{o}$	C	18	21	24
	A	25	28	32
$230 - 290^{o}$	B	25	28	32
	C	29	33	38
	A	16	18	21
$300 - 20^{o}$	B	16	18	21
	C	16	18	21

Summer extremes

During the summer season, here defined as may - august, any return period for a given wind speed should be much longer. When comparing with the conditions at Utsira, where extreme wind analysis is carried out also through the summer season (3), it is likely to reduce the 2, 10, and 50 years wind speed to 2/3 of its yearly value.

3.4 Exstreme wind conditions at the holding area just inside the Bjørnsund light house.

For this area westerly to northwesterly winds should be of the same strength as the winds at free sea level near Vigra airport (6), while during southwesterly winds the speed should be closer to the speed at the airport itself. This give us a 50 years 10 min wind speed of 32 ms^{-1}. When using a 3-5s gust factor of 1.4 in that area, eq. (3.1), (3.2), and (3.3) produce a 100 years 1 min wind speed of 39 ms^{-1}.

Easterly and southeasterly winds probably have the same strength as Ona, the 50 years 10 min wind speed being 22 ms^{-1}, and the 100 years 1 min wind speed according to the discussion above being 27 ms^{-1}.

Southerly winds should also be reduced in relation to Ona. However, the regional wind speed is lower at the outer coast within this sector. Probably a value of 30 ms^{-1} could be used as an estimate of the 100 years 1 min wind speed.

The holding area should be well protected against northeasterly winds and less against northerly winds. This makes 25 ms^{-1} to be a reasonable estimat for the 100 years 1 min wind speed within northeasterly sector, and 30 ms^{-1} within northerly sector.

Table 3.3
Extreme 1 min wind speeds (ms^{-1}) with return periods of 2, 10, and 100 years at the holding area near Bjørnsund light house.

Sector	2 years	10 years	100 years
360 – 30°	20	25	30
40 – 90°	15	20	25
90 – 150°	20	23	27
160 – 220°	20	25	30
230 – 350°	30	34	39

The summer values should again be reduced to 2/3 of the above values.

4. EXTREME WAVE CONDITIONS IN THE INNER PART OF THE ROMSDALSFJORD.

4.1 General remarks.

When a wind blows up at a sea surface, waves are generated. These waves will grow in time, and hence grow in the direction of the travelling air parcel. Further on, the waves at a certain point will grow as the working time of the wind increases. After some time there will be established a balance situation. The energy transferred to the waves by a wind friction effect at the surface, is then used in internal friction processes/ dispersing of the waves.

The wave model used at the Norwegian Meteorological Office models this physics, using the deep sea approximation and a fjord boundary condition, that is, the geometry of the sea/ land. The model of course is a simplification of the real conditions, for instance, only one wind direction, and one speed, is used for the whole area in each calculation. However, several such input values may be used.

4.2 Wind input data.

Calculating waves at the inner part of the Romsdalfjord, it seems that a balance situation is reached at 3 hours. Further on, at site A and B (Fig.1), only westerly (250^0) along wind is strong enough and have a long enough fetch, to produce the high waves.

We first have to calculate the extremes of the 3 hourly mean wind speed at the sites,from the 50 years 10 min mean wind speed (Table 3.1). Fikke, S (9) use the reduction factor 0.8 for transferring max 10 min mean wind speed to 6 hour means. A study of a single coastal storm gave us the value 0.88 to obtain a corresponding 3 hour value. More work is needed to get reliable values for such factors. Probably, the factors is variable, and different factors may be valid at different places. However, the discussion above indicate a factor of 0.9 to be used. Reminding all other sorces of error in the calculation, it should perhaps be a satisfactory estimate.

At site A, the wave generating wind (westerly) may be taken as the mean of the wind speed at site A and B. The 50 years 3 hourly wind speed then is : $25.0.9 = 23\ ms^{-1}$.

At site B, the corresponding wind speed is the mean at site B and C, the 50 years 3 hourly wind speed being $(25 + 30)/2 \ . \ 0.9 = 25\ ms^{-1}$.

At point C, there may be strong wave generating wind from the east, the mean at site B and C being $(34+31)/2 \ . \ 0.9 = 29\ ms^{-1}$. From west, the wind speed at site B is assumed to be of the same strength as the wind further out in the fjord. The wave generating

50 years 3 hourly wind speed is hence estimated to 30 ms^{-1} . 0.9 = 27 ms^{-1} .

To find 3 hourly wind speeds with return periods of 2, 10 and 100 years, the above wind speeds should be multiplicated with by the factors 0.8, 0.9 and 1.04. By doing that, table 4.1 is calculated.

Table 4.1
Wave generating 3 hourly extreme wind speeds, ms^{-1}, with return periods 2,10 and 100 years.

area	sector	2 years	10 years	100 years
A	W	18	20	23
B	W	21	23	27
C	W	22	24	28
	E	23	26	30

4.3 Extreme wave conditions.

The wave model (FJORD-SEA,10) was used in calculating wave heights for easterly and westerly along wind, using 30, 40, 50,and 60 kts as input speeds. The results was plotted as grid points, and are shown in Fig.2 for 50, and 60 kts easterly and westerly wind.

The results above for westerly and easterly wind are shown in Table 4.2. From this table the wave heights generated by the wind speeds taken from Table 4.1 give us 2, 10, and 100 years wave heights by interpolating Table 4.2. These results are given in Table 4.3.

Table 4.2

Wave heights generated by a 3 hourly mean wind speed of 30, 40, 50, and 60 kts. Only directions where high wave heights occur are given.

Area	Wind direction	Wind speeds			
		30 kts ($15.4\ ms^{-1}$)	40 kts ($20.6ms^{-1}$)	50kts ($25.7ms^{-1}$)	60 kts ($30.8ms^{-1}$)
A	247.5^0 (W)	0.7m	1.2m	1.8m	
B	247.5^0 (W)	0.8m	1.3m	2.0m	
C	270^0 (W)	0.8m	1.3m	2.0m	2.5m
C	67.5^0 (E)	0.8m	1.3m	1.9m	2.4m

Table 4.3

Extreme wave heights with return periods of 2, 10, and 100 years at the three sites A, B, and C (Fig. 1) of the inner part of the Romsdalsfjord.

Area	Direction	2 years	10 years	100 years
A	W	0.9m	1.1m	1.5m
B	W	1.3m	1.6m	2.1m
C	W	1.4m	1.8m	2.2m
C	E	1.5m	1.9m	2.3m

4.4 Wave periods.

There is not carried out any special analysis considering wave periods. However, common values during high wave heights ($\sim$ 2 m) are 5 - 6 s, while 3 - 4 s is a typical value for wave heights of $\leq$ 1 m (9).

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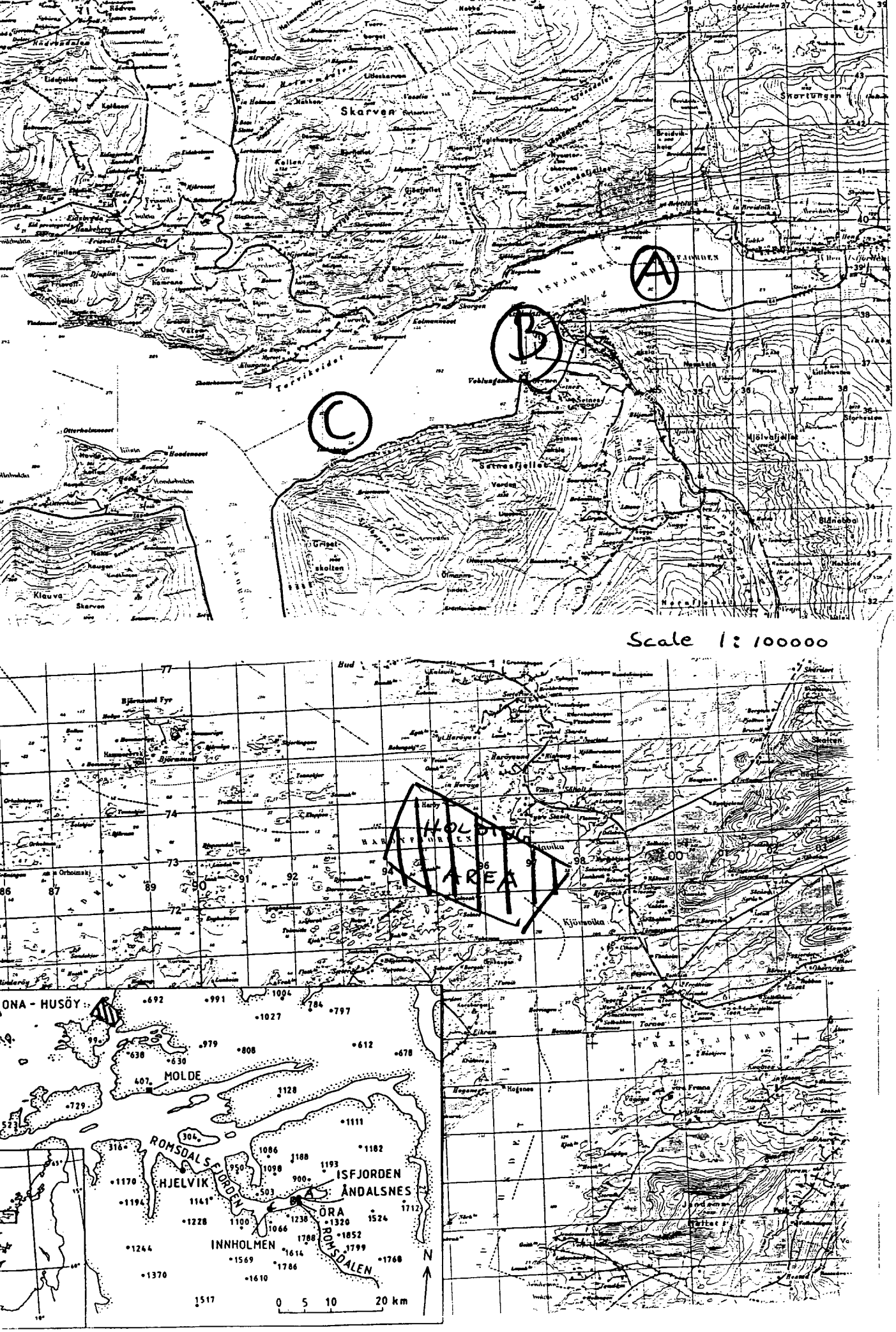


Fig.1 Map of the Romsdal area.

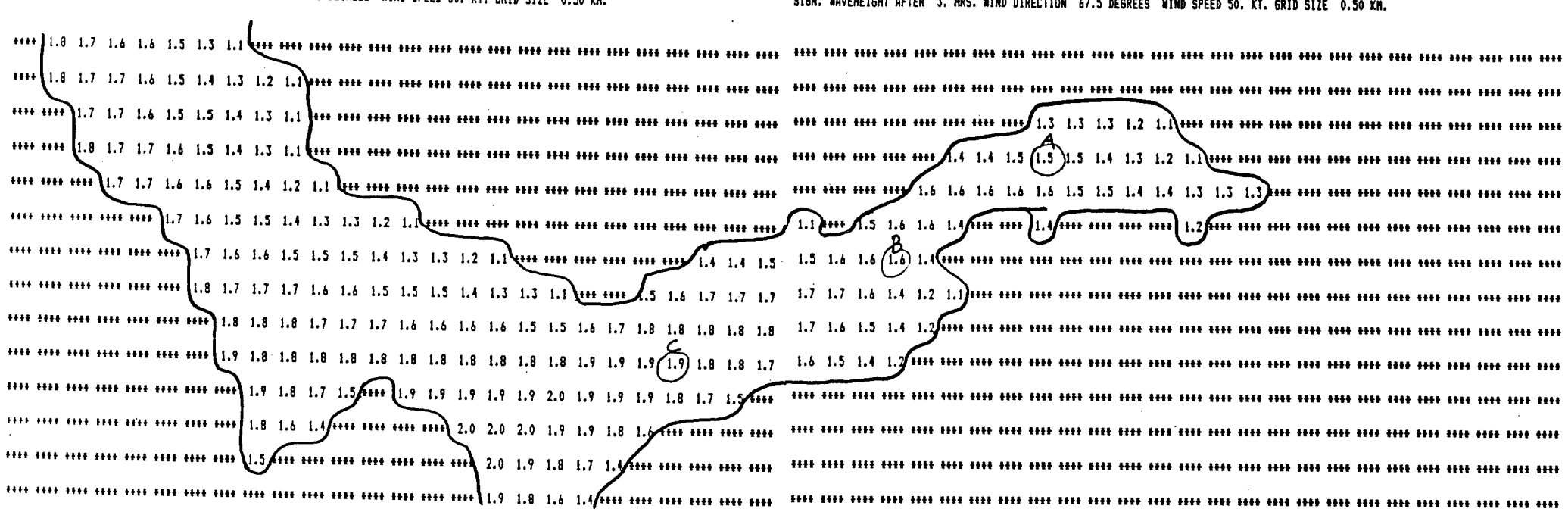


Fig.2a Significant wave heights at the inner part of the Romsdalsfjord calculated at DNMI. Wind speed: 50 kts Wind direc.: 67.5^0

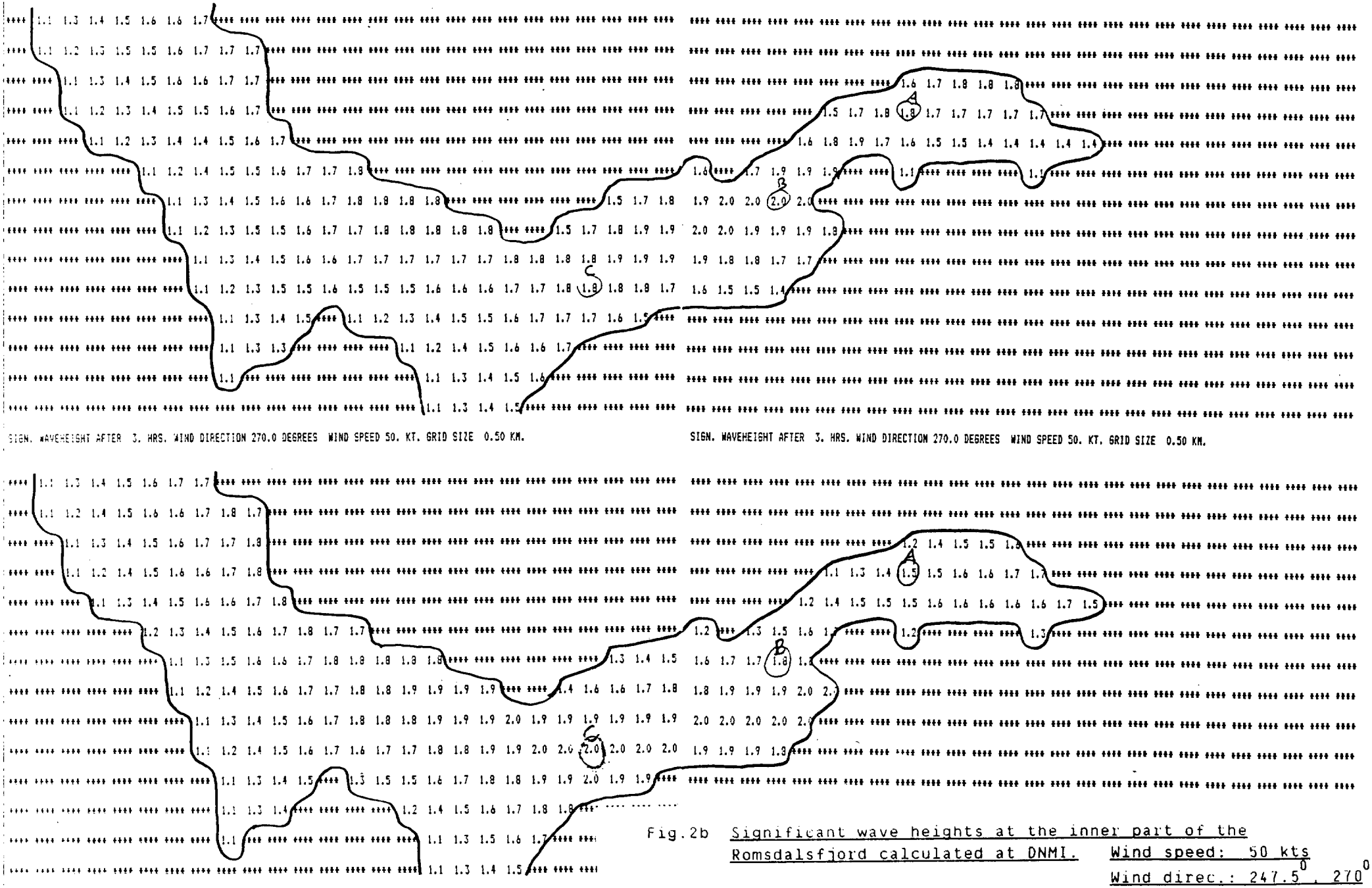
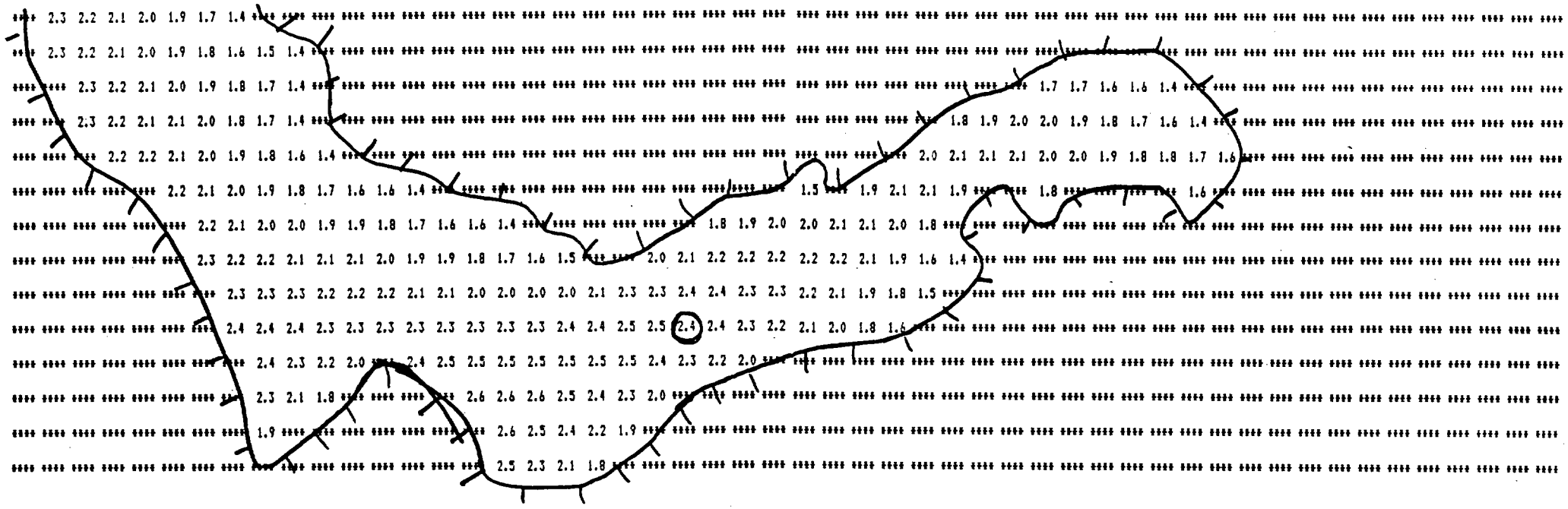
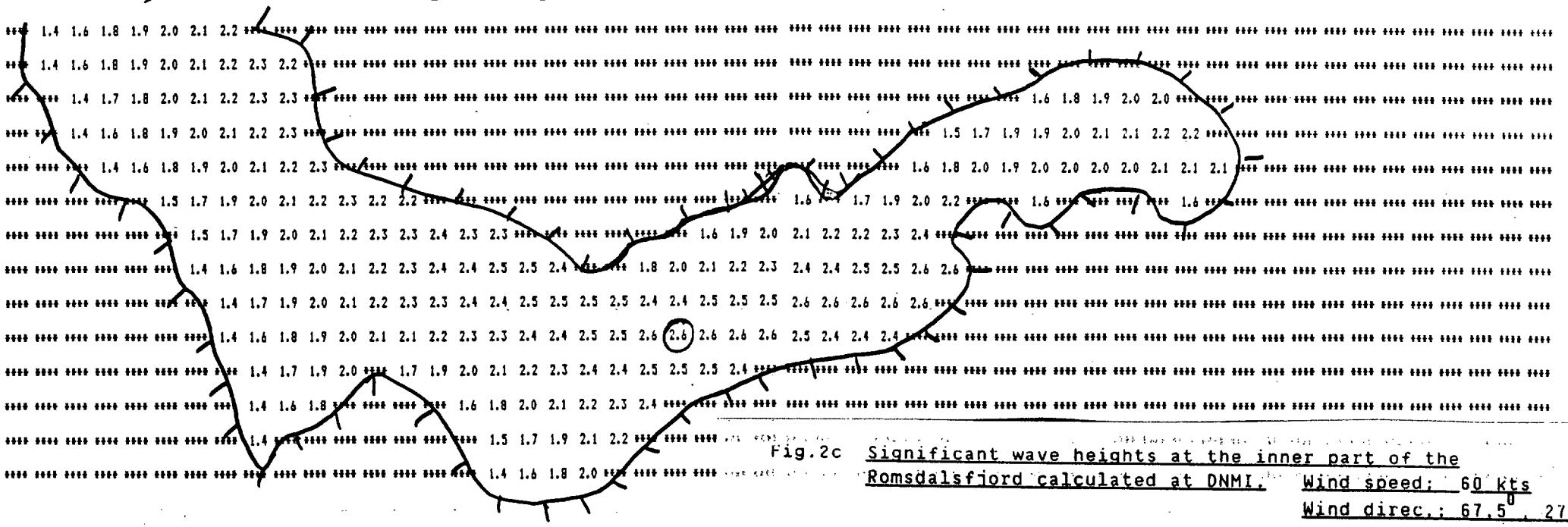


Fig.2b Significant wave heights at the inner part of the Romsdalsfjord calculated at DNMI. Wind speed: 50 kts
Wind direc.: 247.5^0, 270^0



SIGN. WAVEHEIGHT AFTER 3. HRS. WIND DIRECTION 270. DEGREES WIND SPEED 60. KT. GRID SIZE 0.50 KM.



SIGN. WAVEHEIGHT AFTER 3. HRS. WIND DIRECTION 270. DEGREES WIND SPEED 60. KT. GRID SIZE 0.50 KM.

Fig.2c Significant wave heights at the inner part of the Romsdalsfjord calculated at DNMI. Wind speed: 60 kts
Wind direc.: 67.5^0, 270^0

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Our ref.: ES/ibj Your ref.: 1320 Stabekk, 16. april 1986

Med referanse til tidligere utførte tekniske rapporter angående værkriterier, tillater vi å forespørre om oppdaterte værkriterier for Andalsnes-området (se vedlegg).

Mer spesifisert ønsker vi følgende:

- 10 m, 1 min. middel referanse vind med følgende returperiode: 2 år, 10 år og 100 år for de to vedlagte skraverte områder i Fig. 1. Sommer-storm og helårs-storm ønskes vurdert.

- Bølgedata langsetter Isfjorden ønskes på de tre avmerkede områdene i Fig. 2. Bølgedata (H_s og T_p) ønskes for returperiode 2 år, 10 år og 100 år.

- En generell vurdering av tidevanns-strømforholdene i Romsdals-fjorden ønskes.

Er informasjonen utilstrekkelig vennligst ta kontakt med undertegnede.

Med,vennlig hilsen
for NORWEGIAN CONTRACTORS

Espen Sandsdalen
Espen Sandsdalen

Vedlegg.