

STYRELSEN FÖR
VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 43

Pentti Kujala and Jukka Vuorio

RESULTS AND STATISTICAL ANALYSIS OF ICE LOAD MEASUREMENTS
ON BOARD ICEBREAKER SISU IN WINTERS 1979 TO 1985

Sjöfartsstyrelsen
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FOREWORD

The Winter Navigation Research Board present their Report No 43. The report gives the results of ice load measurements, carried out on the icebreaker SISU during the period 1979 to 1985, together with an analysis of the measured data. It gives a valuable contribution to our knowledge about the nature of ice load on a ship's hull.

We thank the authors and their colleagues, the crew of the icebreaker SISU and all others who have assisted in carrying out this research projekt.

Helsinki and Norrköping, June 1986

Jan-Erik Jansson

Kaj Janerus

**RESULTS AND STATISTICAL ANALYSIS OF ICE LOAD MEASUREMENTS
ON BOARD ICEBREAKER SISU IN WINTERS 1979 TO 1985**

Pentti Kujala and Jukka Vuorio

**TECHNICAL RESEARCH CENTRE OF FINLAND
Ship Laboratory**

Espoo, April 1986

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1 INTRODUCTION

The Ship Laboratory of the Technical Research Centre of Finland started the full scale measurements of ice induced loads and responses on the bow shell structures of I.B. Sisu in winter 1978. The results of the winter 1978 measurements are reported in reference /7/. In addition the short-term results from winter 1982 are published in the reference /4/. In this report the results from winters 1979 to 1985 are summarized and statistical analysis of the measured data are presented.

The long-term measurements on board I.B. Sisu have been conducted to clarify the stochastic nature of the ice induced loads and to evaluate sound basis for the statistical analysis of these loads. The results of the full scale measurements have also been most valuable for the verification of the results of the theoretical work conducted /5/. In addition the full scale results have been used in the development of the new ice rules for the Baltic /9/.

Firstly in this report the measuring system is briefly described. Then the conducted measurements are summarized together with the ice conditions experienced by the ship. The analysis of the measurements consist of two parts; analysis of long term measurements from 1979 to 1985 and analysis of two short term trials of winter 1985. This division is carried out because of the differences in the conducted statistical analysis of the measured long-term or short-term data.

2 MEASURING SYSTEM

2.1 General description

The present measuring system consists of 31 strain gauges and 4 ice pressure gauges attached in two locations of the bow shell structures of I.B. Sisu, see Fig. 1 and Fig. 2. The location of the transducers is based on the mean draught of the ship which is typically about 7.6 m at the frame 94 /7/. The draught is usually varying between 7.3 to 7.9 m. The frame and waterline angles are at the frame 94; $\beta = 37^{\circ}$, $\alpha = 10^{\circ}$ and at the frame 114; $\beta = 49^{\circ}$, $\alpha = 23^{\circ}$. When the measurements started in winter 1978 the installation included the transducers between frames 92 and 94 /7/. For winter 1982 most of the transducers between frames 110 and 119 were added to the measuring system /4/. Only the strain gauges on the lower stringer between frames 116 and 119 were installed in autumn 1983 and the two extra shear strain gauges on the frame 111 1/2 were mounted in autumn 1984. The objects of the installations are described in more detail in the chapter 2.2. In addition the ship's speed (V) is registered.

In the long term measurements the data are collected and processed automatically by a microprocessor specially developed for this purpose /6/. The microprocessor forms signals level and peak value distributions for each of the measured channel. It takes 100 samples/second/channel and divides each sample in one of 31 classes according to its amplitude. The distributions are printed on a data cassette and paper tape once a day.

Short term measurements are conducted in order to relate the measured values to the prevailing environmental conditions. During short-term trials the actual time histories are recorded with e.g. a tape recorder or a fast plotter for further analysis.

Length, max	104.6 m
Length, dwl	96.0 m
Breadth, max	23.8 m
Breadth, dwl	22.5 m
Draught, max	8.3 m
Draught, dwl	7.3 m
Height to main deck	12.1 m

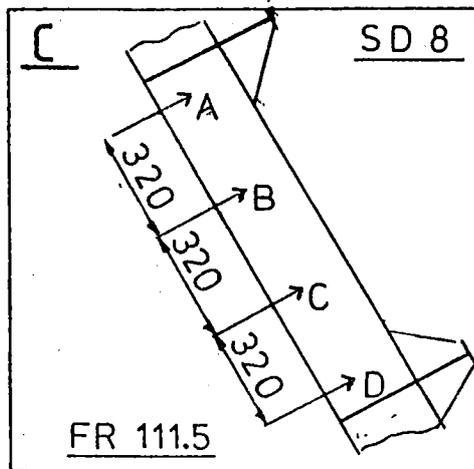
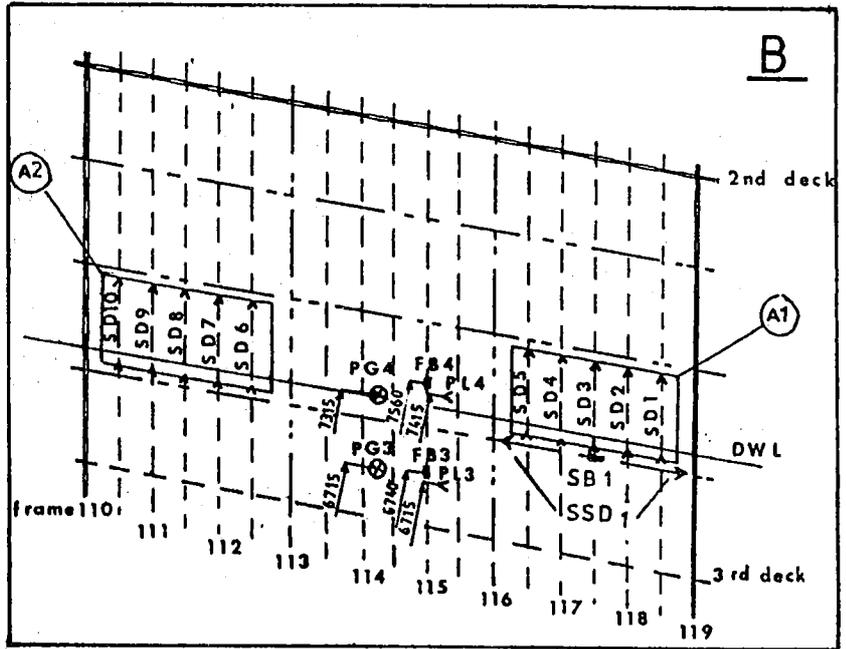
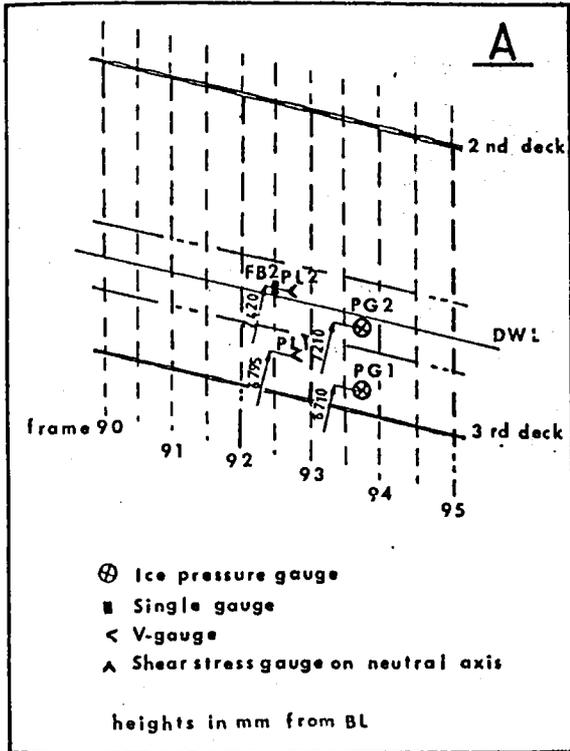
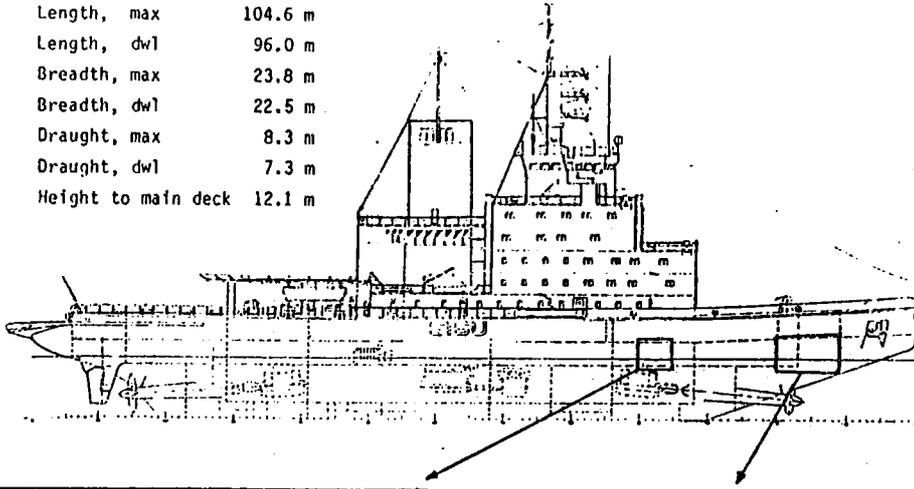


Fig. 1. Location of the transducers.

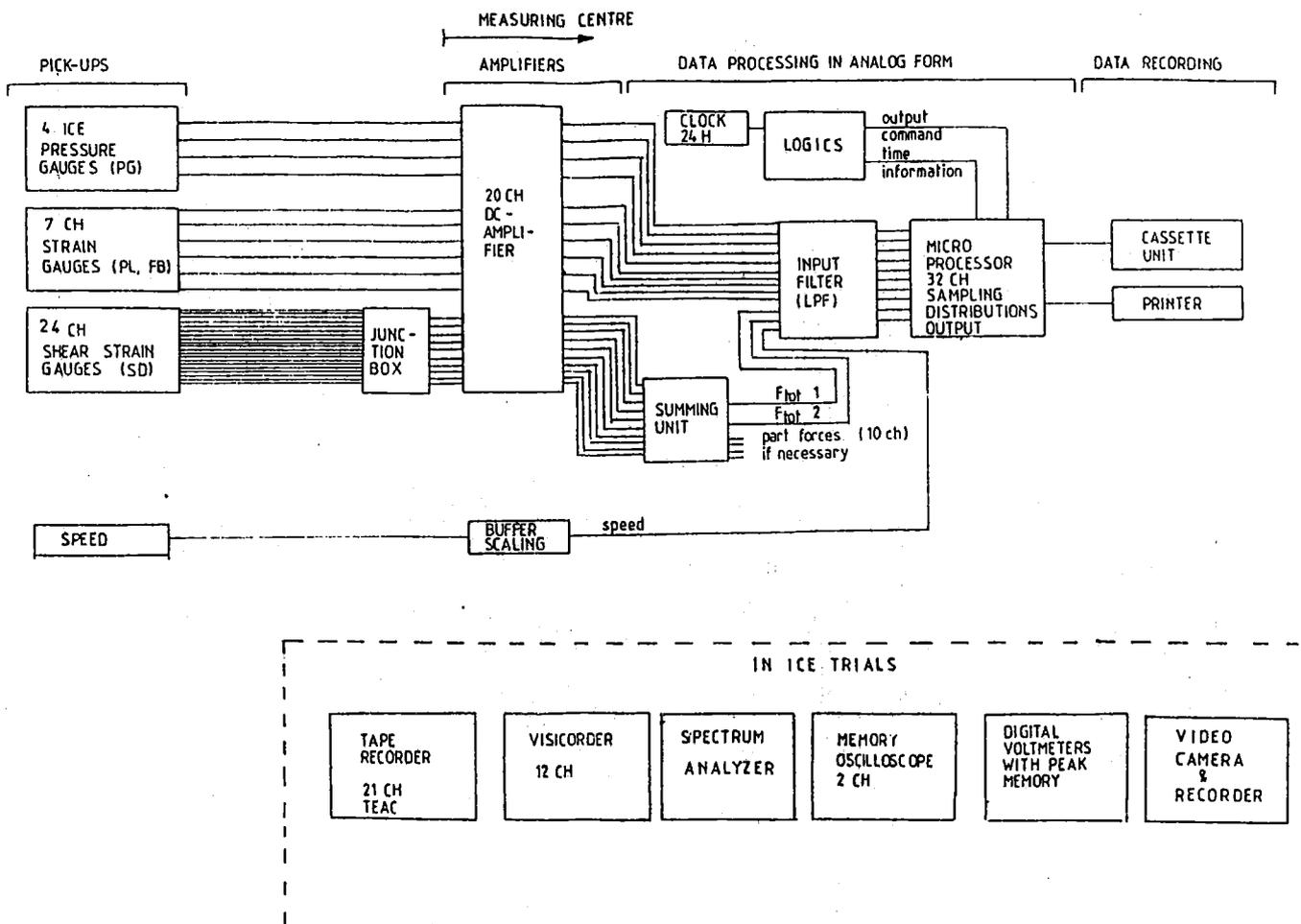


Fig. 2. Layout of the data collecting system.

2.2 Principles of local pressure and total load measurements

Local pressures are obtained with special ice pressure gauges /7/ which sense the ice pressure on a circular area with a diameter of 200 mm. Four gauges are installed to get ice pressures on various locations of the bow shell plating so that the effect of the hull form on the ice induced pressures can be studied. A detailed description of the construction and calibration of the pressure gauges is given in Ref. /7/. The abbreviation PG is used later in this report to refer to the ice pressure gauges. Fig. 3 illustrates the installed ice pressure gauges between frames 114 and 115.

In addition to the stresses on plating (PL) and on the flange of frames (FB) and stringer (SB), the shear differences on the webs of 10 frames (SD) and of one stringer (SSD) are measured as shown in Fig. 1. The shear differences form the basis for the ice load measurements on various contact areas. The loads are obtained from the measured shear differences between upper and lower ends of the frames (SD1... SD10 in Fig. 1) applying influence technique as is described in the following.

Firstly with the finite element model shown in Fig. 4 the relationship between a force, F_j , on a frame j and the shear difference $\Delta\gamma_i$, on a frame i is calculated and as a result the influence coefficient matrix, b_{ij} , is obtained. Calculating this relationship for each frame the result can be given in the following vector form:

$$\Delta\gamma_i = \sum_{j=1}^n b_{ij} \cdot F_j \quad (1)$$

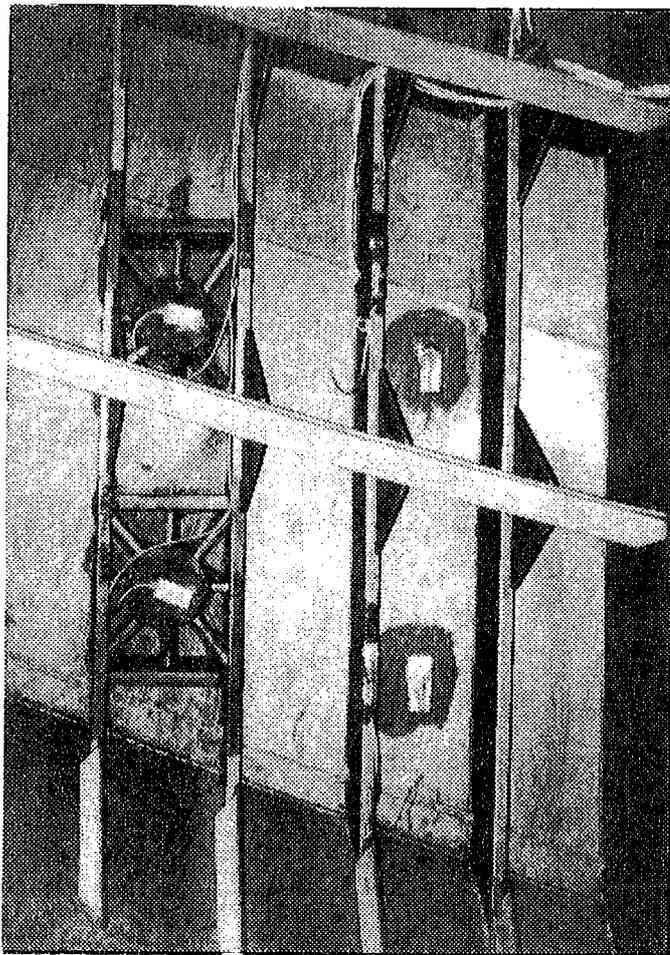


Fig. 3.

The installed strain and ice pressure gauges between frames 114 and 115.

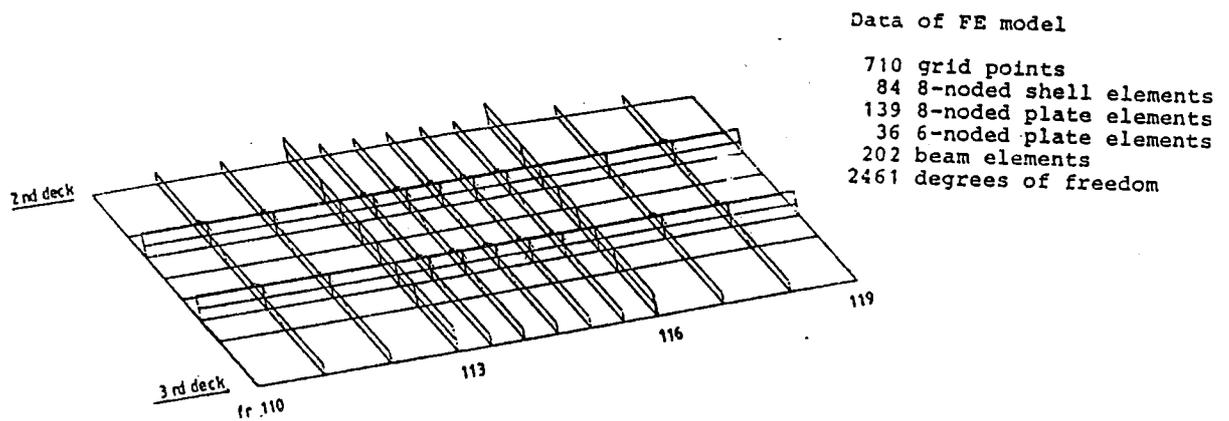


Fig. 4. The finite element model of Sisu shell structures.

After the matrix b_{ij} is formed the load on various frames can be obtained from the measured shear differences by inverting the $[b]$ matrix:

$$\{F\} = [b]^{-1} \{\Delta\gamma\} \quad (2)$$

In the measuring system the multiplication of formula (2) is realized in analog form by a summing unit where the values of influence coefficients determine the values of amplification of each channel. Once the load of separate frames is determined the loads with varying apparent load lengths can be obtained by summing the loads on various frames. As shown in Fig. 1 two load areas (A1 and A2) are installed on the bow shell structures of I.B. Sisu. Later in this report abbreviation FFR is used for the measured load on a frame and FT for the total load on the area of 5 frames (A1 or A2).

The approach to evaluate loads as described above is not possible with the same accuracy for the measured shear differences on the stringer and for the shear differences between the two extra gauges installed on the frame 111 1/2 (gauge B and C in Fig. 1c) because in these cases the shear differences are measured from one structural element only. The load on those areas can, however, be approximated by constructing a 2-dimensional finite element model of these structural elements and describing the relationship between the load and shear difference with one coefficient. Fig. 5 shows the used finite element model of the stringer and Fig. 6 the model of the frame 111 1/2. In this approach the effect of load distribution to other structural elements is not included and some 20 - 30 % lower values are obtained for the load than obtained with the influence technique.

The purpose of the extra gauges on the frame 111 1/2 is to study the location and height of the ice induced loads. Therefore only relative figures of the ice loads on various locations of the frame are

required. These values are not comparable to the load on that frame obtained with formula (2) (FFR8). Abbreviation FFR8 AB, FFR8 BC, FFR8 CB and FFR8 AD are therefore used later in this report for these loads in various parts of the frame 111 1/2. For example abbreviation FFR8 AB describes the load between points A and B (see Fig. 1c). Abbreviation FST is used for the load on the stringer.

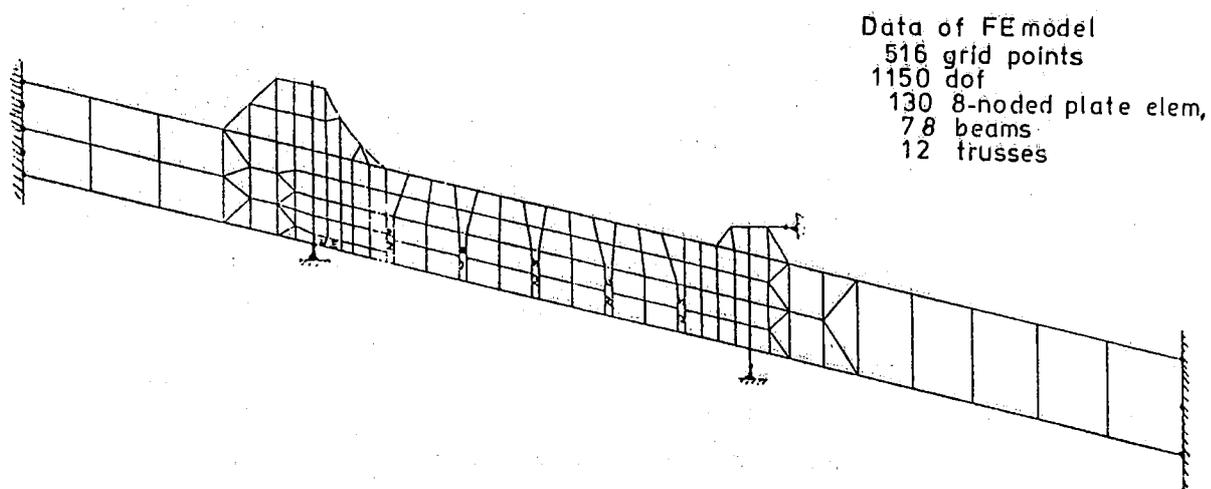


Fig. 5. The finite element model of the lower stringer between frames 116 and 119 to evaluate the relation between shear difference and load on the stringer.

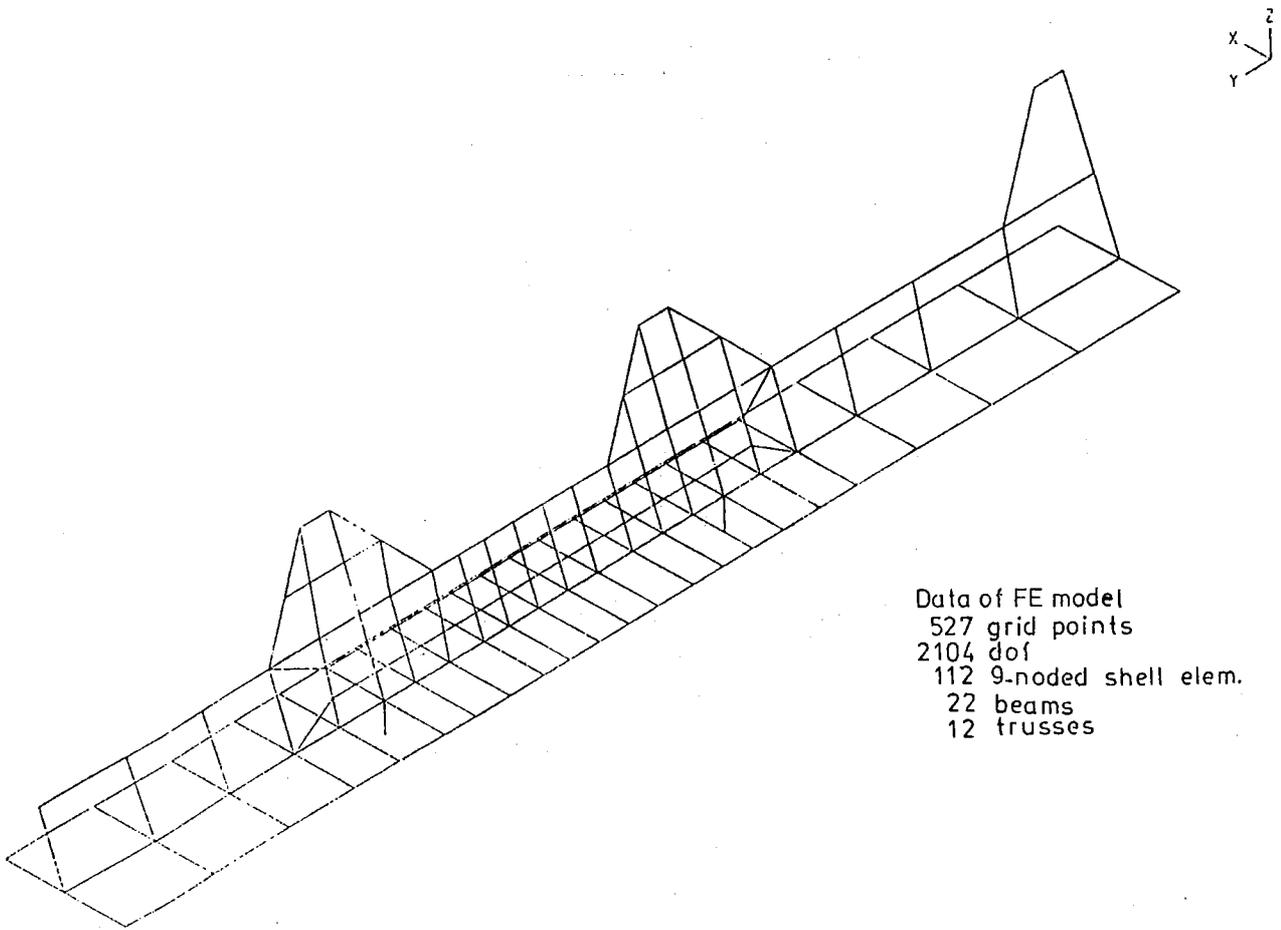


Fig. 6. The finite element model of the frame 111 1/2 to evaluate the relation between shear difference and load on the frame.

3 SUMMARY OF THE CONDUCTED MEASUREMENTS

3.1 Long-term measurements

3.1.1 Ice conditions

Usually the ice breaking season of I.B. Sisu begins at the end of January and finishes at the end of May. During this period the ice conditions vary in a great extent in the Bothnian Bay, where I.B. Sisu usually operates. Figs. 7 ... 10 illustrate the changes in the average ice thickness during the winters 1964 - 1979 /8/. Naturally the thickness of a level ice is only one of the parameters for describing the average ice conditions. The others are e.g. the amount of ridged or rafted ice, which dominates the ice conditions outside the shore region. The probability for the occurrence of ridged ice is about 60 % at the middle of the Bothnian Bay at the beginning of March as Fig. 11 illustrates. Also large open leads can appear on the sea aiding the navigation through ice. On an average the first ice appears in the Bothnian Bay at the end of November and the ice disappears at the end of May, see Fig. 12. As shown in Fig. 12 the ice coverage on the Bothnian Bay is almost 100 % from the beginning of February to the end of April.

Great variations can also exist between various winters. The measurements described in this report cover the winters 1979 - 1985. Appendix 1 gives the ice conditions at the end of February or at the beginning of March for each of these winters in order to illustrate the average nature and the greatest ice extent of the winters under consideration. Table 1 summarizes also some typical features of the measured winters.

3.1.2 Conducted measurements

Usually the long-term measurements have started in February and finished at the end of April. Table 1 shows the measuring period in each winter together with the successful measuring time in days.

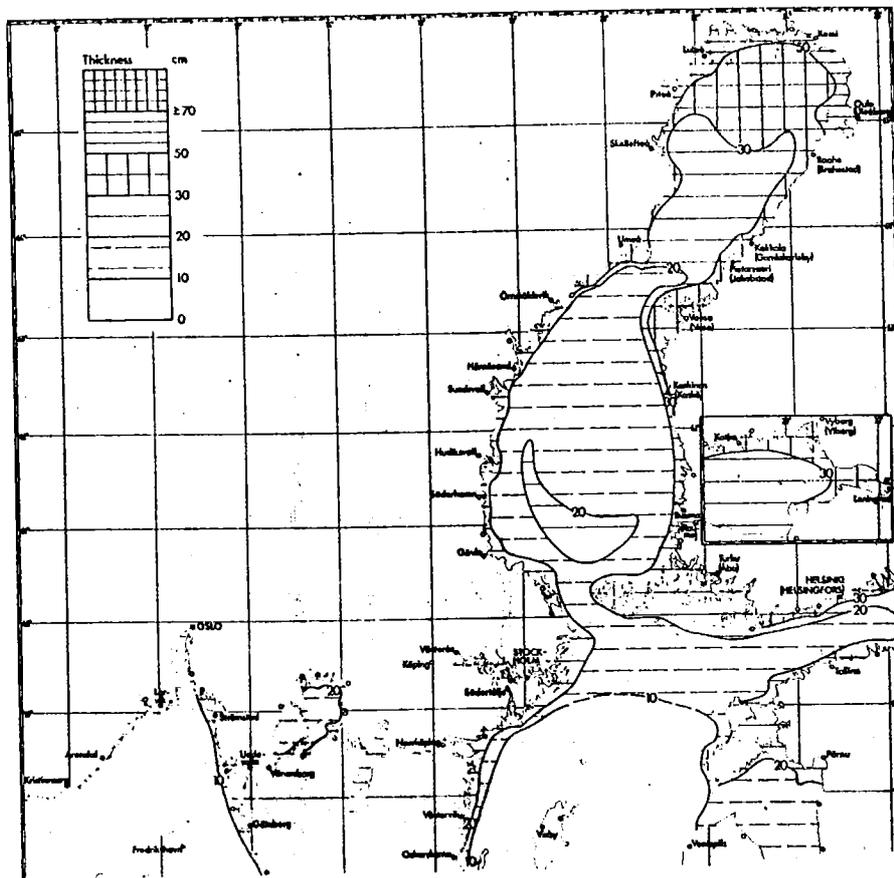


Fig. 7. The average ice thickness on the Baltic during winters 1964 - 1979 on 1st of February /8/.

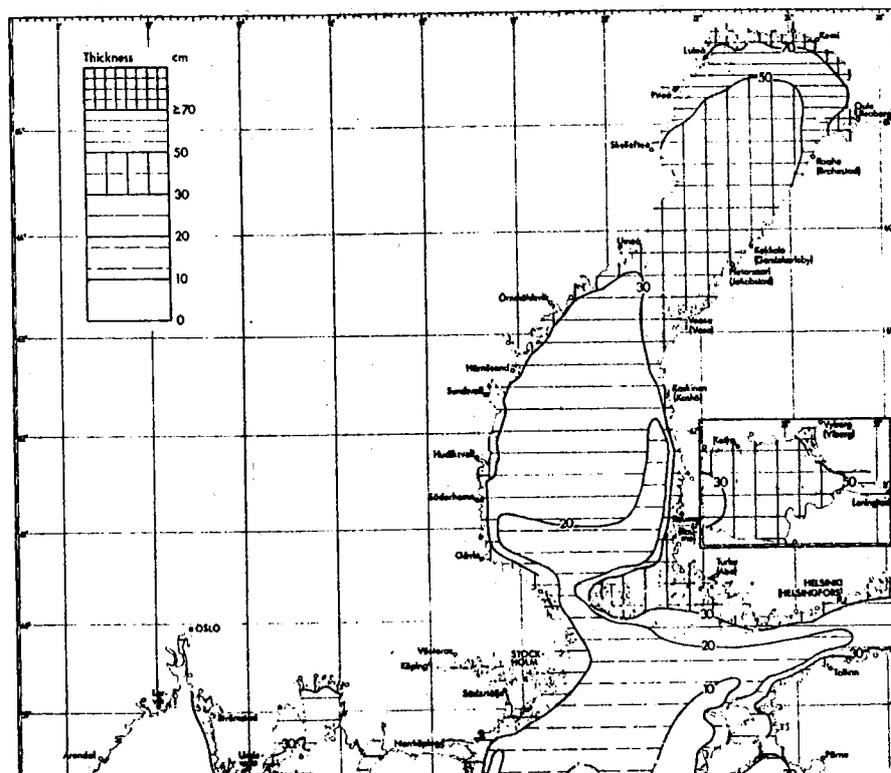


Fig. 8. The average ice thickness on the Baltic during winters 1964 - 1979 on 1st of March /8/.

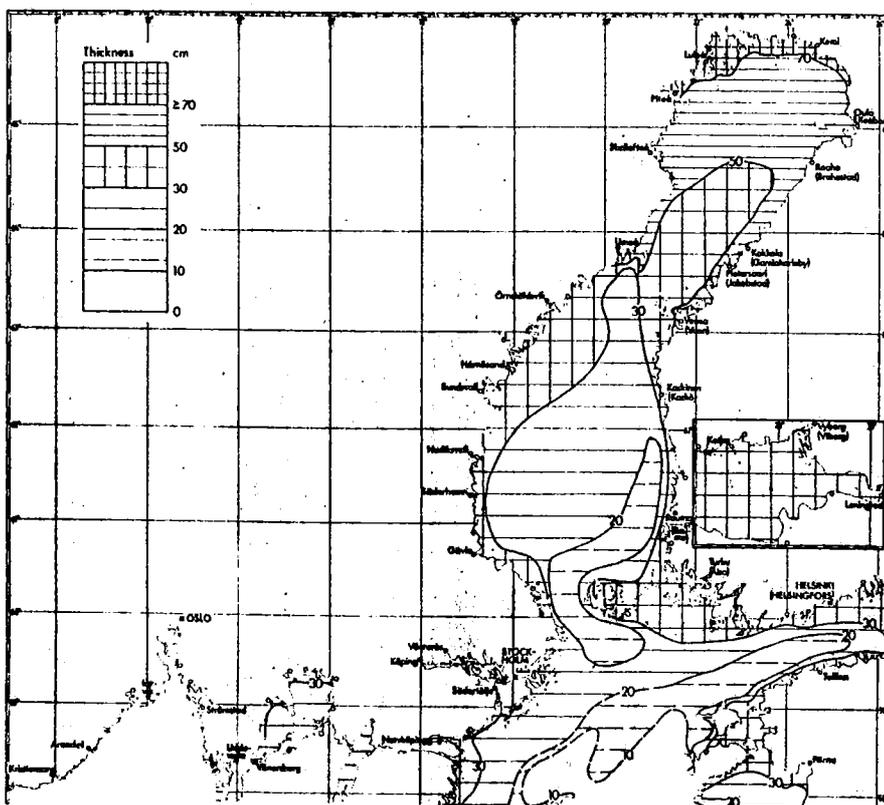


Fig. 9. The average ice thickness on the Baltic during winters 1964 - 1979 on 1st of April /8/.

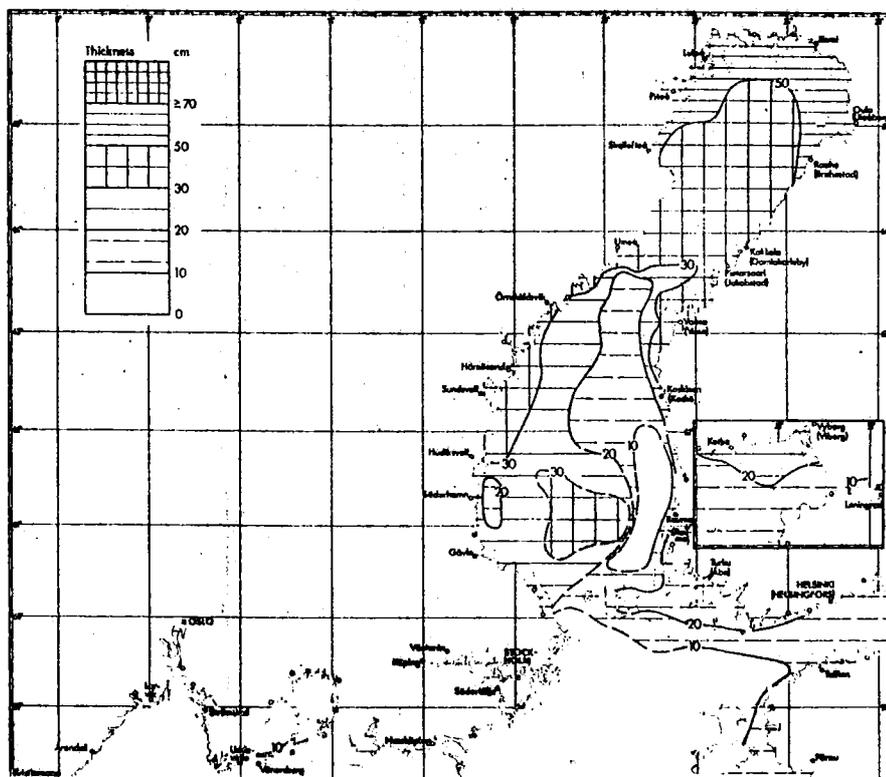


Fig. 10. The average ice thickness on the Baltic during winters 1964 - 1979 on 1st of May /8/.

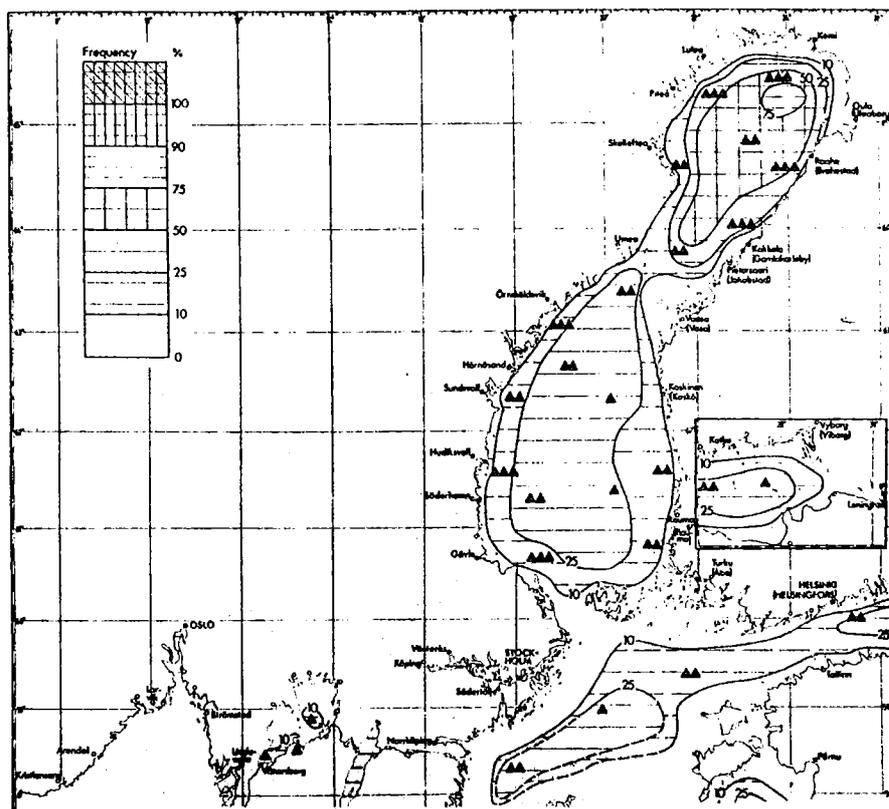


Fig. 11. The frequency of the occurrence of ridges on the Baltic during winters 1964 - 1979 on 1st of March /8/.

The time evolution of the ice cover in central areas of different basins
 Istäckets tidsutveckling för centrala delar av olika delbassänger
 Jääpeitteen ajallinen kehitys eräiden altain keskiosissa

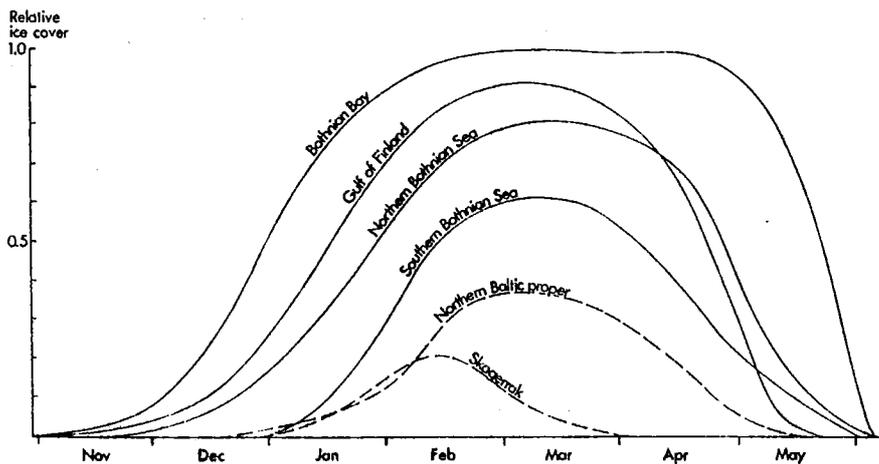


Fig. 12. The relative ice cover in the various areas of the Baltic during an average winter /8/.

3.2 Short-term measurements in winter 1985

In long-term measurements the effect of various ice condition is difficult to distinguish as e.g. during one day I.B. Sisu encounters a number of different type of ice conditions. In order to study the ice load in spesified environmental conditions short-term trials are required.

In winter 1985 two short-term trials were conducted. The first in 21 - 22th January and the second in 2-3rd of April. Figs. 13 ... 14 illustrate the ice conditions on the operation area of I.B. Sisu during those periods.

In the first period the level ice thickness varied between 10 - 30 cm and air temperature between -20 to -25 °C. The total measuring time was about 106 minutes. The draught at the fore ship was 7.95 m.

In the second period the level ice thickness varied between 40 to 20 cm and air temperature between +2 to -2 °C. The total measuring time was about 216 minutes. The draught at the fore ship was 7.5 m.

In the short-term measurements the following channels were recorded with 21-channel tape recorder for further analysis:

FFR6, FFR7, FFR8, FFR9, FFR10, FT1, FT2, FFR7+8, FFR7+8+9, FFR6+7+8+9, FFR8 AB, FFR8 BC, FFR8 CD, FFR8 AD, PG4, PL4, FB4 and speed.

The channels for the short-term recording were chosen so that the characteristics of the contact between ship and ice can be studied. Therefore all the chosen channels are located about the same draught and near each other in longitudinal direction.

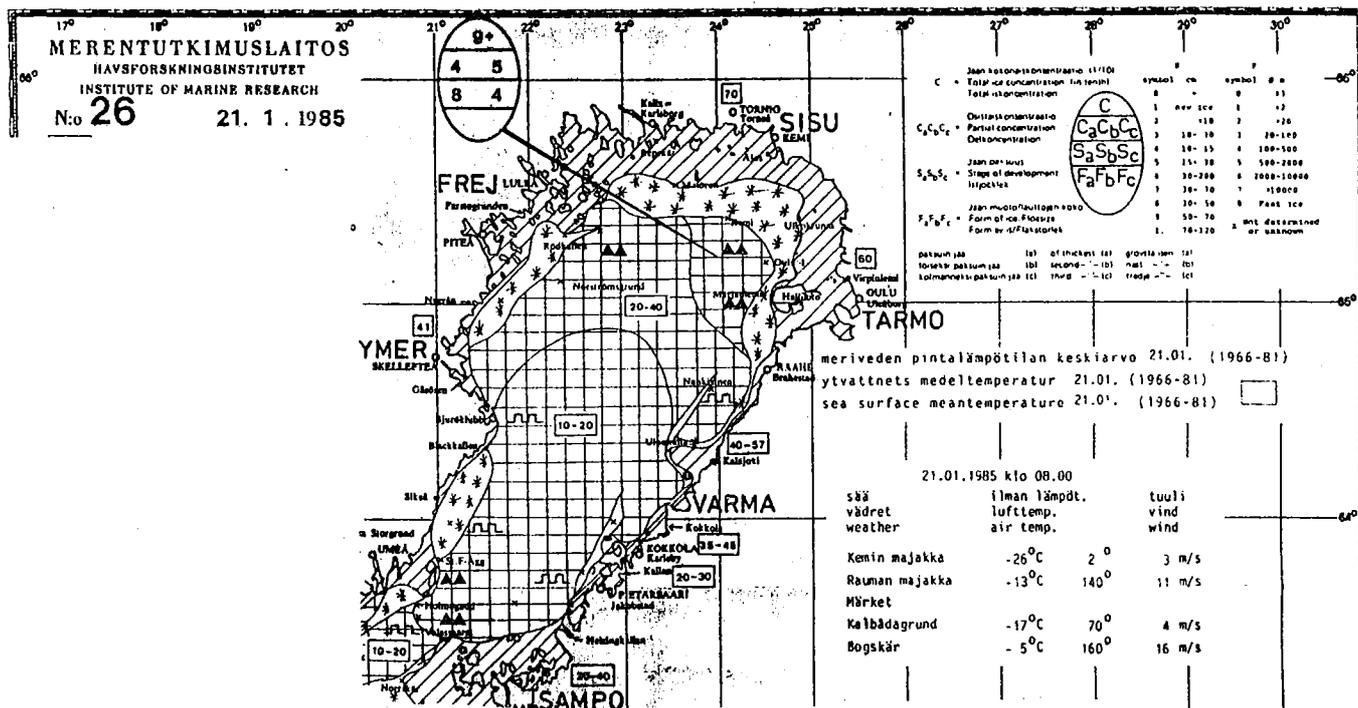


Fig. 13. The ice conditions on the Bothnian Bay on 21st January 1985.

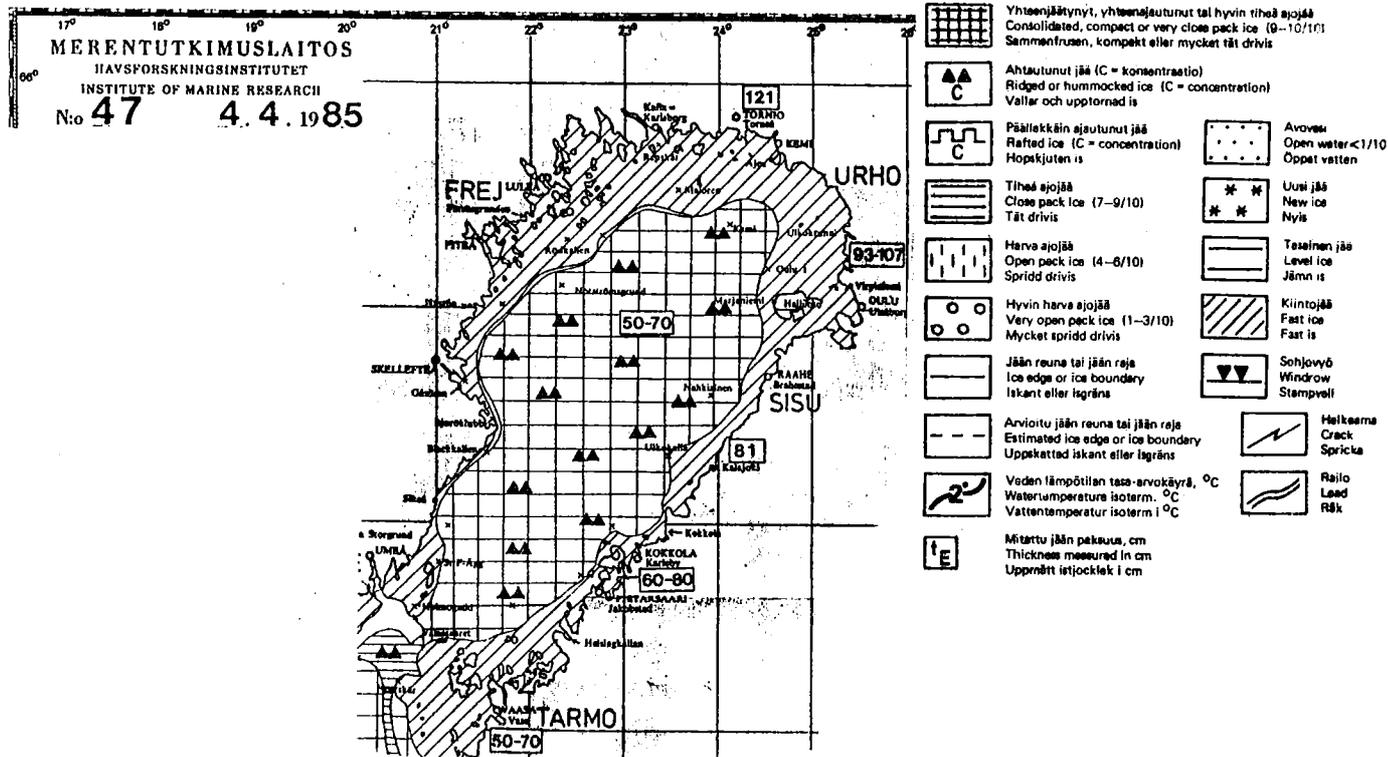


Fig. 14. The ice conditions on the Bothnian Bay on 04th April 1985.

The measurements during the short-term trials were conducted when I.B. Sisu was sailing in level ice. Outside the fast shore region it is difficult to find pure level ice as usually some ridges of rafted ice exist. The measuring periods were chosen so that the level ice was dominating and only minor ridges existed. The measurements were stopped when the ice situation changed and continued again when pure level ice appeared. The speed of I.B. Sisu varied during the measurements from 10 to 15 knots.

4 RESULTS OF THE MEASUREMENTS

4.1 Short-term measurements

The total measuring time in both of the short-term trials consists of short (about 20 - 30 minutes) periods which are summed up to achieve the final results. The peak amplitude distributions of the measured channel after the summation is given in Appendix 2 for the measuring period 21 - 22nd January and in Appendix 3 for the measuring period 03 - 04 April together with the results of the statistical analysis described in chapter 5. The mean frequency of the measured peaks, F_{av} , is also shown in the figures of the appendices. The mean frequency is determined from the total amount of peaks in each channel divided by the total measuring time. The statistical analysis described in chapter 5 is based on this data.

Some examples of the time histories of the measured loads on the frames are given in Fig. 15 for the measuring period 21 - 22nd January and in Fig. 16 for 03-04th April. From the time histories the following conclusions can be drawn:

- Duration of impacts on a frame varies in Fig. 15 from about 20 ms to 300 ms and in Fig. 16 from about 20 ms up to 600 ms.
- The random nature of the ice crushing process is clearly indicated by the measured time histories as none exactly similar appearance for the load development can be distinguished.
- The load length is typically few frame spacings. Usually a short time difference exists between the maximum values of adjacent frames eventhough the maximum values of 3 - 4 adjacent frames can occur simultaneously (see e.g. Fig. 15b, 15d, 15e and 16c).

- The load height is mostly less than 30 centimetres as usually only one of the signals FFR8 AB, FFR8 BC or FFR8 CD appear with the same time event. Some figures also clearly show the movement of the load from the upper measuring level (FFR8 AB) to the lower one (FFR8 CD) during the ice breaking process (see e.g. Fig. 16a and 16b).

Fig 15 a Some measured time histories at 22.01.1985

Scale: FT 2 | 50 kN FFR 6...10 | 20 kN FFR 8 AB, CD, AD | 20 kN FFR 8 BC | 20kN

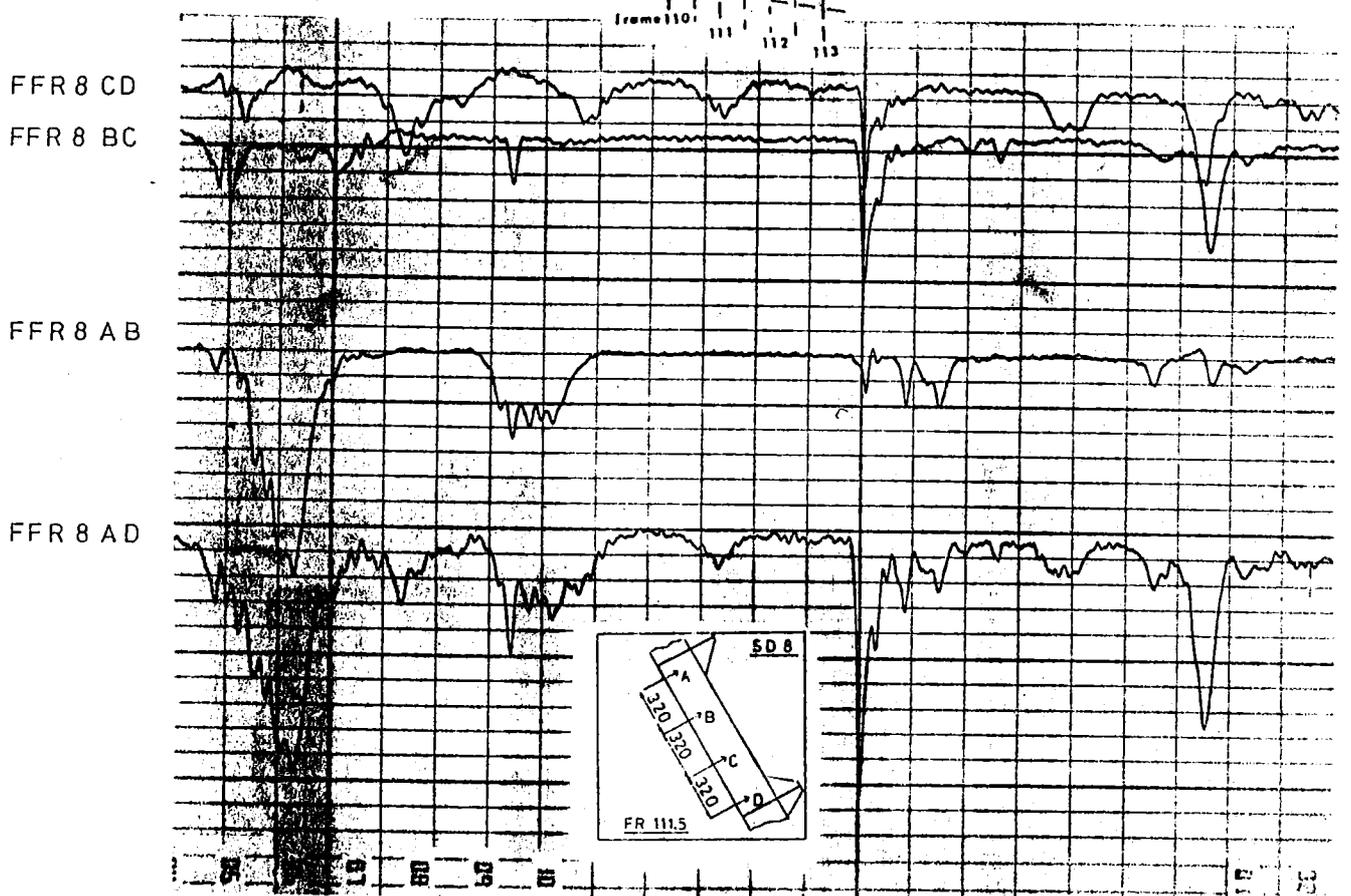
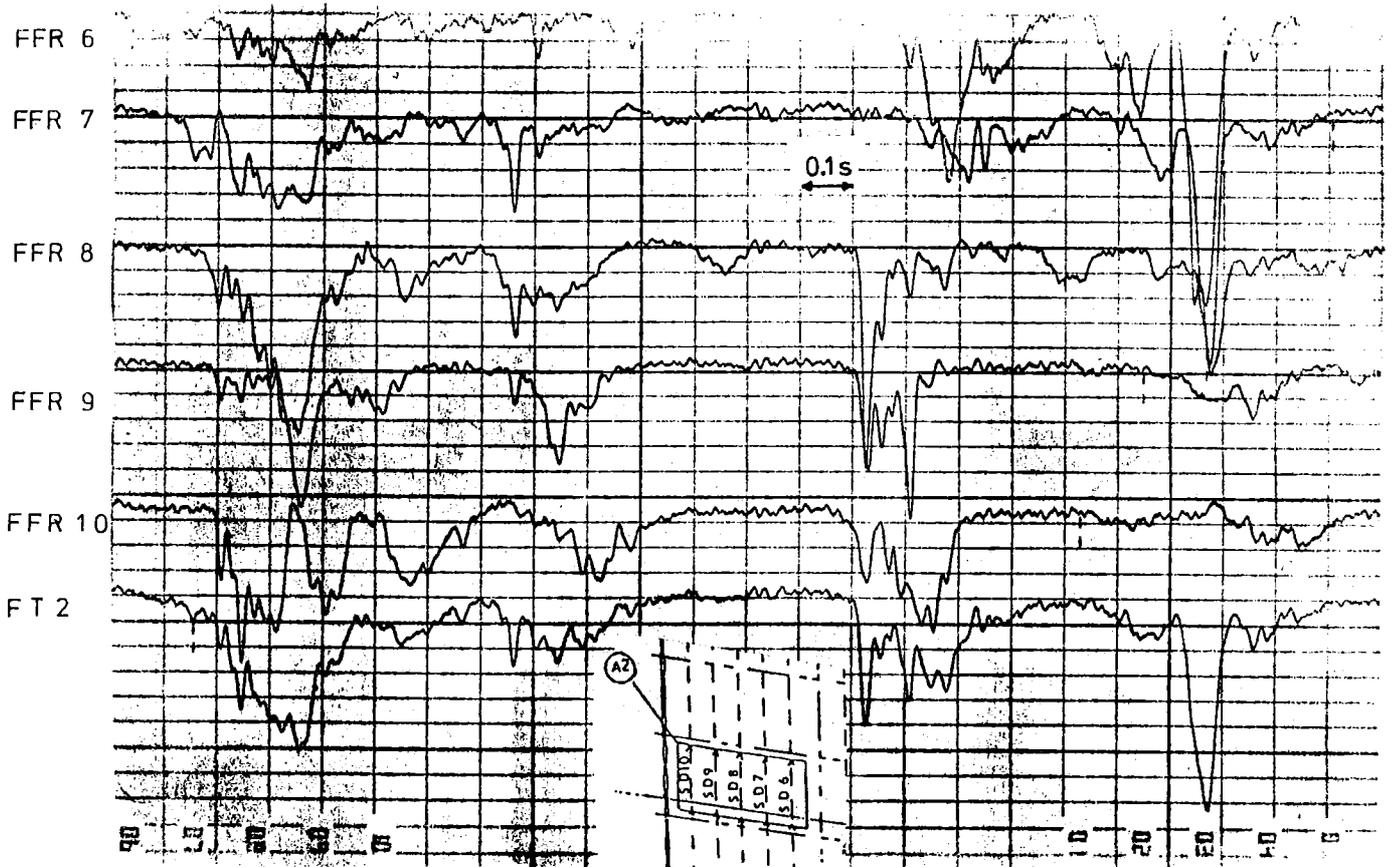


Fig 15 b Some measured time histories at 22.01.1985

Scale: FT 2 [50 kN FFR 6...10 [20 kN FFR 8 AB, CD, AD [20 kN FFR 8 BC [10 kN

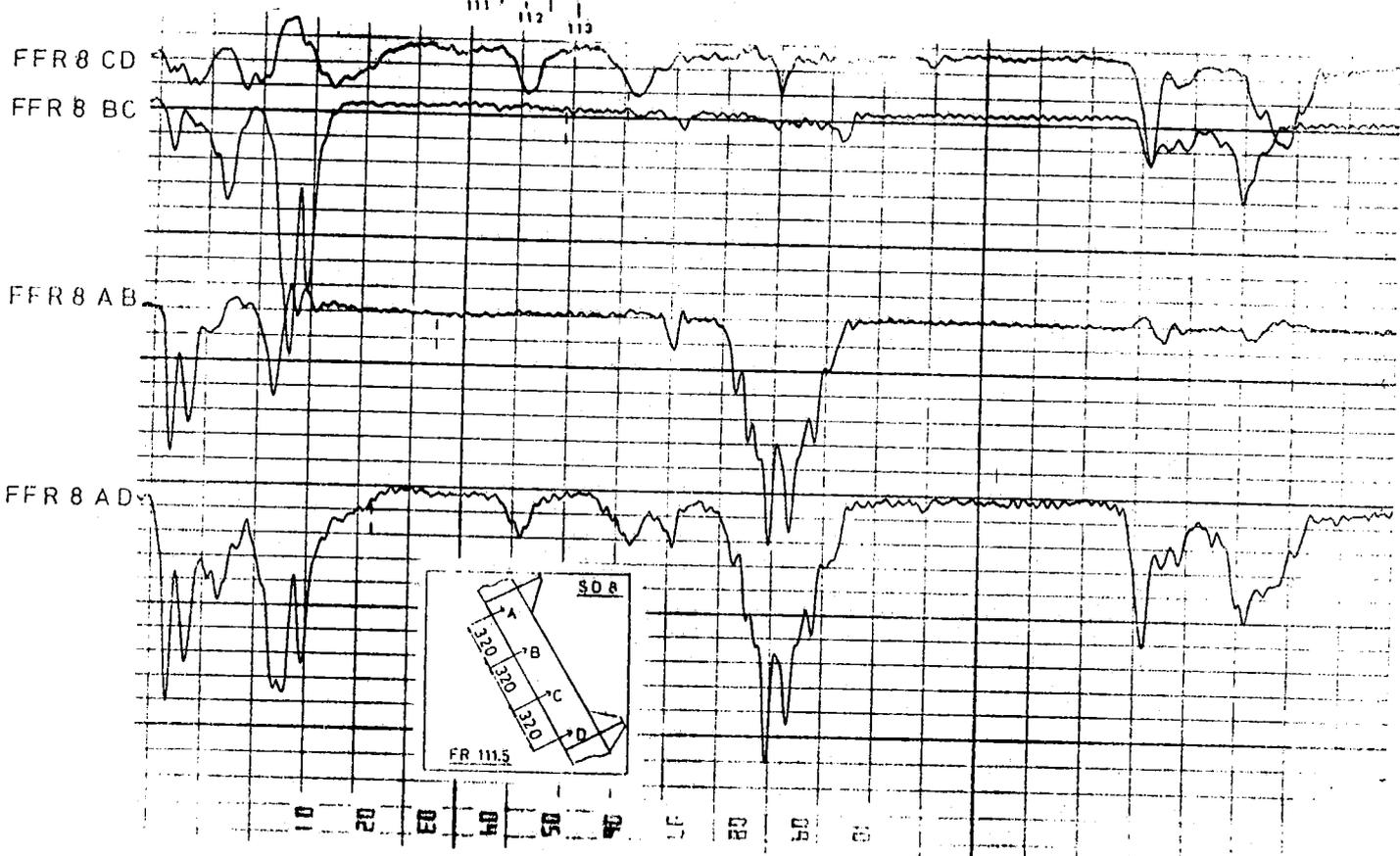
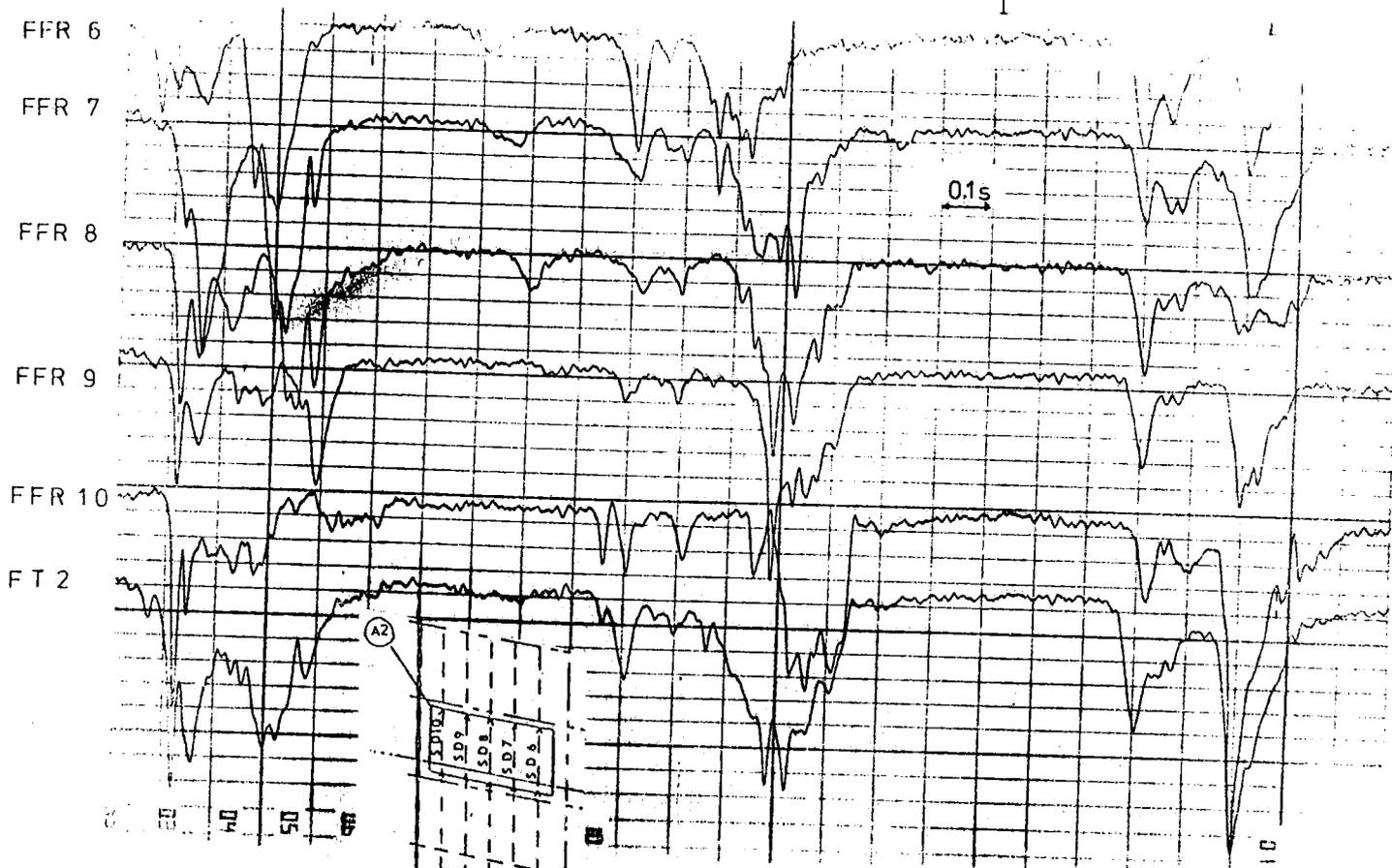


Fig 15c Some measured time histories at 22.01.1985

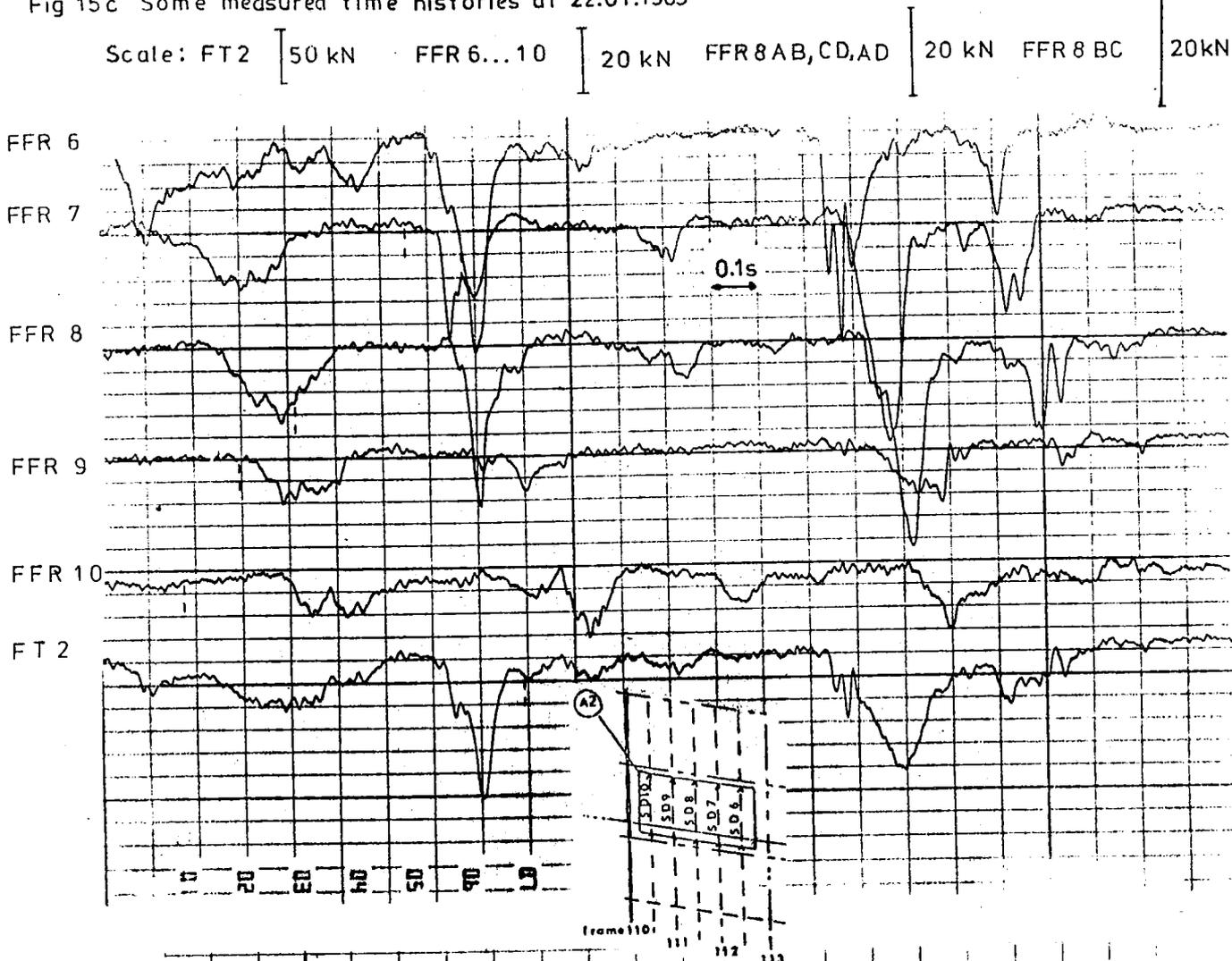


Fig 15d Some measured time histories at 22.01.1985

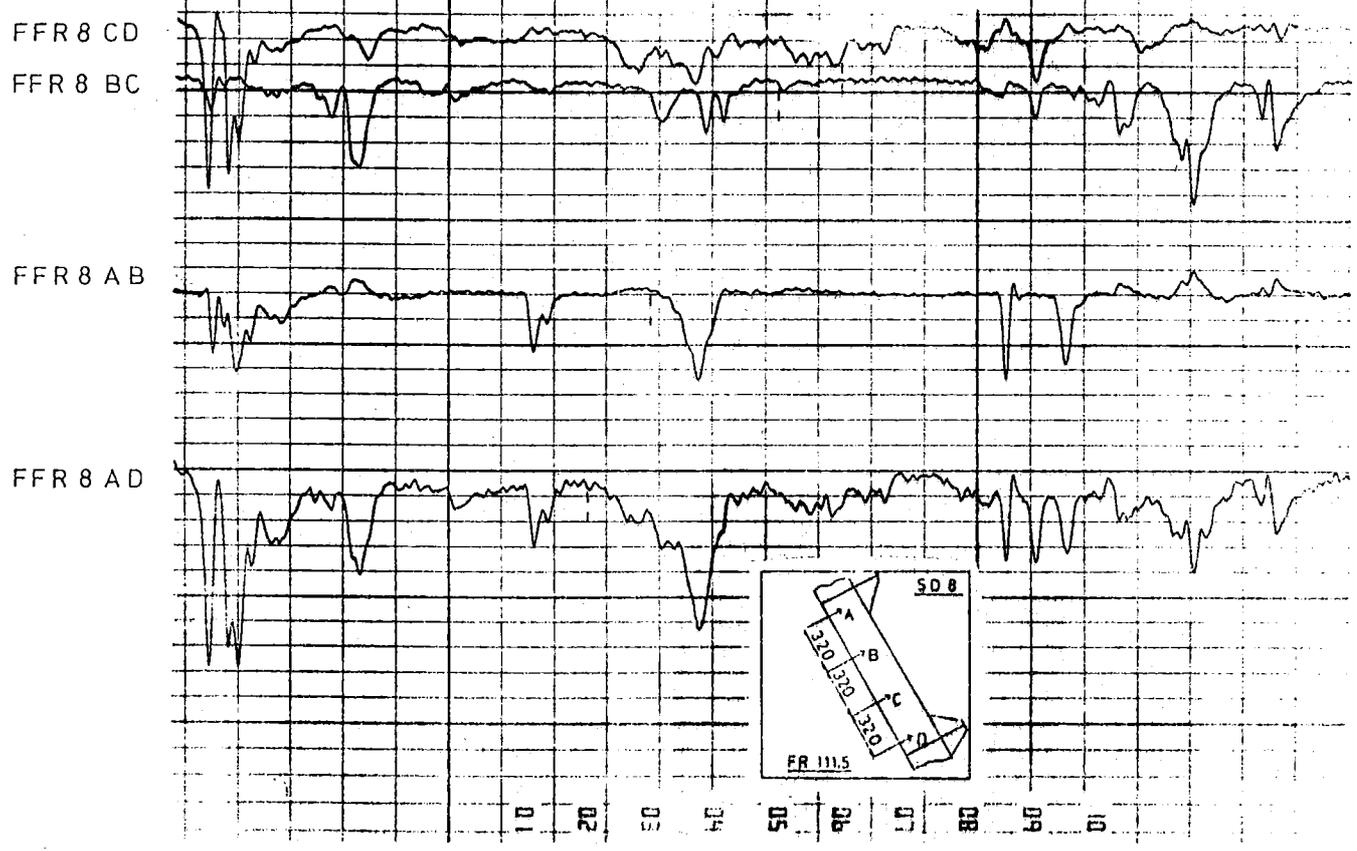
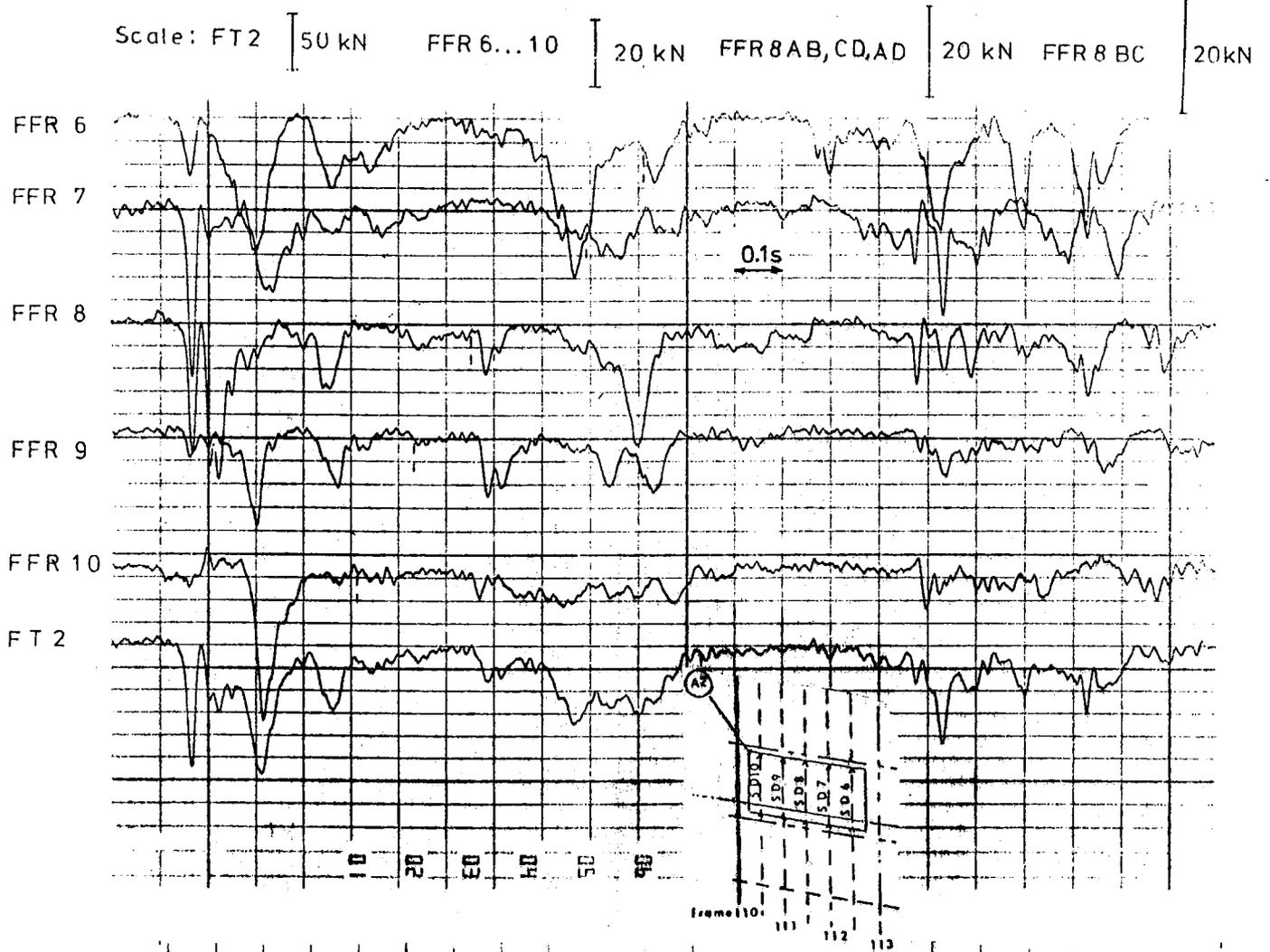


Fig 15e Some measured time histories at 22.01.1985

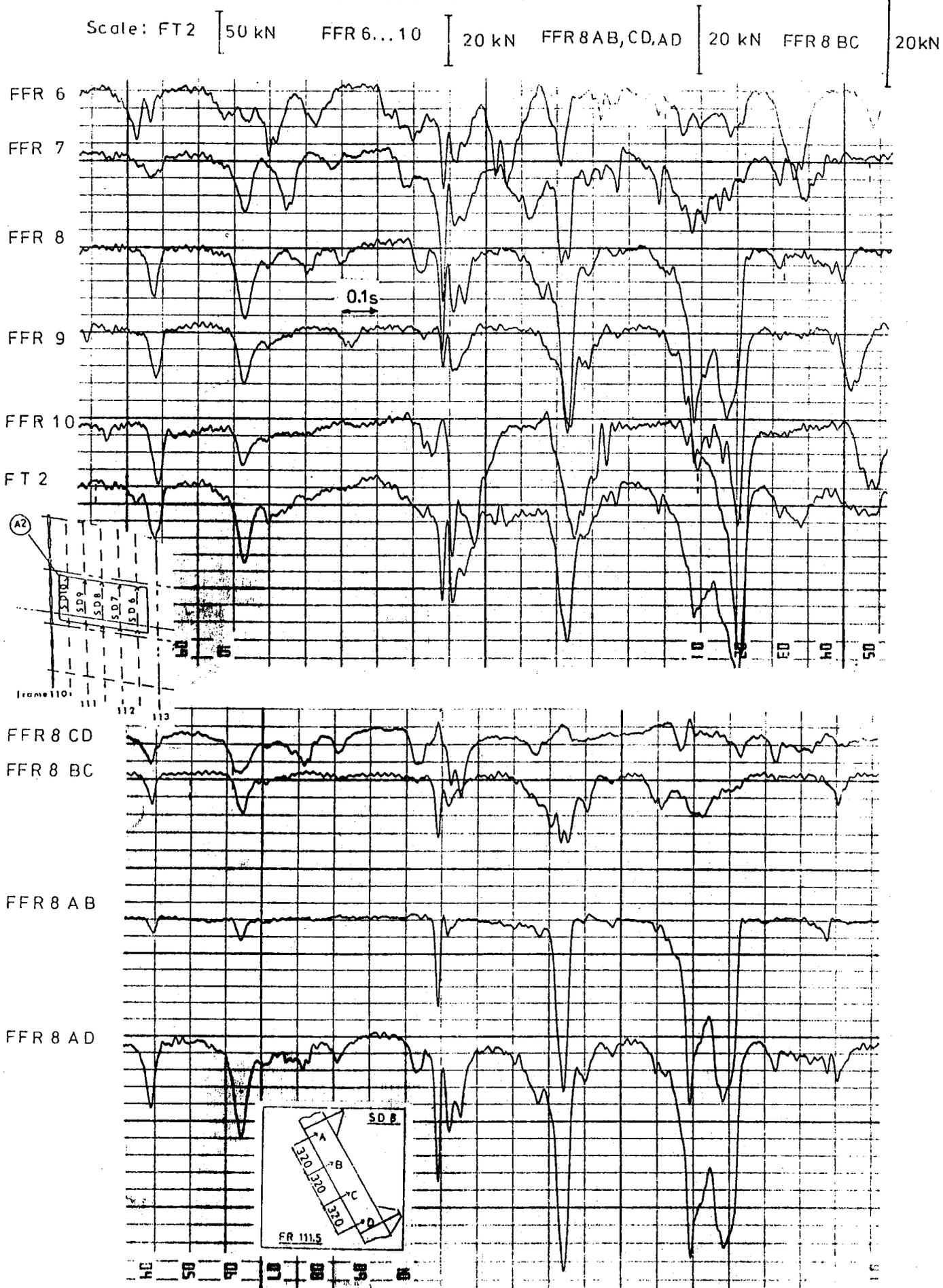


Fig 15 f Some measured time histories at 22.01.1985

Scale: FT2 [50 kN FFR 6...10 [20 kN FFR 8AB,CD,AD [20 kN FFR 8 BC [20kN

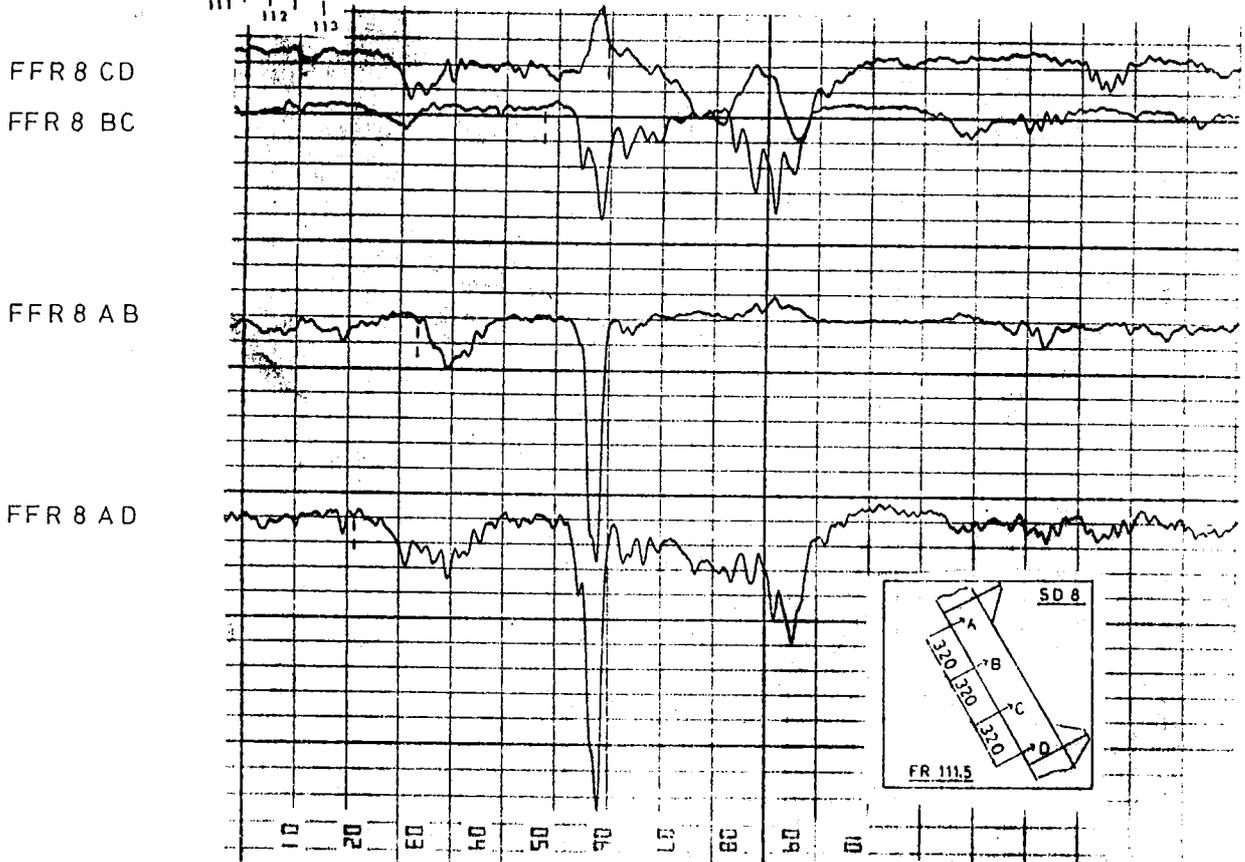
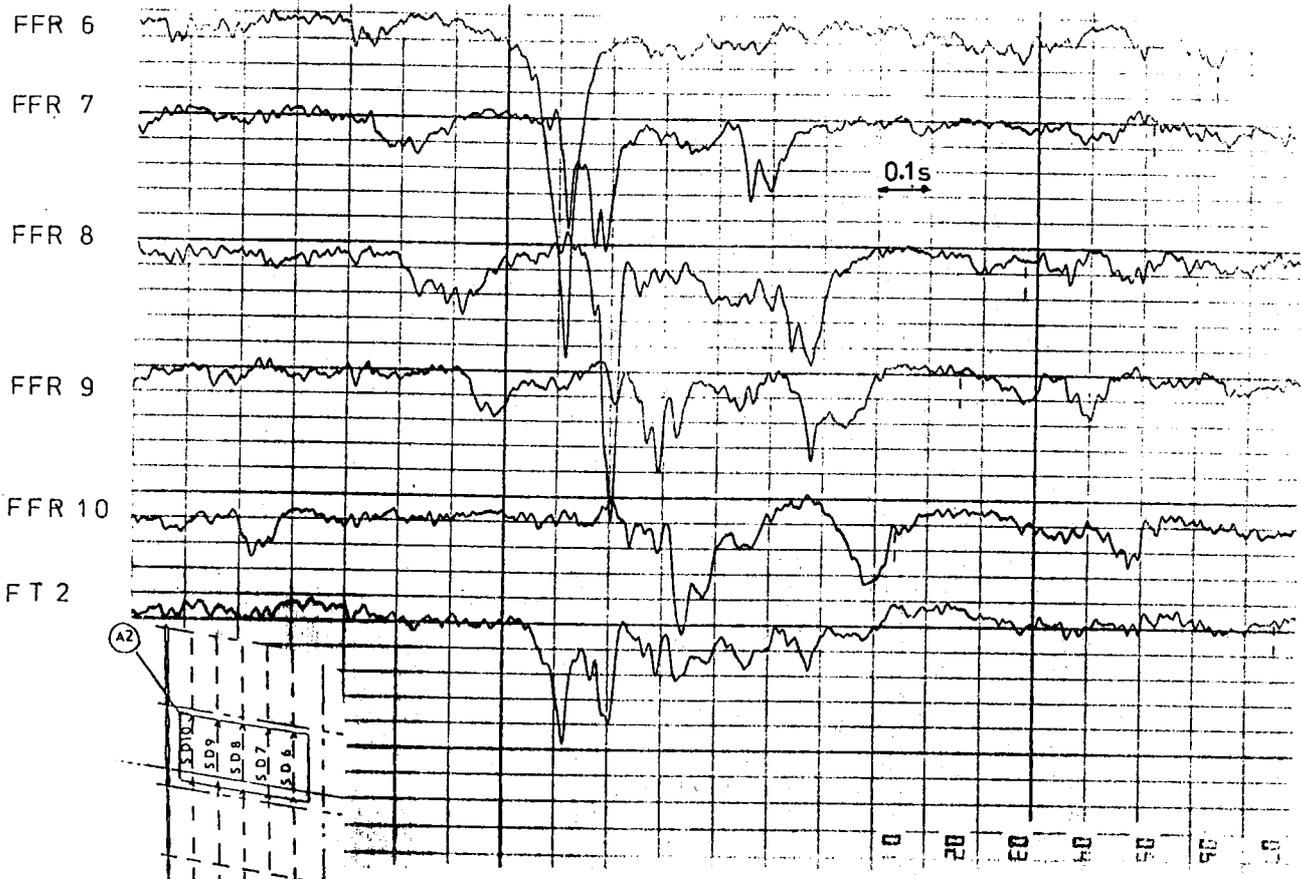


Fig.16 a' Some measured time histories at 03.04.1985

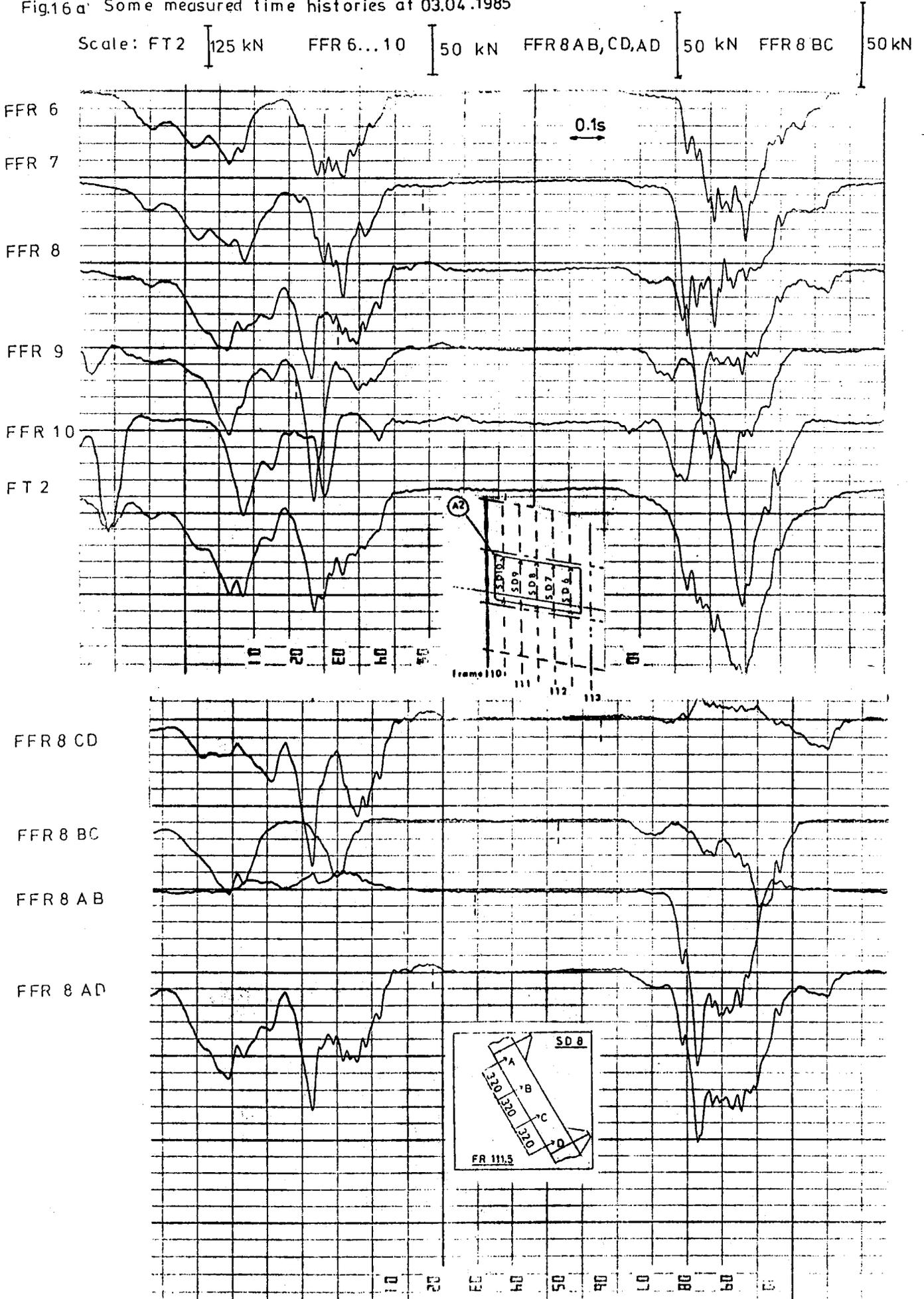


Fig.16 b Some measured time histories at 03.04.1985

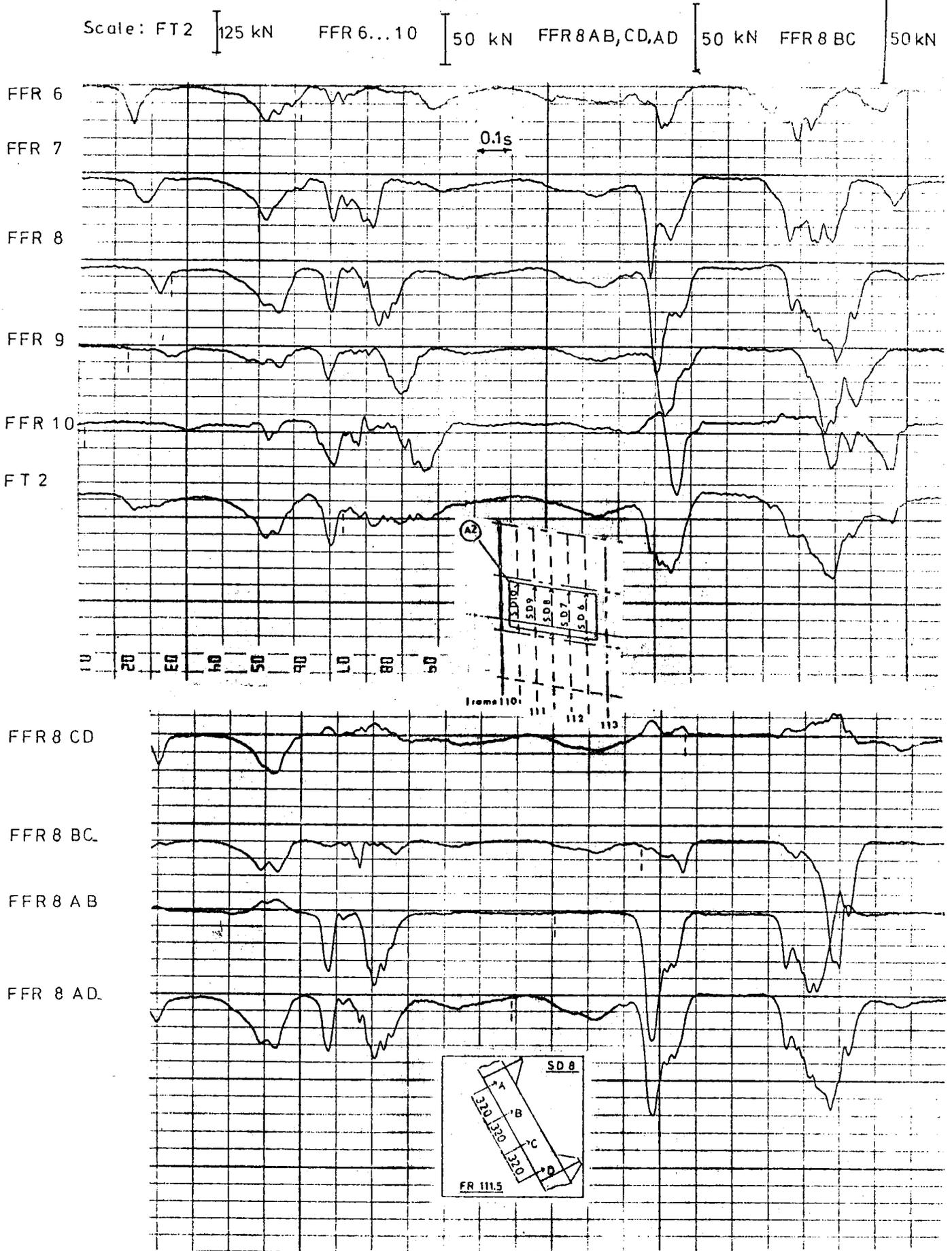


Fig.16 c: Some measured time histories at 03.04.1985

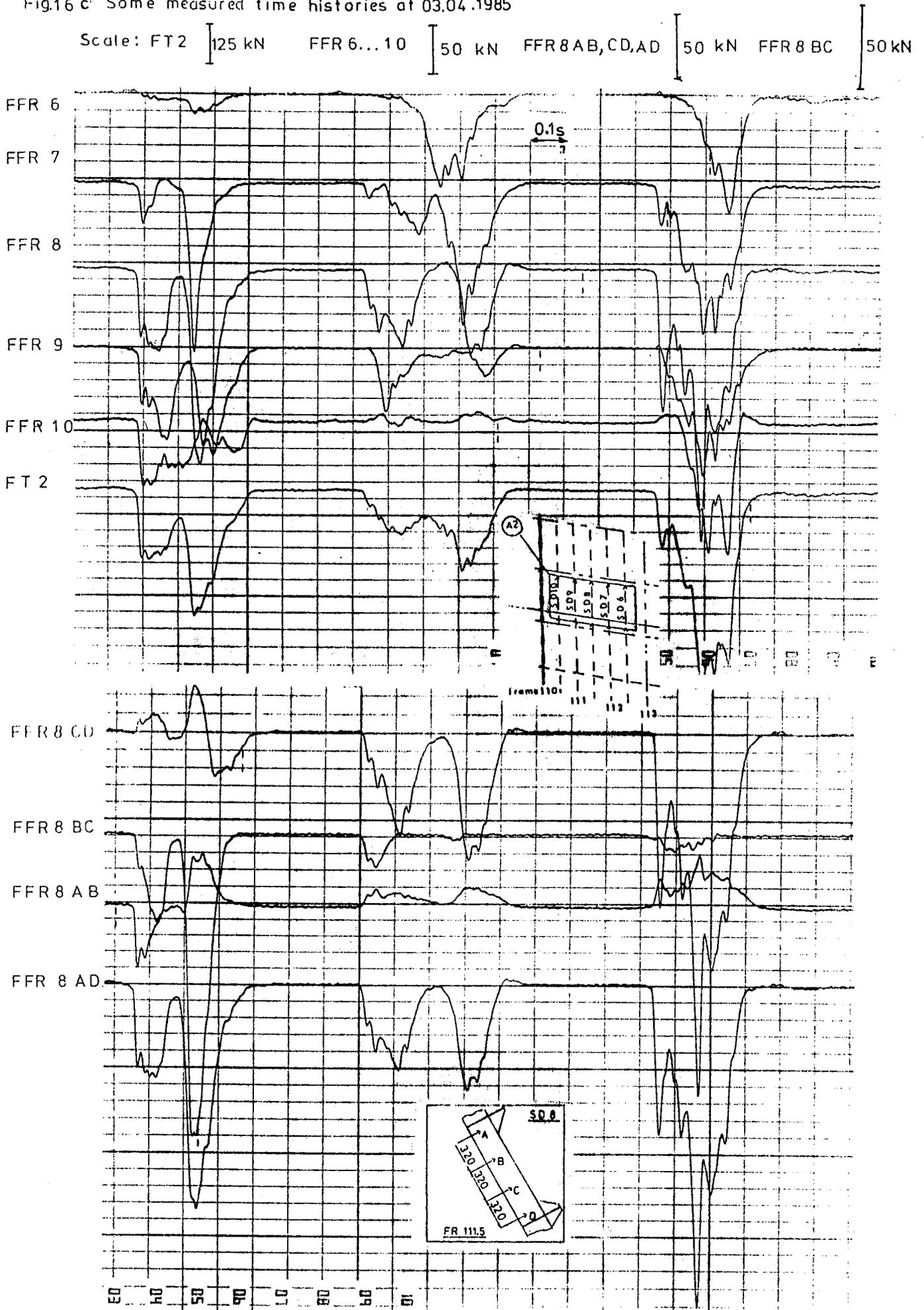


Fig.16 d Some measured time histories at 03.04.1985

Scale: FT2 | 125 kN FFR 6...10 | 50 kN FFR 8 AB, CD, AD | 50 kN FFR 8 BC | 50 kN

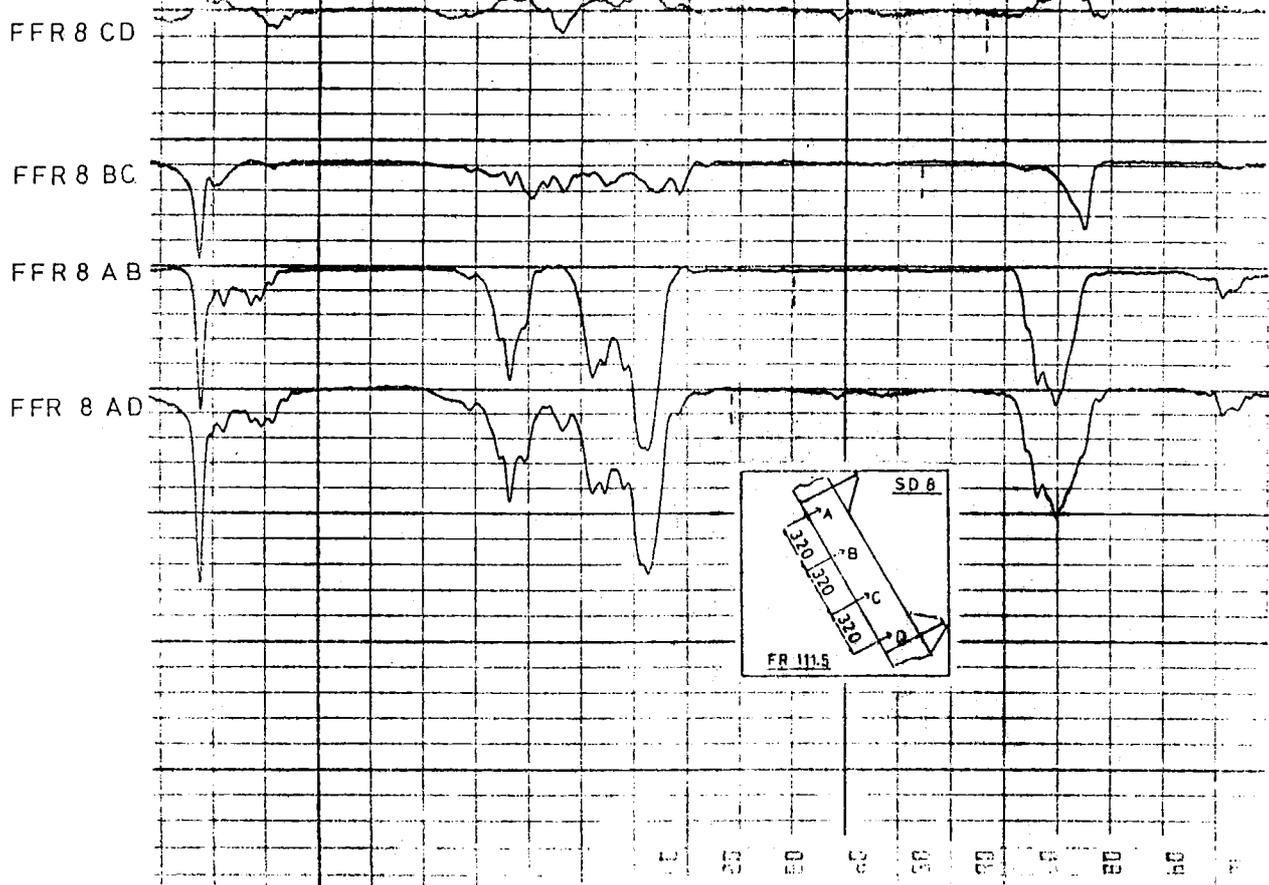
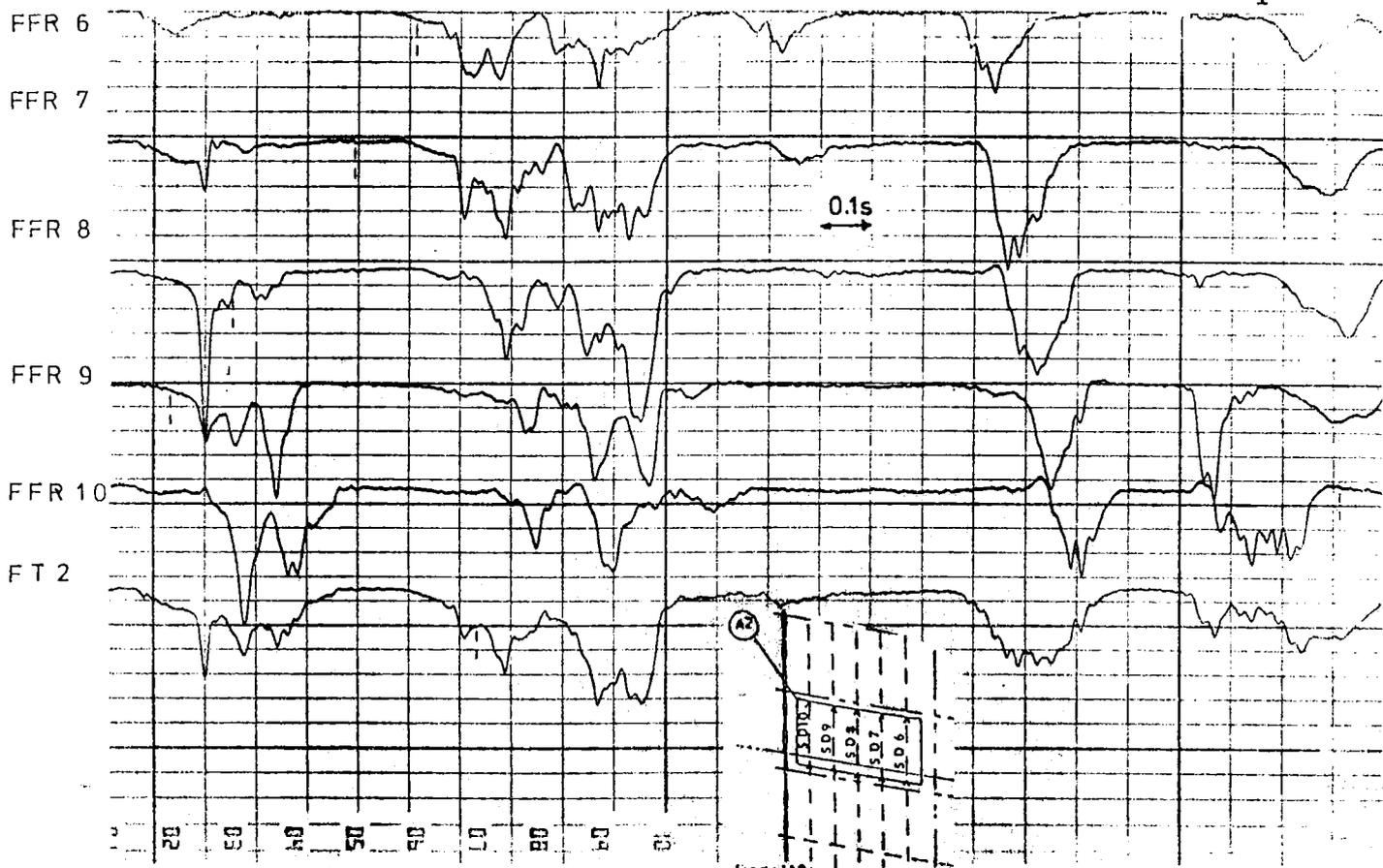
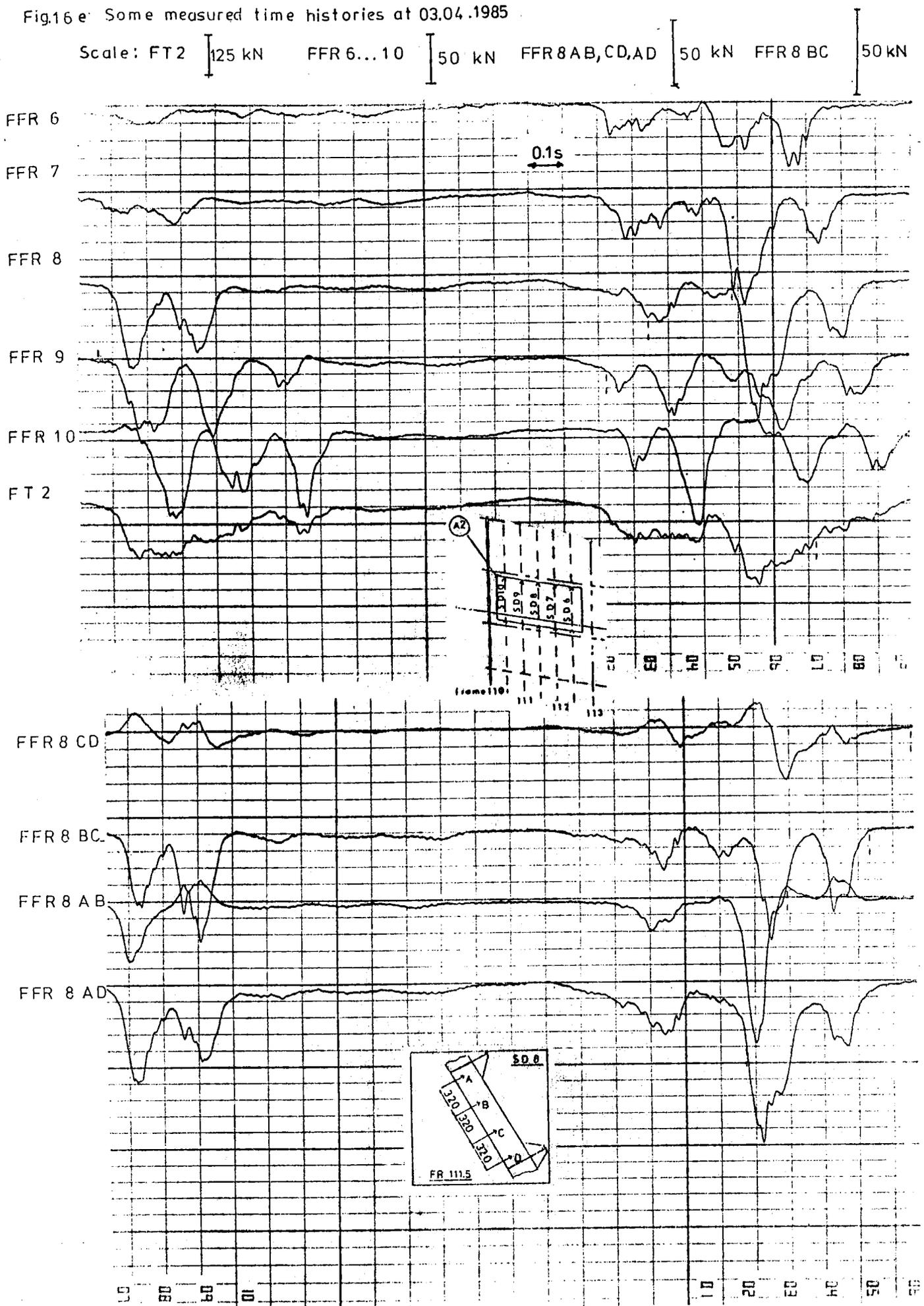


Fig.16 e: Some measured time histories at 03.04.1985



4.2 Long-term measurements

The measured speed of I.B. Sisu varies mainly in the range of 10 to 13 knots during a day as shown in a typical daily distribution of Fig. 17. The daily maxima of the measured ice loads and structural response between years 1979 to 1985 form the basis of the statistical analysis of the long-term data. Fig. 18 and Fig. 19 illustrate as an example the measured daily maxima during the last three years of the conducted measurements for the channels PG4 and FFR8, respectively. Again the random nature of the measured ice pressures and loads is clearly indicated. The measured maximum values for each channel are given in Table 4 on page 43. The measured daily maxima for each channel are sampled together for the statistical analysis. The obtained distributions of the daily maxima are shown in Appendix 4 together with the extreme distributions fitted on this data as described in the next chapter.

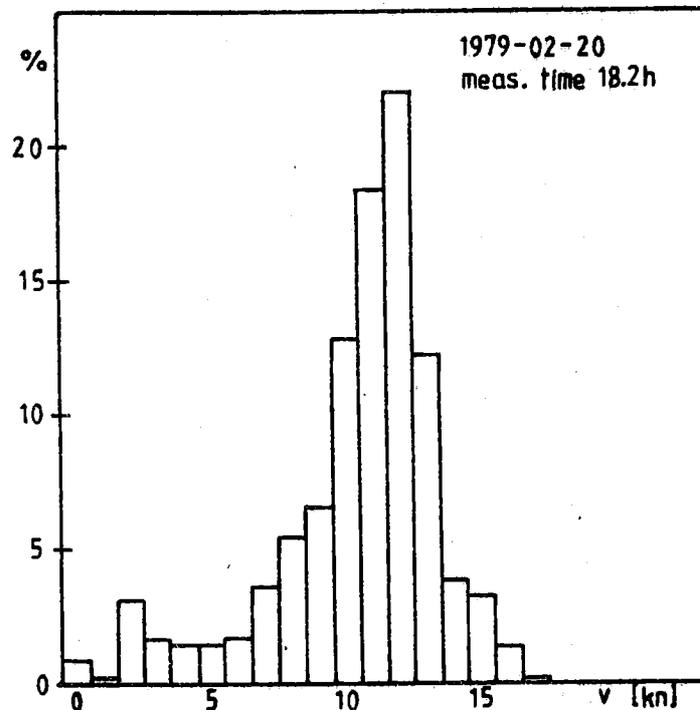


Fig. 17. A typical daily distribution of the measured ship's speed.

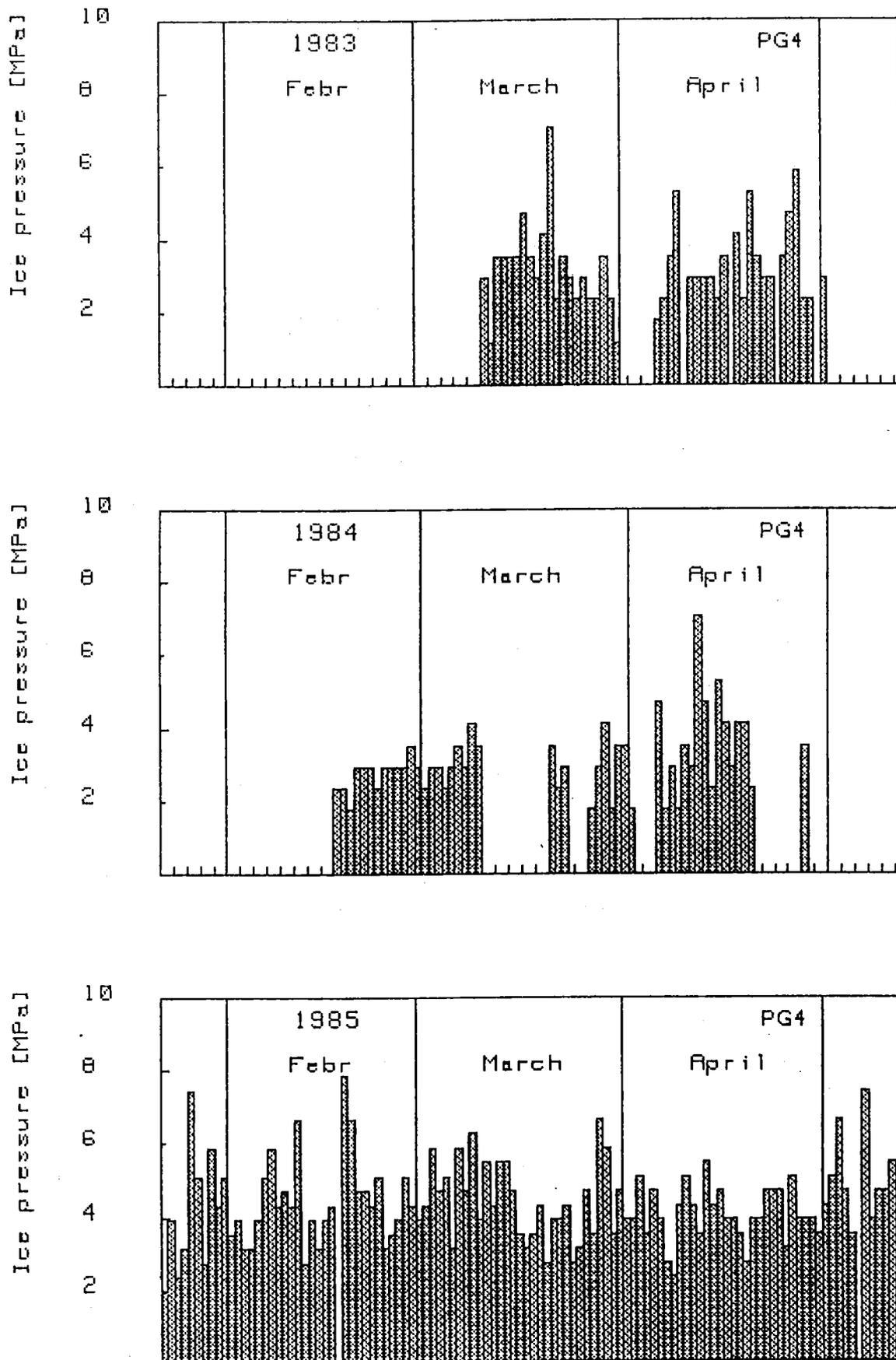


Fig. 18. The measured daily maxima between years 1983 - 1985 for the channel PG4.

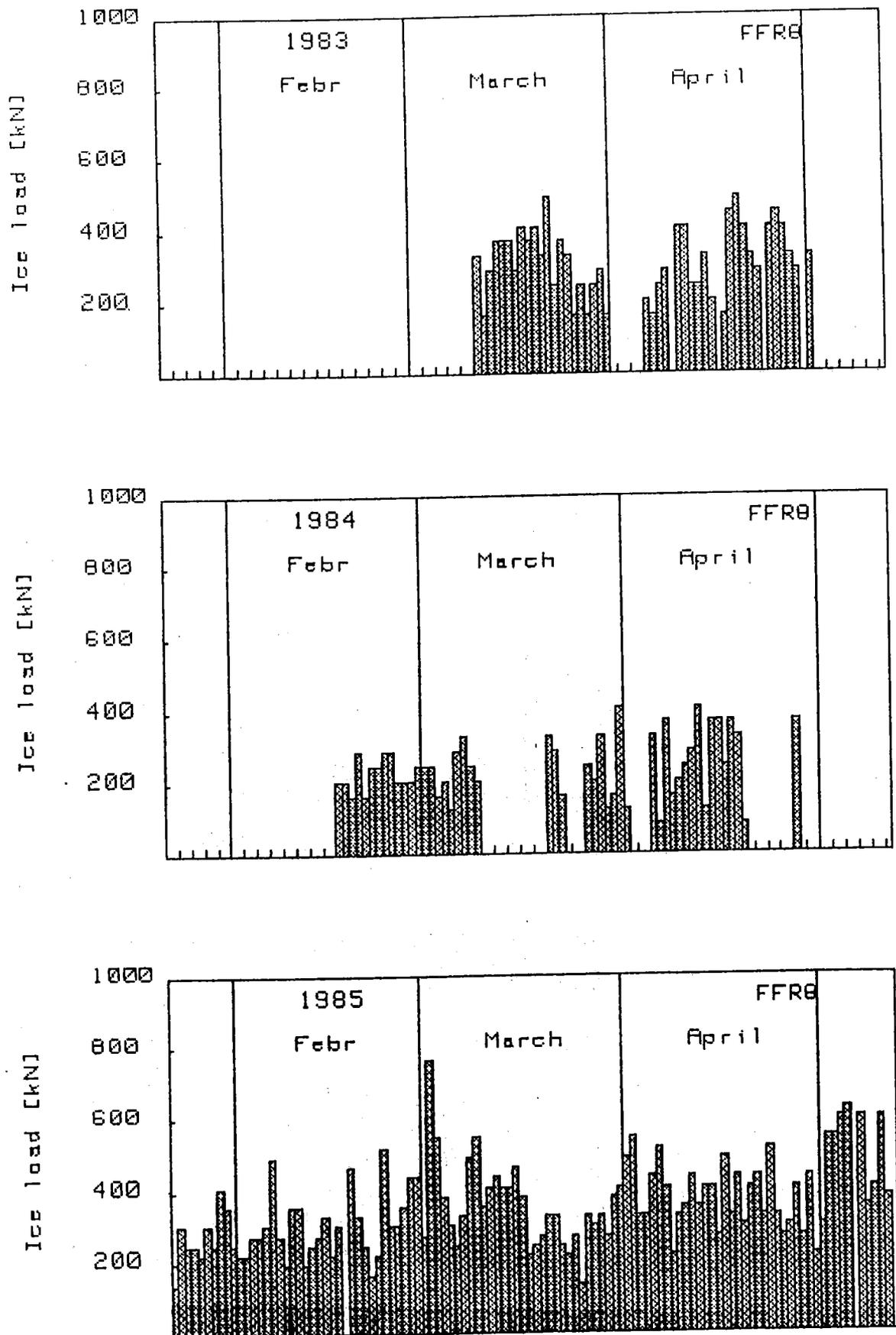


Fig. 19. The measured daily maxima between years 1983 - 1985 for the channel FFR8.

5 STATISTICAL ANALYSIS OF THE MEASURED RESULTS

5.1 General

Ice induced loads have a strong stochastic nature as indicated by the measured time histories on Figs. 15 to 16 and by the daily maxima of Figs. 18 to 19. Therefore statistical analysis are required to study the phenomena associated with ship-ice interaction and to evaluate a basis for extrapolation of the measured results.

The statistical characteristics can be studied either through the measured peak amplitude or daily maxima distributions. These distributions have a different character as peak amplitude distribution includes all the measured amplitudes and daily maxima distribution includes only the greatest amplitude during one day. Consequently the peak amplitude distributions content much more information of the basic nature of ship-ice interaction than the daily maxima. The differences in the statistical analysis of these two distributions are discussed in more detail in reference /2/.

In the following the statistical analysis of the short-term measurements are based on the peak amplitude distributions and the analysis of the long-term measurements are based on the measured daily maxima. This results from the fact that the peak amplitude distribution is very sensitive to the environmental conditions and therefore in long-term measurements each condition should be analyzed separately. This is practically impossible and so the measured daily maxima have to be used for extrapolation purposes of the measured long term data. The drawback of this is that the obtained results are difficult to relate to any specified environmental conditions and the results are applicable only to the ships with similar operation history.

5.2 Short-term measurements

The peak amplitude distributions shown in Appendix 2 and 3 from the data base for the statistical analysis of the short-term data of 21.-22.01.1985 and 02.-03.04.1985. In order to find the most suitable distribution for describing the measured results four generally known distributions are fitted on the measured peak amplitudes of the load FFR8. The studied distributions are; Rayleigh, Weibull, Log-Normal and Exponential. Fig. 20a gives the density function of these distributions on the measured data and Fig. 20b illustrates the estimated extremes with various distributions.

The estimated extremes together with the measured data (*) are plotted as a function of number of peak amplitudes needed to obtain the long-term values. The following relationship exists between the number of peak amplitudes, n , and the cumulative initial distributions, $F(u_n)$:

$$n = \frac{1}{1-F(u_n)} \quad (3)$$

This equation is valid for all exponential type distributions with large n . The value u_n is called the characteristic largest value with n observations /1/. The return period can be obtained once the frequency of the peak amplitudes, F_{av} , is known.

The measured values (*) are plotted on Fig. 20b applying the following procedure. The mean values of each class formed by the automatic measuring unit are chosen to represent all the peak amplitudes inside a class. The cumulative probability for a mean value of a class, x_m , representing the m th to $m + k$ th observations is calculated with the

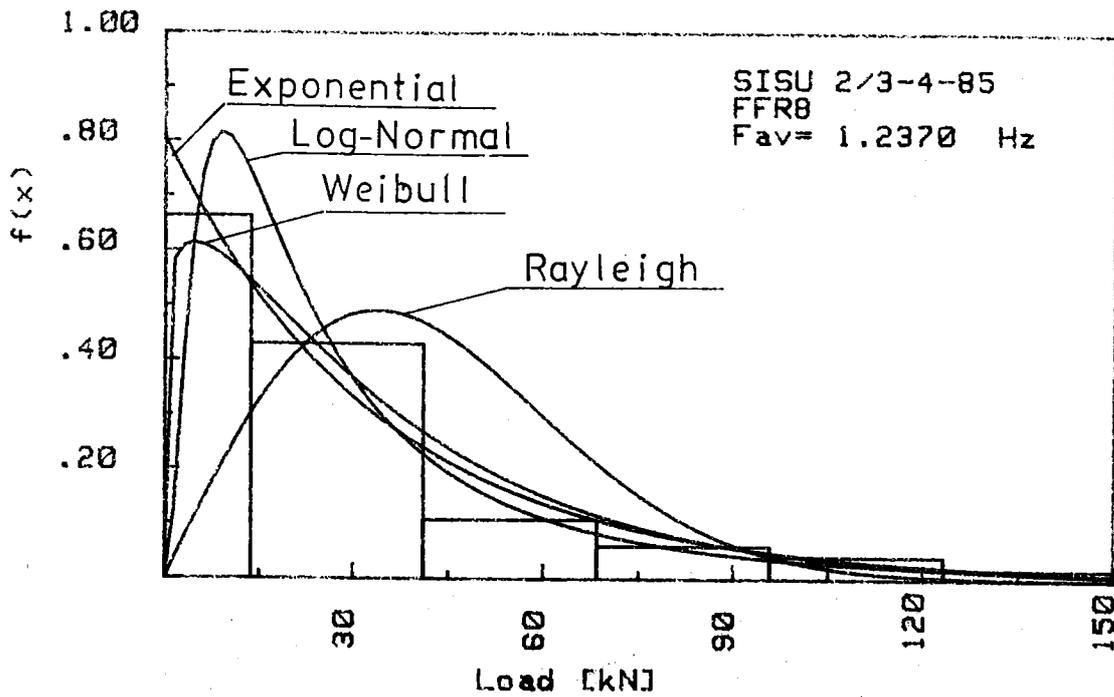


Fig. 20a. The studied initial distributions on the measured peak amplitude distribution of FFR8.

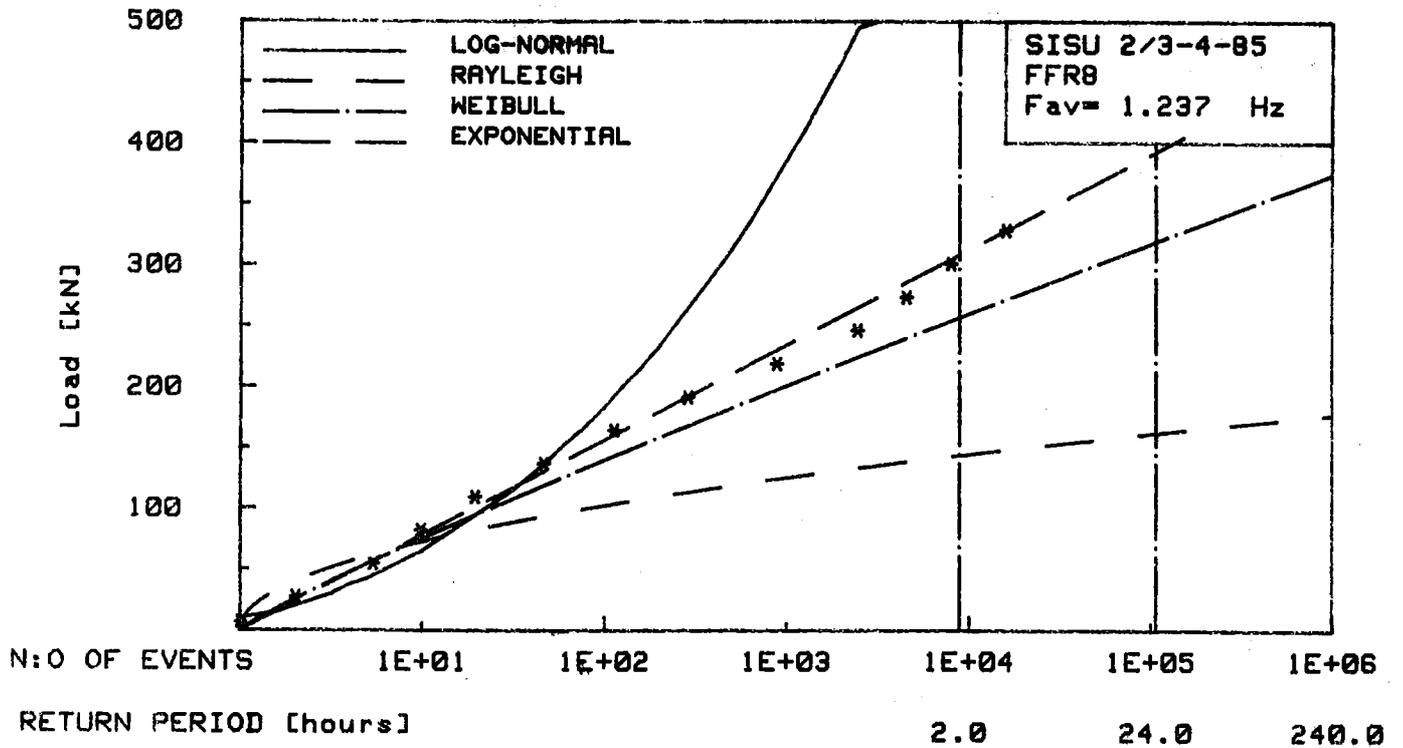


Fig. 20b. Estimated extremes with various distribution together with the measured data (*).

following formula /1/:

$$F(x_m) = \frac{\sqrt{m(m+k)}}{N+1} \quad (4)$$

where N is the total number of observations, k is the number of observations in a class under consideration and m is the total number of observations in the lower classes. Once the cumulative probability is known the formula (3) can be applied and the measured values plotted.

As Fig. 20b clearly indicates the experimental distribution fits best on the measured data. The Rayleigh distribution gives far too low and Log-Normal far too high estimates for the extreme values. Weibull gives also fairly good estimation, which is obvious due to the fact that the exponential distribution is one special case of the Weibull distribution. The parameter estimation procedure is, however, different for Weibull and Exponential distributions. The Weibull distribution is not found to give as good estimations for the extreme values as that of Fig. 20b throughout the measured results, whereas the Exponential distribution fits fairly well on all of the measured data. Consequently in the following only the Exponential distribution is used to extrapolate the measured results.

Appendix 2 and 3 show the results of the extrapolation of the short-term measurement for the measuring period 21.-22.1.1985 and 02.-03.04.1985, respectively.

The exponential distribution has the following form:

$$f(x) = \lambda x^{-\lambda x} \quad (5)$$

$$F(x) = 1 - e^{-\lambda x} \quad (6)$$

where $f(x)$ is the initial and $F(x)$ the cumulative distribution. Exponential distribution has only one parameter, λ and it is estimated from the relationship $\lambda = 1/\bar{x}$ where \bar{x} is the sample mean /3/. Table 3 summarizes the calculated values for λ together with the mean frequency of peak amplitudes in various channels. Also the extrapolated values with various return periods are given in Table 3. The extrapolated values can be obtained either from the figures in Appendices 2 and 3 or applying the following formula /1/:

$$u_n = \frac{\text{Ln}(n)}{\lambda} \quad (7)$$

where n is number of peak amplitudes in the time period under consideration which can be calculated using the average frequency of two peak amplitudes in various channels. Formula (7) shows that the exponential extremes form a straight line on the half-log paper as illustrated also in Appendices 2 and 3. Formula (7) also indicates that to double the most probable extreme value the number of peak amplitudes have to be squared.

5.3 Long-term measurements

Gumbel extreme distributions are fitted on the measured daily maxima and the extrapolated long-term extremes are evaluated with the Gumbel distributions. Both Gumbel I and Gumbel III asymptotic distributions are fitted on the measured data. Fig. 21a shows as an example the measured daily maxima of the channel FRR 8 and Fig. 21b gives the estimated long-term extremes together with the measured daily maxima. The results for the other channels are given in Appendix 4. Gumbel III results always to a lower estimate for long-term extremes than Gumbel I because Gumbel III approaches to some specified upper limit whereas Gumbel I has no upper limit. The parameter estimation and the characteristics of these distributions are described elsewhere in more detail /1, 7/ and in the following only the results of the statistical analysis are summarized.

Table 4 gives the obtained most probable extreme values with return periods of 10, 100 and 1000 days together with the total measuring time and measured maximum values. The extrapolated values are based on the Gumbel III asymptotic distribution, when Gumbel III fits on the measured data. In those cases when Gumbel III fits not on the measured data, the extrapolated values are taken according to Gumbel I distribution and Gumbel III is not plotted on the measured data (see Appendix 4).

Another way to analyze the long-term data is to sum up all the measured peak amplitudes and then fit a probability distribution on that data. This has been done for the channel PG1 as described in reference /2/. The problem with that approach is, however, that the lower classes get too pronounced role when fitting statistical distributions on that data. This is due to the fact that when I.B. Sisu sails in light ice conditions or in channel ice most of the samples go to the lower classes. These ice conditions form a remarkable part of the typical operation history of I.B. Sisu.

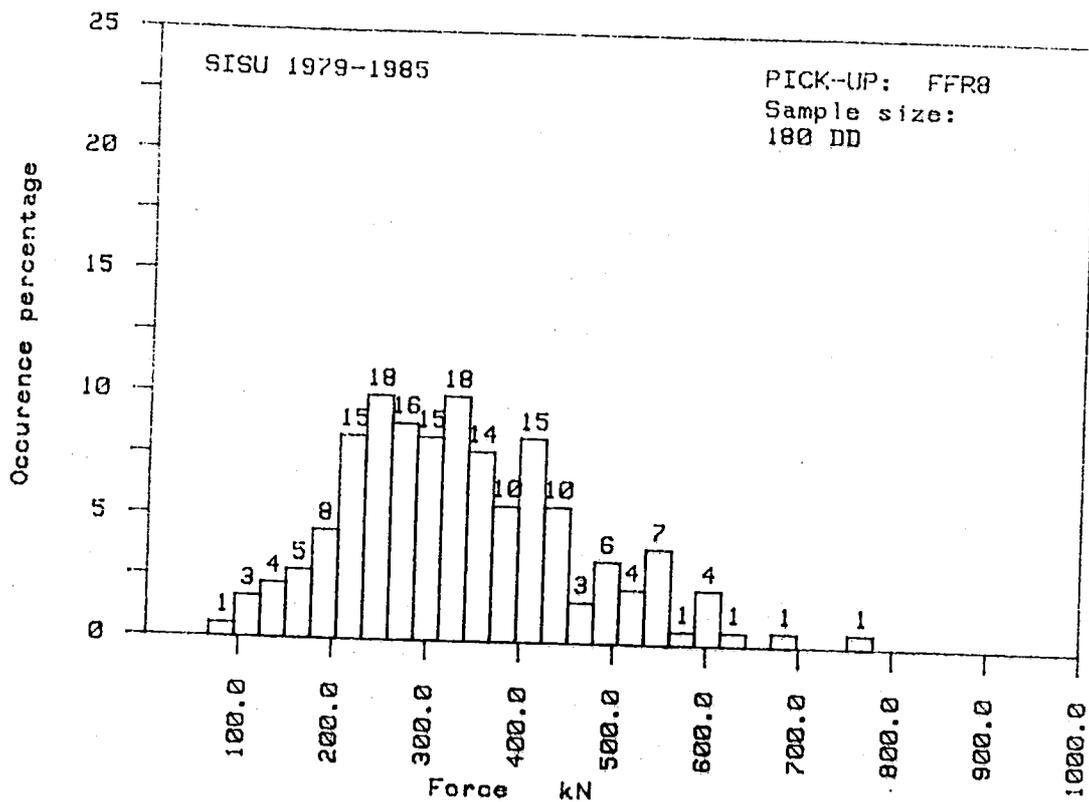


Fig. 21a. The distribution of the measured daily maxima of the channel FFR 8.

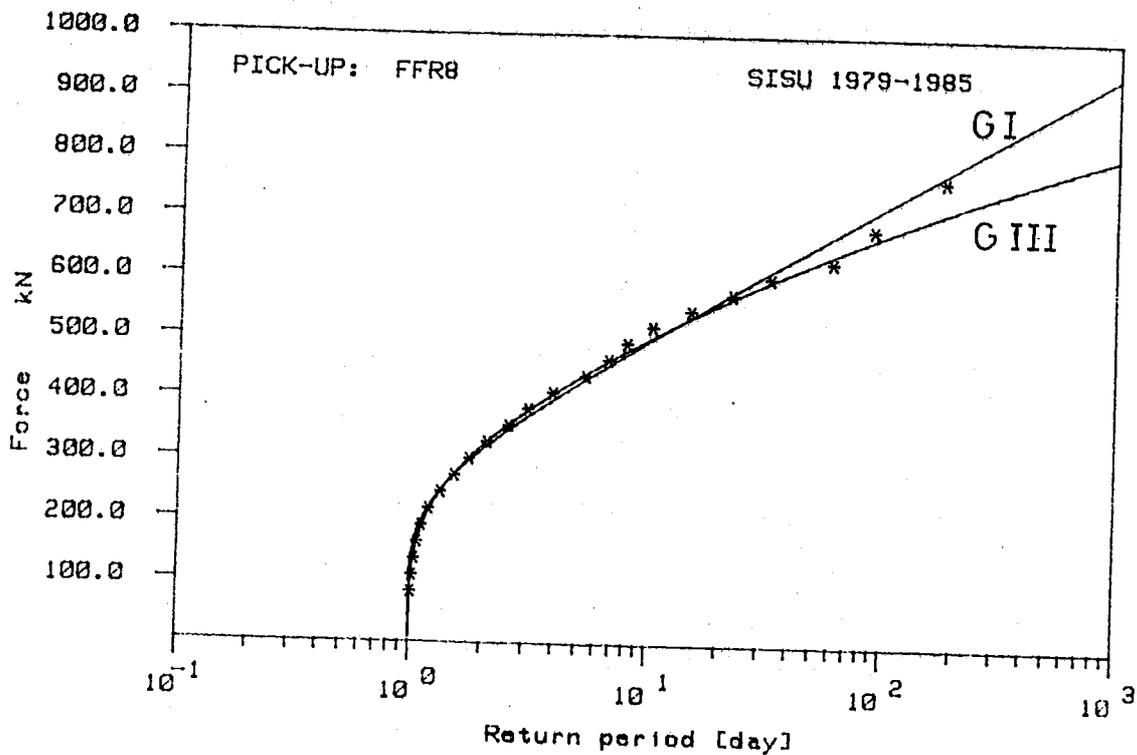


Fig. 21b. The estimated long-term extremes for the channel FFR 8 together with the measured daily maxima.

Table 4. The results of the statistical analysis of the long-term data.

		Measured values		Extrapolated values		
		Measuring time [day]	Measured Max.	Return period [day]		
				10	100	1000
PG1	[MPa]	241	11.5	8.1	10.4	12.2
PG2	"	91	10.5	7.4	9.8	11.8
PG3	"	113	8.3	5.6	8.1	10.3
PG4	"	223	7.8	5.6	7.4	8.7
PL1	[N/mm ²]	91	220	153	195	222
PL2	"	29	180	143	178	201
FB2	"	312	155	91	118	138
PL3	"	178	240	146	206	263
FB3	"	219	210	113	168	217
PL4	"	223	300	170	245	320
FB4	"	220	310	181	258	332
FFR1	[kN]	158	739	475	674	863
FFR2	"	179	739	438	620	795
FFR3	"	157	821	450	654	852
FFR4	"	159	767	426	618	802
FFR5	"	158	657	395	605	796
FFR6	"	223	712	442	594	713
FFR7	"	202	548	432	618	792
FFR8	"	180	767	500	676	809
FFR9	"	158	602	402	559	694
FFR10	"	179	630	434	582	699
FFR7+8	"	111	1314	795	1055	1257
FFR 7+8+9"		111	1396	1001	1284	1475
FFR6+7+8+9"		111	1560	1200	1536	1757
FT2	"	178	1725	1219	1608	1887
FT1	"	158	1643	1064	1433	1735
SB1	[N/mm ²]	159	200	114	165	218
FST1	[kN]	159	1275	775	1089	1356
FFR8 AB	"	111	407	309	387	439
FFR8 BC	"	111	475	355	453	521
FFR8 CD	"	111	586	401	538	646
FFR8 AD	"	111	548	445	581	677

Consequently the lower and upper parts of the summed distributions are not in balance as the upper classes obtain samples only in harder ice conditions. This problem can be overcome by doing short-term measurements in various ice conditions and fitting statistical distributions on the data of each conditions separately. After that the long-term distributions can be evaluated by summing up the obtained distributions so that the occurrence probability of each ice conditions is taken into account in the analysis. This requires, however, a lot of full scale measurements in various typical ice conditions and at present there does not exist such data bank.

5.4 Discussion of the obtained results

The mean frequencies of the encountered peak amplitudes are strongly related to the environmental conditions as shown in Table 3. The frequencies of the load amplitudes are about 5 times bigger in the April measurements than in January measurements. The differences between the measured occurrence frequencies of the local ice pressures (PG4) and stresses on plating (PL4) are even more pronounced. This shows the sensitivity of these quantities to the position and height of the ice induced loads. The effect of the draught can also be seen from the fact that the highest load on the frame 111.5 occurred on the upper part (FFR8 AB) during the January measurements and on the lower part (FFR8 CD) during the April measurements.

The comparison of the most probable extreme values with return periods of 10 days in Table 3 and Table 4 reveals that the analysis of the short-term April measurements and long-term measurements give a similar estimate for these extremes. This indicates that the environmental conditions during the April measurements represent the average conditions experienced by I.B. Sisu during the measured winters.

The results of the statistical analysis of the long-term data shown in Table 4 arise the following comments:

- The ice pressures measured on the frame 93 3/4 are about 30 % higher than those measured on the frame 114 1/2. This fits well with the earlier studies of the effect of the hull shape on the ice induced pressures /5, Fig. 27/.
- The stresses on the plating are lower on the frame 92 3/4 than those on the frame 115 1/4 which is contradictory to the measured pressures. This indicates that the contact between ship and ice has a different character between those two areas. Similar contradictions exist between the measured pressures of PG3/PG4 and stresses PL3/PL4.
- The measured stresses on the frame 92 1/2 are considerably lower than those on the frames 115 which is partly due to the fact that the span of the frame 92 1/2 is about 75 % of that of the frame 115 and partly due to the effect of the ship draught on the measured stresses. The mean draught of I.B. Sisu is typically 7.6 m // therefore most of the contacts occur at the midspan of the frame 115 where the strain gauge FB4 locates.
- The measured loads on the frames of area 1 and area 2 have the same order of magnitude. The small differences between the loads on the frames can be explained to result from the stochastic nature of the ice induced loads. The total load on area 1 is about 10 % smaller than that of area 2 which can be due to effect of the bow shape on the ice induced loads.
- The measured load on the stringer is about 25 % smaller than the load in the area 1 which is due to the transfer of the load to the adjacent stringers through the frames.

In the next chapter the measured load configurations on the area 2 are analysed in more detail.

5.5 Obtained loads on area 2

The summation of the measured loads on the frames FFR6 to FFR10 enables the presentation of the ice induced loads as a function of the contact length, see Fig. 22. Fig. 22 is based on the data given in Tables 3 and 4.

The measured loads with varying load length enable also the evaluation of the line load $p_{av} \cdot h_c$ (p_{av} = average pressure h_c = contact height) as a function load length, l_c . The following form is assumed for this relationship /5/

$$p_{av} h_c = C \left(\frac{l_c}{s} \right)^{-a} \quad (8)$$

where s is frame spacing, a and C are constants. Table 5 gives the calculated constants with various return periods and in Fig. 23 are plotted as an example the obtained curves from the long-term data.

Table 5. The constants for the line load equation (8) according to the short- and long-term measured and extrapolated results.

	21.-22.01.1985			02.-03.04.1985			1979 - 1985		
	Return period [hour]			Return period [hour]			Return period [day]		
	2	24	240	2	24	240	10	100	1000
C [kN/m]	432	588	727	803	1025	1230	1291	1737	2078
a	0.28	0.28	0.28	0.40	0.41	0.41	0.42	0.45	0.47

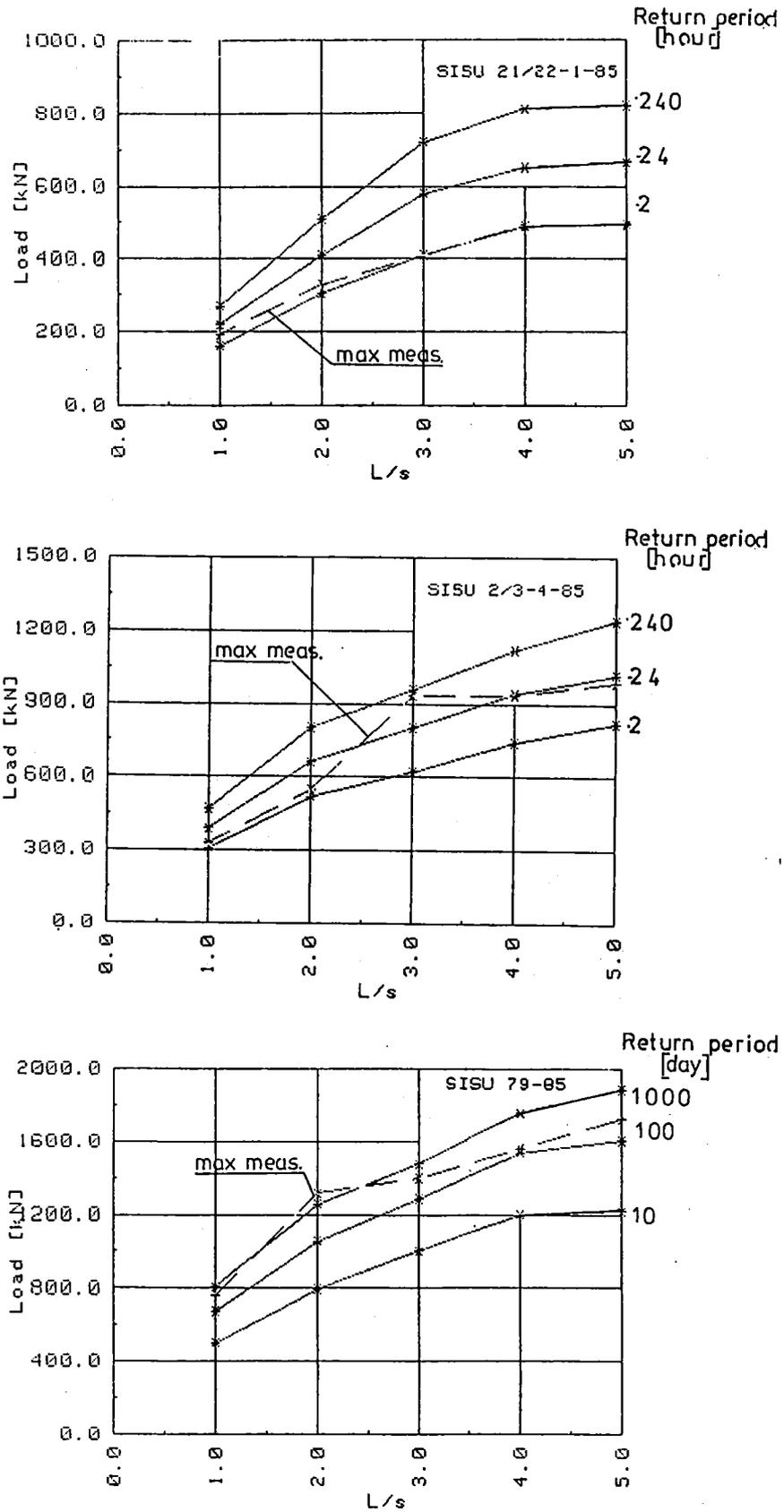


Fig. 22. The measured extrapolated loads based on the short- and long-term results on the frame FFR7 ... FFR10 as a function of load length (s = frame spacing).

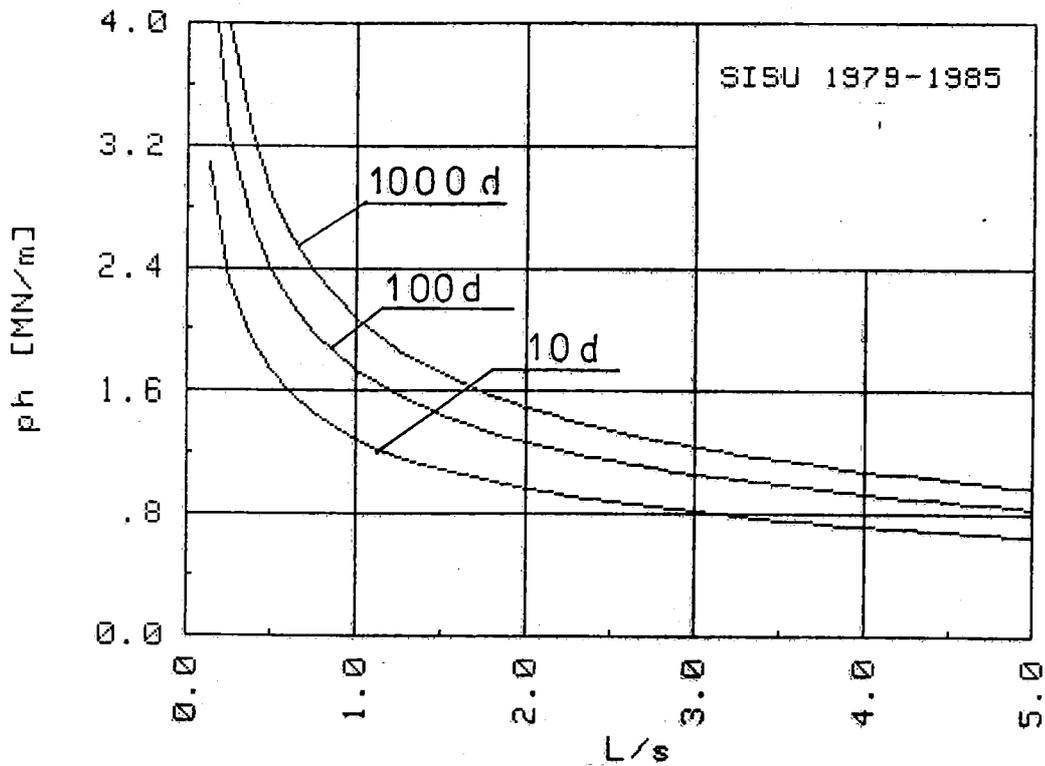


Fig. 23. The line load $p_{av} \cdot h_c$ as a function of load length as based on the long term data with various return periods.

Once the line load $p_{av} \cdot h_c$ is established the design average pressure can be evaluated assuming some value for the contact height. The earlier analysis of the measurements on board I.B. Sisu have indicated that the contact height of 0.30 m is suitable /4/.

6 CONCLUSIONS

The measurements conducted between years 1979 to 1985 include totally 327 days of navigation in ice. The measuring system included five channels during winter 1979 and the number of channels have increased gradually including finally in winter 1985 29 channels. The automatic data gathering system has worked successfully throughout the winters.

Great variations have occurred in the characteristics of winters during the long-term measurements. The mildest winters have been 1980, 1982 and 1983 when the maximum ice thickness near Oulu reached only the value of about 0.60 m. During winter 1985 the ice thickness reached the highest figure having the value of 1.10 m.

The stochastic nature of the ice induced loads is clear. The measured peak amplitudes of the ice induced loads follow the exponential statistical distribution. The parameters of the exponential distribution are related to the existing environmental conditions. The extrapolated results of the short-term measurements in 0.40 - 0.70 m thick level ice with the exponential distribution correspond fairly accurately to the calculated estimates with the Gumbel asymptotic distributions fitted on the measured long-term daily maxima.

The highest measured ice pressures have achieved the value of 11.5 MPa at the frame 94 and 8.3 MPa at the frame 114. The maximum load of 821 kN has occurred on a frame and the total load between webframes has been 1725 kN at its maximum. The average pressure on the shell structures reduces thus as a function of the apparent contact length. The measured time histories indicated that the load height in the typical ice contacts is less than 0.30 metre.

7 ACKNOWLEDGEMENT

The financial support of the Finnish Board of Navigation and Technical Research Centre of Finland has enabled the work carried out for this report. Also without the close and fruitful co-operation with the Finnish Board of Navigation and the crew of I.B. Sisu during the passed winters this study would not have been possible, which is here gratefully acknowledged.

Our special thanks are expressed to Professor Petri Varsta for his inspiring attitude in the difficult stages of this project. He also initiated these measurements and set the main aims for the project while working in VTT Ship Laboratory. The contribution of Mr. Kaj Riska to this project between years 1979 - 1983 is also gratefully acknowledged.

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APPENDIX 1 Typical ice conditions during the measured winters

APPENDIX 2 Results of short-term measurements on 21.-22.01.1985

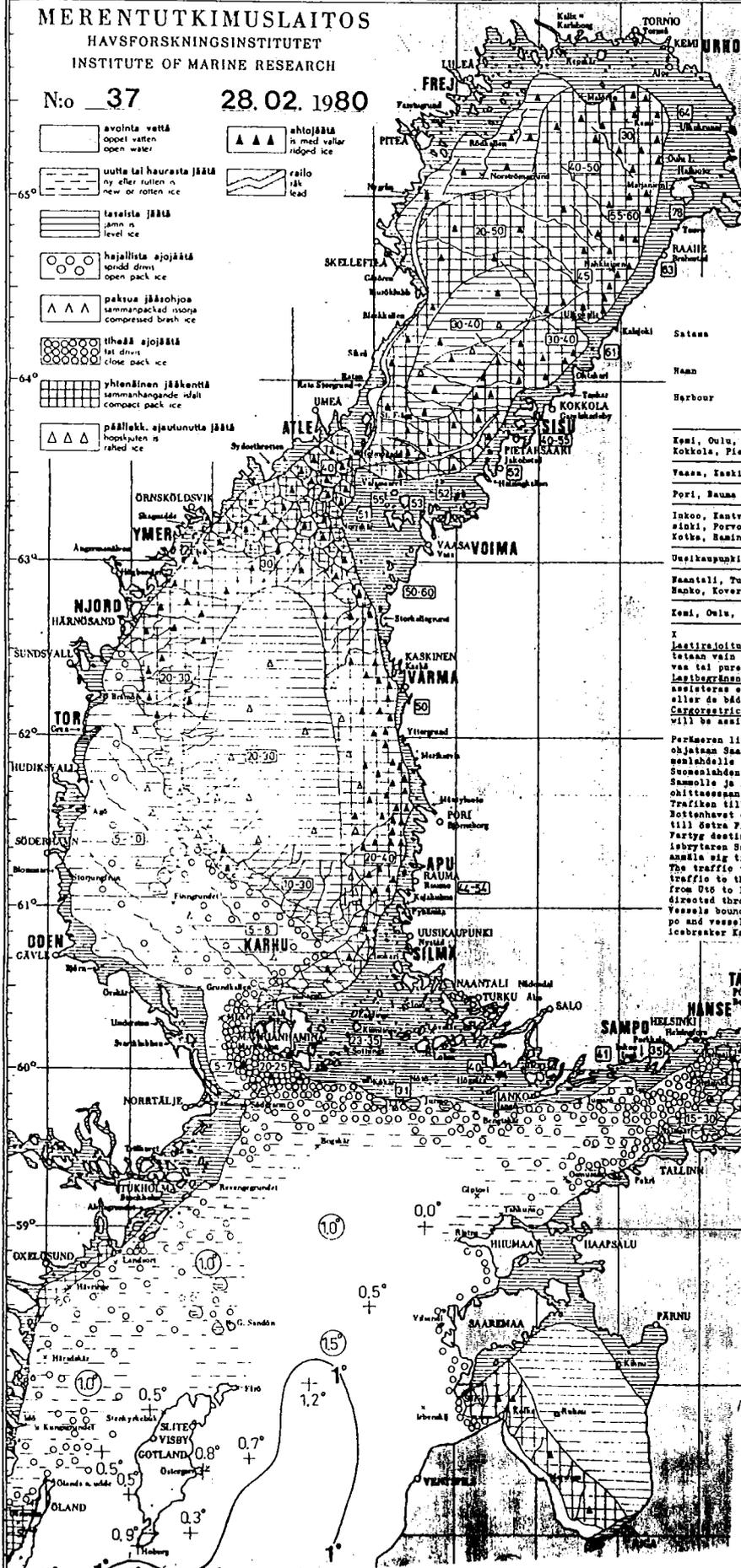
APPENDIX 3 Results of short-term measurements on 02.-03.04.1985

APPENDIX 4 Results of long-term measurements in winters 1979 to 1985

MERENTUTKIMUSLAITOS
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N:o **37** **28.02.1980**

- avointa vettä
open water
- uutta tai haurasta jäää
ny eller ruten is
new or rotten ice
- tasalaista jäää
javn is
level ice
- hajallista ajojäää
spridd drivis
open pack ice
- pakkaa jäästöjää
sammanhängande isora
compressed brash ice
- tihää ajojäää
tätt drivis
close pack ice
- yhtenäinen jääkenttä
sammanhängande isfall
compact pack ice
- päällystettyä ajojäää
hoppsjuten is
ridged ice
- ahojäää
is med vallar
ridged ice
- callo
is led



meriveden pintalämpötilan keskiarvo 1.3.(1967-79)
 ytvattnets medeltemperatur 1.3.(1966-79)
 sea surface mean temperature 1.3.(1966-79)

28.2.1980 klo 08.00

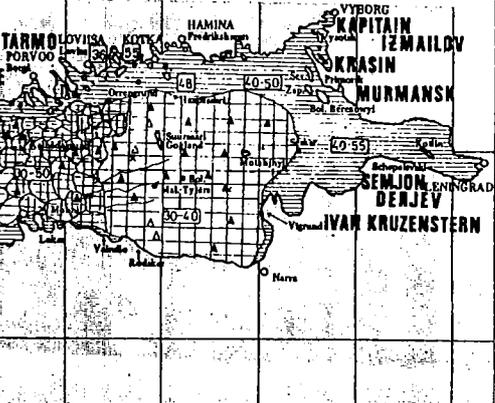
SÄK väderlek	ilman lämpöt.	tuuli
weather	lufttemp.	wind
Kemlin majakka	- 1.2 °C	230 ast. 16 m/s
Ulkokalla	- 0.8 °C	200 ast. 16 m/s
Märket	- 5.2 °C	210 ast. 6 m/s
Kalvädaggrund	- 2.2 °C	-

LIKENNERAJOTUKSET
TRAFIKBEGRÄNSNINGARNA
RESTRICTIONS TO NAVIGATION

Satama	Jääluokka, joka vähintään vaaditaan	Kantavuus/dvt, joka vähintään vaaditaan	Toisaansastot-päivä
Harbour	Ice class, som minst krävs	Dräktighet/dvt, som minst krävs	Datum för kraftträdande
	Finnish-Swedish ice class, demanded at least	Tonnage/dwt, demanded at least	First day of validity
Kemi, Oulu, Raase, Kokkola, Pietarsaari I	IA	5000	16.2.1980
Vaasa, Kaskinen	IA, IB	2000	16.2.1980
Pori, Rauma	IA, IB	2000	24.7.1980
Imko, Santvik, Hel-Simoli, Porvoo, Loviisa, Kotka, Hamina	IA, IB, IC, II	1500 2000	16.2.1980
Uusikaupunki	I, II	1300	10.2.1980
Naantali, Turku, Hangö, Koverhar	I, II	1300	16.2.1980
Kemi, Oulu, Raase I	IA	4000	5.3.1980

Läsnärajotukset: Kemlin, Ouluun, Raaseen, Kokkola ja Pietarsaaren avustetaan vain aluksia, joilla on satamaa kohden vähintään 1500 tonnia lastattavaa tai purettavaa tai molempia yhteensä.
Läsnärajotukset: Till Kemi, Uleåborg, Brahestad, Karleby och Jakobstad lasterats endast fartyg som per haan har minst 1500 ton att lasta eller lossa eller de båda tillsammans.
Cargorestrictions: Only ships with a minimum cargo of 1500 ton per harbour will be assisted to Kemi, Oulu, Raase, Kokkola and Pietarsaari.

Perkäsen liikenne ohjataan Ahvenanmeren kautta. Selkämeren liikenne ohjataan Saaristomeren kautta Utösti Isokariin. Liikenne Itämerelle Suomalaiselle johdetaan Harmaan kautta saaristovylkylle pitkin Suomenlahden satamiin menneiden laivojen tulee ilmoittautua jäänurista ohittessaan 59:n leveyspiiristä.
Trafiken till Botniska viken dirigeras via lands hav. Trafiken till Bottenhavet dirigeras via Skärgråshavet från Utö till Isokär. Trafiken till Östra Finlands viken dirigeras via Gråhara längs skärgrådsfarleden. Fartyg destination till hamnar i Finlands viken skall anmäla sig till Isbyrtaren Sampo och fartyg destination till hamnar i Botniska viken skall anmäla sig till Isbyrtaren Karhu före passage av latitud 59°N. The traffic to the Bothnian Sea will be directed via land Sea. The traffic to the Bothnian Sea will be directed through the Archipelago Sea from Utö to Isokari. The traffic to the eastern Gulf of Finland will be directed through Harmaa along the archipelago fairway. Vessels bound to ports in the Gulf of Finland must inform icebreaker Sampo and vessels bound to ports in the Gulf of Bothnia must inform icebreaker Karhu before passage of the latitude 59°N.

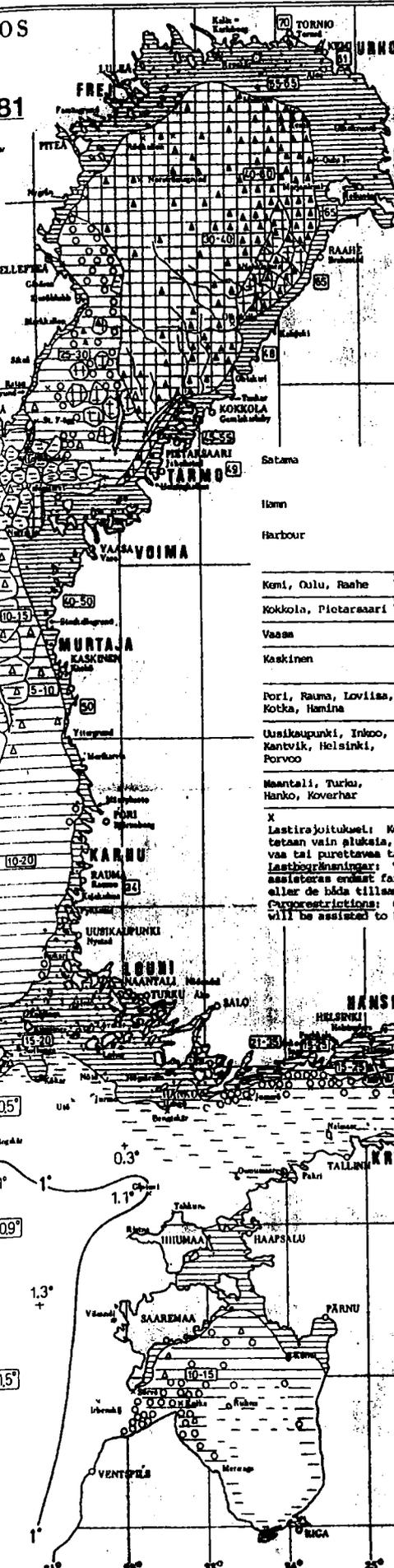


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 PL 166 PB 166
 00141 Helsinki 14 00141 Helsingfors 14

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No **39** **5. 3. 1981**

-  avointa vettä
open water
-  uuttia tai haurasta jäää
ny eller ruten is
new or rotten ice
-  lasista jäää
junn is
level ice
-  hajallaista ajojäää
laxt is
open pack ice
-  paksumu jääshojoe
sammanpackad isora
compressed brash ice
-  tihessä ajojäää
tät drivis
close pack ice
-  yhtenäinen jääkenttä
sammenhängande isfält
compact pack ice
-  säälilläkö ajautunutta jäää
hoggskuten is
ridged ice
-  säälilläkö
is med ställar
ridged ice
-  raitio
räk
lead



SISU

5.3.1981 klo 08.00

ilman lämpötilä lufttemp. air temp.	tuuli vind wind
Ulkokalla -20.0 °C	40 1 m/s
Kemlin majakka -20.6 °C	30 3 m/s
Märket -8.4 °C	35 7 m/s
Kalbidagrund -11.3 °C	355 6 m/s

LIKENNERAJOITUKSET
TRAFIKBEGRÄNSNINGARNA
RESTRICTIONS TO NAVIGATION

Satama Hamn Harbour	Jääluokka, joka vähintään vaaditaan Isklass, som minst krävs Finnish-Swedish ice class, demanded at least	Kantavuus/tv.t., joka vähintään vaaditaan Dräktighet/tv.t., som minst krävs Tonnage/twt., demanded at least	Voimaastumis-päivä Datum för ikraft-trädande First day of validity
Kemi, Oulu, Raahе X	IA	1000	26.2.1981
Kokkola, Pietarsaari X	IA	2000	26.2.1981
Vaasa	IA, IB	2000	19.2.1981
Kaskinen	IA, IB IC, II	1300 2000	19.2.1981
Pori, Rauma, Loviisa, Kotka, Hamina	IA, IB, IC II	1300 2000	3.3.1981
Uusikaupunki, Inko, Kouvola, Helsinki, Porvoo	I, II	1300	3.3.1981
Mantali, Turku, Hangö, Koverhar	I, II	900	3.3.1981

X Lastirajoitukset: Kemiin, Ouluun, Raahen, Kokkolaan ja Pietarsaaren avustetaan vain aluksia, joilla on satamana kohden vähintään 1500 tonnia lastattavaa tai purettavaa tai molempia yhteensä.
 Lastibegränsningar: Till Kemi, Uleåborg, Brahestad, Karleby och Jakobstad assisteras endast fartyg som per hamn har minst 1500 ton att lasta eller lossa eller de båda tillsammans.
 Portrestrictions: Only ships with a minimum cargo of 1500 ton per harbour will be assisted to Kemi, Oulu, Raahе, Kokkola and Pietarsaari.

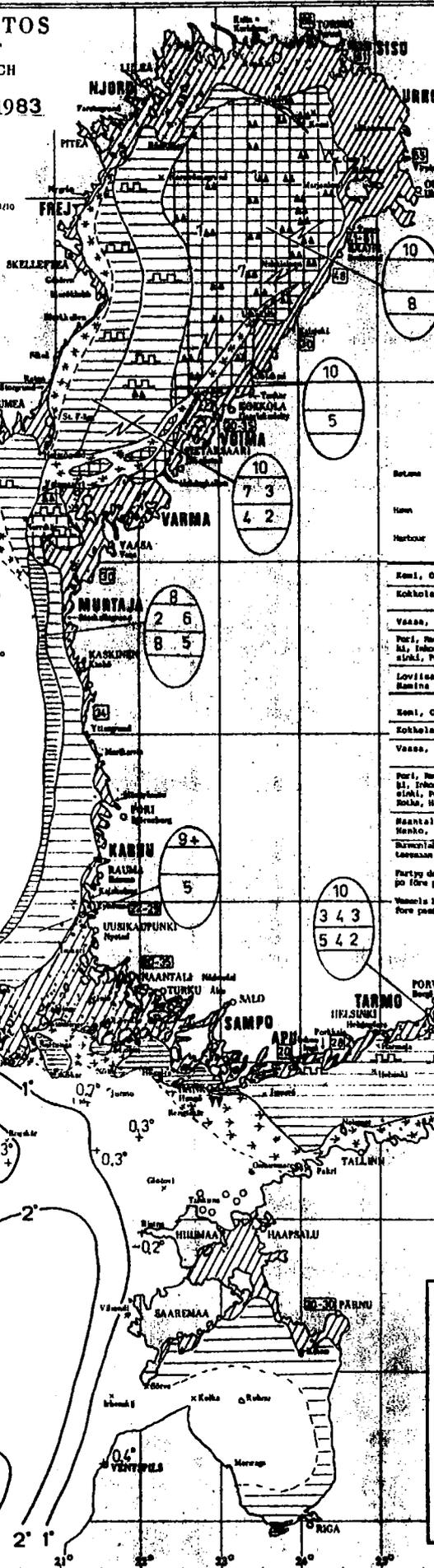
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 PL 166 00141 Helsinki 14 PO 166 00141 Helsingfors 14

Virket 02.150 35.00 15
 Ylästaber 5.3.1981

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No: 38 3. 3. 1983

- Yhteislaatualue, yhteislaatualue tai hyvin lähekköidä
 Consolidated, compact or very close pack ice (B-10/10)
 Sammenhængende, kompakt eller meget tæt driv
- Ahtausalue jäs IC = konsentraatio
 Ridge of hummocked ice IC = concentration
 Valtor och upphöjningar
- Parfärdigt öppet driv
 Refined ice IC = concentration
 Högskytat is
- Tunnare öppet driv
 Close pack ice (7-9/10)
 Tätt driv
- Harva öppet driv
 Open pack ice (4-6/10)
 Spridd driv
- Mycket harva öppet driv
 Very open pack ice (1-3/10)
 Mycket spridd driv
- Jäsdriv
 Ice edge or ice boundary
 Iskanti eller ryggar
- Arvode jäsdriv
 Estimated ice edge or ice boundary
 Uppskattad iskanti eller ryggar
- Vatten lämpöretaste arvode
 Water temperature isotherm, °C
 Vattentemperatur isotermer, °C
- Mätutvärde jäsdriv
 Thickness measured in cm
 Uppskattad tjocklek i cm
- Hårnålar
 Cracks
 Sprickor
- Råls
 Leads
 Rännor



Jäsdrivsklasseringstabell (1/10)

Totals	Symbol	mm	Symbol	P
C	C	0	0	11
C	C	1	1	12
C	C	2	2	13
C	C	3	3	14-15
C	C	4	4	16-2000
C	C	5	5	2000-10000
C	C	6	6	10000
C	C	7	7	10000
C	C	8	8	10000
C	C	9	9	10000
C	C	10	10	10000

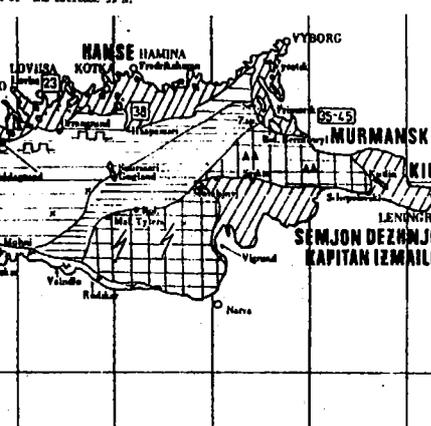
LIKKENNERAJOTUKSET
 TRAFIKBEGRÄNSNINGARNA
 RESTRICTIONS TO NAVIGATION

Belägen	Jämförbara, jäsdrivsklassering	Rastavstånd/Öppet drivskiljning	Valdagsbestämning
Namn	Isklass, som minst krävs	Driftlighet, som minst krävs	Datum för utfärdande
Harbör	Finska/Svenska isklass, bestämd åt least	Varning/Öppet drivskiljning	First day of validity
Kemi, Oulu, Raase	I A	2000	5.2.1983
Kokkola, Pietarsaari	I A, I B I C, II	1200 2000	5.2.1983
Vasa, Raskinon	I, II	1200	5.2.1983
Pori, Rauma, Uusikaupunki, Iisko, Kouvola, Helsingfors, Porvoo	I, II	900	10.2.1983
Lovisa, Kotka, Hamina	I, II	900	11.2.1983
Kemi, Oulu, Raase	I A	2000	8.3.1983
Kokkola, Pietarsaari	I	2000	8.3.1983
Vasa, Raskinon	I A, I B I C, II	1200 2000	8.3.1983
Pori, Rauma, Uusikaupunki, Iisko, Kouvola, Lovisa, Kotka, Hamina	I, II	1200	8.3.1983
Ånankallio, Turku, Hangö, Koverhar	I, II	900	8.3.1983

Sammanfattning av de viktigaste förhållandena i de olika delarna av havet. Förstaprioritet ges åt de delar som är mest utsatta för is. Förstaprioritet ges också åt de delar som är mest utsatta för is. Förstaprioritet ges också åt de delar som är mest utsatta för is.

Partij destinationer till hamnarna i Finska Viken skall anmäla sig till isstyrarna Sjö- och isstyrelsen senast 5 dagar före passage av latitud 59 grader N.

Vessels bound for ports in the Gulf of Finland must inform the icebreaker Sampo before passage of the latitude 59 N.



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 PB 100

0150 ESQD 15

Välkommen!
 Tjänstgöring 3.3.1983

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INSTITUTE OF MARINE RESEARCH

No. 37 27. 2. 1984

Legend:

- Ice concentration symbols (0-100%)
- Ice types (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z)
- Navigation symbols (depth, soundings, etc.)
- Other symbols (ports, etc.)

Ice concentration symbols:

0	1	2	3	4	5	6	7	8	9	10
0	1	2	3	4	5	6	7	8	9	10

Ice types:

Ca	Cb	Cc	Cd	Ca	Cb	Cc	Cd
Sa	Sb	Sc	Sd	Sa	Sb	Sc	Sd
Fa	Fb	Fc	Fd	Fa	Fb	Fc	Fd

meriveden pintalämpötilan keskiarvo 27.2. (1966-82)
ytvattimen medeltemperatur 27.2. (1966-82)
sea surface meantemperature 27.2. (1966-82)

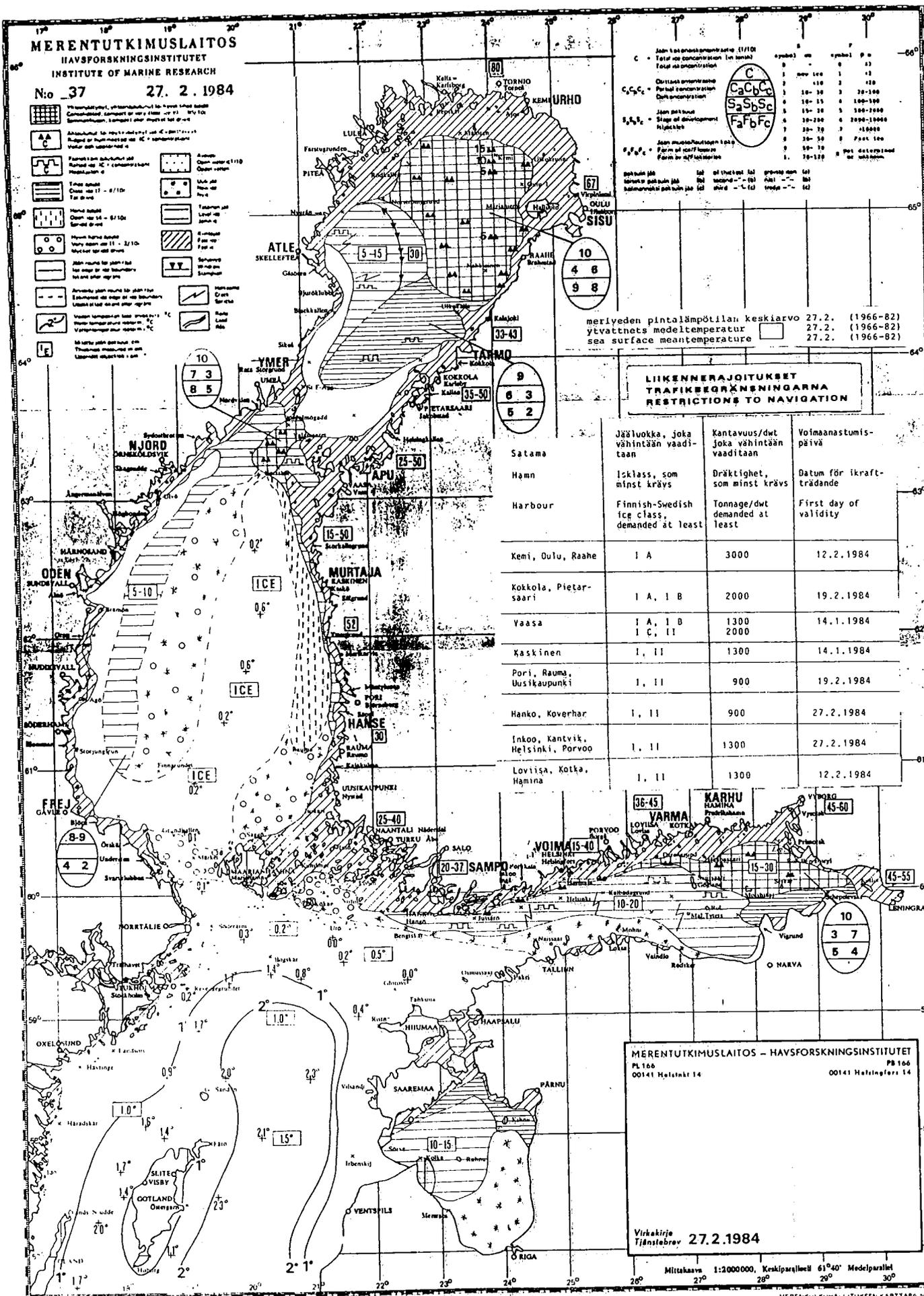
LIIKENNERAJOTUKSET
TRAFIKBEGRENINGARNA
RESTRICTIONS TO NAVIGATION

Satama	Jääluokka, joka vähintään vaaditaan	Kantavuus/dwt joka vähintään vaaditaan	Voimaastumis-päivä
Hamn	Isklass, som minst krävs	Dräktighet, som minst krävs	Datum för ikraft-trädande
Harbour	Finnish-Swedish ice class, demanded at least	Tonnage/dwt demanded at least	First day of validity
Kemi, Oulu, Raahе	I A	3000	12.2.1984
Kokkola, Pietar-saari	I A, I B	2000	19.2.1984
Vaasa	I A, I B I C, II	1300 2000	14.1.1984
Kaskinen	I, II	1300	14.1.1984
Pori, Rauma, Uusikaupunki	I, II	900	19.2.1984
Hanko, Koverhar	I, II	900	27.2.1984
Inkoo, Kantvik, Helsinki, Porvoo	I, II	1300	27.2.1984
Loviisa, Kotka, Hämeenlinna	I, II	1300	12.2.1984

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Virkakirje
Tjänstebrev 27.2.1984

Mittakaava 1:2000000, Keskiparalleli 61°0' Medelparalleli 27°
28° 29° 30°



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HAVSFORSKNINGSINSTITUTET
INSTITUTE OF MARINE RESEARCH

No **36** 25.2.1985

**LIIKENNERAJOITUKSET
TRAFIKBEGRÄNSNINGARNA
RESTRICTIONS TO NAVIGATION**

Satama	Jääluokka, joka vähintään vaaditaan	rentous, jota vähintään vaaditaan	Voimastumispäivä
Harbour	Ice class, which at least is required	Ice strength, which at least is required	First day of validity
Kaoli, Oulu, Raase	IA	4000	15.2.1985
Kokkola, Pietarsaari	IA	4000	15.2.1985
Vaasa, Kastina, Pori, Rovaniemi	IA	2000	25.2.1985
Uusikaupunki, Hangö, Kouvola, Jämsä, Kouvola, Helsinki, Porvoo, Kotka, Rauma, Hangö, Mariehamn	IA, IB	2800	15.2.1985
Marshalli, Jorlu	IA, IB IC, II	1302 2800	15.2.1985

* Laitteen kokoon vähintään 2000 tonnia lastattavana tai purkattavana tai molempia yhteensä, kun miina 2000 tonni lasta eller lossa eller de båda tillsammans.
 * Minimum cargo at least 2000 ton per harbour.
 Laitteen Pontonimitteli ohjataan saaristovyöhykkeen ulkopuolelle ja Isokarmin kautta.
 Laitteen lastaus- ja purkustelu Suomenlahden ohjataan Porin kautta saaristovyöhykkeen ulkopuolelle.
 Suomen tulotien laivojen tulot siirretään Järvenpään Varmalle ohitustien 50:n läheisyyteen.
 Trafikin läpi Suomeen väkän dirigeras langs skärgöresfarleden via Utö och Isokari.
 Trafiken till Isokari och östra Finland väkän dirigeras via Porkele langs skärgöresfarleden.
 Farliga laster måste till hamnar i Finland skall anmäla sig till Isokari via Varna. Före passage av Isokari ska grader 5.
 The traffic to the middle and eastern Gulf of Finland will be directed along the archipelago fairway via Utö and Isokari.
 The traffic to the middle and eastern Gulf of Finland will be directed via Porkele along the archipelago fairway.
 Vessels bound for Finnish ports must inform the icebreaker Varna before passage of the latitude 59 N.

Ään lämpötila-merkintä (1/10)
 Total ice concentration (10 tenths)
 Total ice concentration

C, C.C.C. = Osittain ohenteista Partial concentration
 Ohenteista Ohenteista
 S, S.S.S. = Ään laatu/paksuus Stage of development
 Ohitehket Ohitehket
 F, F.F.F. = Ään muoto/fortiojen laatu Form of ice/Forms
 Form of ice/Forms

Symbol 0-9
 0 0-10
 1 10-20
 2 20-30
 3 30-40
 4 40-50
 5 50-60
 6 60-70
 7 70-80
 8 80-90
 9 90-100

Not determined or unknown

