235 | 1964

SCHRIFTENREIHE SCHIFFBAU

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Statistical Analysis of Casualties to Ship Hull

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TABLE OF CONTENTS

STATISTICAL ANALYSIS OF CASUALTIES TO SHIP HULL

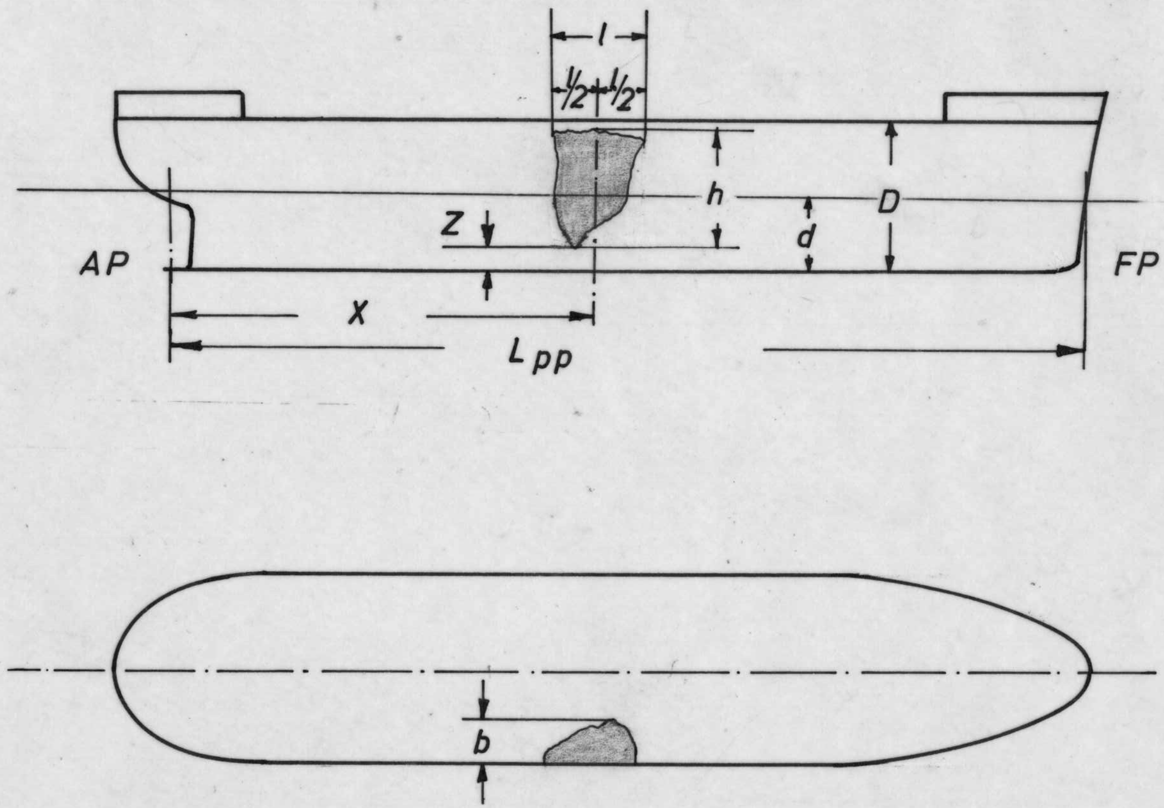
Introduction

Based on SDS 2, SDS 5 and SDS 14, containing damage data reported by Canada, Federal Republic of Germany, France, Ghana, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, Turkey, UdSSR, United Kingdom, USA, the SDS Working Group of the Fed. Rep. of Germany has prepared a statistical investigation of damage data. Because SDS 16 has not been available in time, the few data contained in this paper have not been considered.

The general result of the investigation is, that the number of casualties is far too small in order to give a comprehensive survey about the damage of ships. Nevertheless some useful statements are possible. From a realistic point of view it seems better to investigate now, how the hitherto results can be used than to continue ad infinitum with the attempt, to obtain definite and comprehensive results. This does not mean, that the collection of damage data is to be stopped. From time to time a reanalysis of the damage data will be of use. But it is useless, to struggle for the statement of a great number of relationships, which are not significant because of the statistical scatter.

In the following, the same methods as in SDS III/9 App.1 "Statistical Analysis of Casualties to Ship Hull" are used. The used nomenclature regarding the damages is shown on the attached Fig. A.

Dimensions and Location of Damage



Lpp	Length between perpendiculars	l	Length of damage
D	Depth	b	Penetration of damage
d	Effective draught	h	Height of damage
X	Distance from AP to centre of damage	Z	Distance from base line to the lower point of damage

Fig. A

In connection with the statistical investigations of damage extension some nations have made known the number of decks for several struck ships,being set up in the damage cards.But unfortunately only a small number of data was to use to evaluations in such detailed investigations being neccessary to obtain practicable results.

Calculations are based on the papers SDS 19,22,23,24 and 25,containing datas according to SDS 2, 5, and 14.

Refering to the investigations of collisions only the data of struck ships have been used for calculations.

1. Damage Length

1.1. Distribution law of damage length; collisions only

Log-normal distributions fit very well the empirical distributions of the damage lengths plus a constant. This is shown in Fig. 1.1.01 and 02 for the whole range of ship length, in Fig. 1.1.03 and 04 for ships with L_{pp} less than 100 m and in Fig. 1.1.05 and 06 for ships with L_{pp} more than 100 m.

Some statistical characteristics, calculated from the damage data, are given in Table I.

Table I and the Fig. 1.1.03 to 1.1.06 indicate a strong dependence of the damage lengths on the ship length.

1.2. Mean, median and deciles of damage lengths in dependence on the ship length; collisions only.

In Fig. 1.2.01 and 02 the small circles corresponds to the means, medians and upper and lower deciles of the damage lengths of ships with L_{pp} less resp. more than 100 m. They are placed above the mean length of all ships with L_{pp} less than 100 m resp. above the mean lengths of ships with L_{pp} more than 100 m.

Through the circles run fat straigth lines. The lines fit quite well polygons, which connect the means, medians resp. deciles of the damage length, corresponding to ten ranges of ship lengths. The ranges are indicated in Fig. 1.2.01 by a,b...k. The distribution functions corresponding to the ranges are given in Fig. 1.2.12 to 20 and the statistical characteristics in Table II.

It is important to observe, that the increase of the upper decile with the shiplength is greater than the increase of the median, the mean or the lower decile.

For the straight lines in Fig. 1.2.01 and 02, approximating the increase of mean, median and deciles with the ship length, the following formulas are valid:

$$\text{Mean} = 0{,}0662\ L_{pp}\ \text{m} + 0{,}70\ \text{m}$$

$$\text{Median} = 0{,}0643\ L_{pp}\ \text{m} - 1{,}12\ \text{m}$$

$$\text{Upper decile} = 0{,}1164\ L_{pp}\ \text{m} + 3{,}98\ \text{m}$$

$$\text{Lower decile} = 0{,}0238\ L_{pp}\ \text{m} - 1{,}25\ \text{m}.$$

It is clear that the formulas are only applicable to the considered range of ship lengths. In Fig. 1.2.03 a comparison of mean and median with the 1960 Convention formula $l = 0{,}03\ L_{pp} + 10'$ is given.

In fig . 1.2.04 the partners of collision are plotted, on the abscissa the struck ships,on the ordinate the ramming ships.The straight line runs through two circels which mark the means of ship lengths less and more than 100 m , both the ramming and the stuck ships. The mean of all striking and struck ships is marked too.

One can see the larger ships are striking the larger too. This may be the reason that the larger extensions of damage occure to the larger vessels.

1.3 Influence of place of casualty on the distribution of damage length; collisions only

The distribution functions of the damage length for different places of casualty is shown in fig. 1.3.01 to 12. In order to exclude in a certain degree the influence of the ship length, the sample has been splitted: The figures show the distribution of damage lengths of ships with $L_{pp} < 100$ separated from that of ships with $L_{pp} > 100$ m. Some characteristic values of the distributions are given in table IV and IV.

So far as the small sample allow a statement at all, it can be observed, that the log normal distribution fits the distribution of damage length's obtained for different places of casualties.

In order to examine, if the difference between the distribution function for different places of casualty are caused by the random scatter of the data or if there are real differences, significance tests according to Smirnow have been made.

Δ_{max} is the maximum difference between two distribution functions, which with probability α is not exceeded, if the difference between these two distribution functions is caused by the random scatter of the data.

If the difference between two distribution functions is greater than Δ_{max}, there is - if α is a small value - only a small probability, that the difference is random and that the distributions really would be the same. In this case it can be stated with a high degree of certainty, that the distributions are different.

If the maximum difference between two distributions are smaller than Δ_{max}, this does not mean, that the difference is only random and that in realty both are the same distributions. It only means, that it can not be excluded with a high degree of probability, that they are different.

The following table shows, that in this case the number of data is to small to state, that the distribution functions for different places of casualty are different.

Table

Dependence of damage length on place of casualty

L_{pp} less than 100 m

Comparison between the distribution functions of	greatest difference between the distribution function	significance limit Δ_{max} for α=5%
harbours and coast areas	2%	24,0%
harbours and open sea	28,5%	30,7%
coast areas and open sea	29,5%	32,8%

Dependence of damage length on place of casualty

L_{pp} more than 100 m.

comparison between the distribution functions of	greatest difference between the distribution function Δ_{max}	significance limit for α =5%
harbours and coast areas	10,9%	18,5%
harbours and open sea	7,0%	28,5%
coast areas and open sae	8,8%	28,2%

In this connection it is of interest to observe the distribution of casualties upon the places on which they have occured. With all the reported data the following percentages have been established:

	collisions	groundings and strandings
harbours etc.	40,9%	56,9%
coast areas	40,4%	32,8%
open sea	18,7%	10,3%

1.4. Distribution law of damage length, groundings and strandings only.

In this case also log-normal distributions fit the empirical distributions of the damage length (fig.1.401-06)

From the figures and from Table V it is to be seen that there is a strong dependence of the damage length on the ship length.

A comparison with the results of 1.1 (especially Table I) shows, that the damage length due to groundings and strandings more frequently reaches the greater values than those due to collisions.

2. Penetration of damage

The distribution function of the penetration of damage is given in Fig. 2.0.01 and 2.0.02 resp. Fig. 2.0.03 and 2.0.04 for ships with L_{pp} less resp. more than 100 m. The figures show, that shifted log-normal distributions fit very well the empirical distributions.

Some statistical characteristics, calculated from the damage data are given in Table VI.

The figures and Table VI indicate a strong dependence of the penetration of damage on the ship length.
In fig. 2.0.05 comparison is given between median and resp. mean of damage penetration in dependence of beam and penetration of Convention Formula $b = 0.2\ B$ (see Regular 7 d ii).

3. Location of damage

3.1. Distance of damages from the aft perpendicular

Histograms resp. distribution functions of the distance of damage from the aft perpendicular are given in

Fig. 3.1.01 resp. 3.1.02 for all ship lengths; collisions

Fige.3.1.03 resp. 3.1.04 for all ship lengths; groundings and strandings

Fig. 3.1.05 resp. 3.1.06 for ships with $L_{pp} < 100$ m; collisions

Fig. 3.1.07 resp. 3.1.08 for ships with $L_{pp} > 100$ m; collisions.

It is difficult to observe any regularity in the histograms and the distribution functions. The only fact to gather from the figures and from medians and deciles is, that the frequency of damages of the forward part of the ships is higher than that of the aft part and that relative high frequency occur about the midship section.

3.2. Distance of damages above keel

An estimation of the frequency of different vertical positions of damages is given in fig. 3.2.01. This histogram shows, that about 30% of all damages extend nearly to the bottom of the ship. Below the half draught extend about 60% of the damages and ca. 15% of the damages have their lowest point above the line of flotation.

4. Relation between damage length and location of damage

In order to investigate the relation between damage length and location we consider first the hypothesis, that they are independent. In this case the median of the damage length must be nearly constant over a relative broad interval AB of the shiplength (cf. fig. 4.0.01 and 4.0.02). This holds not only for particular shiplengths but also for a range of shiplengths (clearly in this case only for the smallest interval AB of the involved shiplengths).

The figures 4.0.01 and 02 show a range AB of 64% L_{pp} for ships with L_{pp} of about 50 m and AB = 72,6% L_{pp} for ships with L_{pp} of about 150 m.

In fig. 4.0.03 the medians of the damage length (collisions only) are plottet against the distance of centre of damage from A.P. for all shiplengths. The median is established with the damage data. Because of the small number of data for each intervall, we can not expect, that this median has the same value as the median, which could be determined from a for greater number of data. The shaded strips about the median in fig. 4.0.03 cover with probability of 90% resp. 95% the "real" median (that is the median, which we would determine, if we would have a very great number of datas).

From the fig. 4.0.03 follows, that the hypothesis that the medians in the intervals in the range AB are equal, can not be rejected. But this does not mean, that they are equal. This [illegible] The number of data is to small be rejected. But this does not mean, that they are equal. This means with other words: The number of data is to small in order to make other statements than that: It is not impossible, the medians are equal.

The same conclusion can be drawn from fig. 4.0.04 for the case of damages, occuring at groundings and strandings.

5. Wind and sea conditions at time of casualty

The quite limited data makes it impossible to determin the exact relationship between wind and sea conditions and the occurence of casualties resp. the extension of damages. In order to get approximative results at least for the first case (weather and occurence of damage) two ways seem practicable:

1. The conditional probability resp. distribution of wind and waves occuring at the same time as casualties is determined. In this way we would get the desiered distribution, but this distribution would be very inaccurate because of the statistical scatter of the data.

2. The abolute distribution of wind and waves without regard to casualties is acceptet although these distributions give only an approximative probability of wind and waves occuring at casualties. For this case exact distributions are well known from the reports of weatherships etc; these also show the dependence of wind and waves on different locations.

D e p e n d e n c e   o f   d a m a g e   e x t e n d   o n   n u m b e r   o f   d e c k s

At the third session the working group agreed to supplement the particulars previously submitted with informations as to the number of decks involved in damage.
Unfortunately the number of applicable data to calculations was very small and so no fairly secured results have been obtained available in time to the members of the last session of the SDS-Working Group .
After having obtained some more data the investigations have been repeated , but the results of the new calculations established by the greater number of data do not differ significantly to the previously obtained values.
Considering the number of decks in the range of damage of struck ships , investigations have been made to ascertain a dependence of the damage extend on the number of decks.
As it is known already that there is a strong dependence of damage lengths on lengths of ships some groups have been established arranged to the type of ship and to the length Lpp.
The following system led to samples.

Dry Cargo Vessels and Passenger Ships

Lpp less than 100 m	Lpp more than 100 m
1 deck	1 deck
2 decks or more	2 decks
	3 decks or more

Tanker

Lpp less than 100 m	Lpp more than 100 m
1 deck	1 deck
2 decks or more	2 decks or more

It was supposed all decks which had been informed for in the report had been involved in the impact in the range of the damage extend although this was not evident in all submitted informations.
The number of data was reduced by the fact taat in many cases the number of decks was known when the extend of damage was unknown and vice versa .So a part of the informations was without use to these calculations. This lack was not to remove although a certain number of nations had submitted the number of decks for various ships,gathered in the damage cards. In the following part a description of the way of calculation is given.
The means of the damage lengths of each established sample are shown in Fig. 6001 (and Fig. 6001a with an increased number of data). The circles mark the means of damage lengths in dependence on the means of the Lpp-lengths of the samples. Additionally the straight line of Fig. 2.1.01 of the " Statistical Analysis of Casualties to Ship Hull " SDS IV / 6 is shown too .
Suppose parallel lines drawn through each of the circles to the given straight line of means of damage lengths. If there would be a remakable influence to the extend of damage in dependence on the number of decks in this range the calculated means for every established sample would differ in an obvious manner.The means of ships with a greater number of decks would be found below the straight line of fig. 2.1.01 .
One can see , this assumption being not confirmed, the bigger vessels have the greater number of decks but the larger extends of damage too. Also a study with a greater number of data led to nearly the same result. (C.f. Fig. 6001a).
With respect to cargo-vessels submitted data allowed some detailed calculations. Special comparisons have been established for four samples. (c.f. Fig. 6002 - 6013).
Calculating the distribution functions of damage lengths in dependence on the number of decks for certain ranges of Lpp, no significant differences are pointed out,comparing the distribution functions by Smirnoff Test. The same result was found by

comparing the frequency of a certain product of damage lr length and penetration of damage.

The result of these calculations is :

No influence to extends of damages can be stated with respect to a greater number of decks in the range of location of damage, but nevertheless it cannot be stated that there will not be perhaps such an influence. Submitted data are too scarce to establish more detailed calculations with a minimum of statistical truth.

Table I

1.1 Characteristics of Distribution Functions of the Damage Length;Collisions only.(c.f.Fig. 1.1.01 - 1.1.06).

range of Lpp	all	$<$100 m	$>$100 m
location of casualty	all	all	all
number of ships	312	125	187
90%confidence limits	6.9%	10.9%	8.9 %
mean	7.88 m	4.83 m	9.97 m
standard deviation	8.08 m	5.39 m	9.01 m
constant a	5.0 m	1.0 m	3.0 m
median	6.00 m	2.90 m	7.90 m
upper decile	19.2 m	11.3 m	20.7 m
lower decile	0.0 m	0.20 m	2.10 m

Table II a

1.2. Characteristics of Distribution Function - Dependence of Damage Length on Length of Ships; Collisions only.
(c.f. Fig. 1.2.01 -1,2.03 and 1.2.11 -1.2.20).

range of Lpp	25 -40 m	40 -60 m	60 -80 m
range c.f. fig.1.2.01	a	b	c
location of casualty	all	all	all
number of ships	25	26	23
90% confidence limits	23.7%	23.3%	24.6 %
mean	1.90 m	4.10 m	6.20 m
standard deviation	2.35 m	3.19 m	5.97 m
constant a	1.0 m	1.0 m	1.0 m
median	1.10 m	3.10 m	5.00 m
upper decile	4.90 m	8.57 m	12.0 m
lower decile	0.0 m	0.77 m	1.77 m

Table II b

1.2. Characteristics of Distribution Function - Dependence of Damage Length on Length of Ships; Collisions only.
(c.f. Fig. 1.2.01 - 1.2.03 and 1.2.11 - 1.2.20).

range of Lpp	80 - 100 m	100 - 120 m	120 - 130 m
range c.f. Fig. 1.2.01	d	e	f
location of casualty	all	all	all
number of ships	19	22	38
90% confidence limits	27.2 %	25.2%	19.5%
mean	5.40 m	9.15 m	9.80 m
standard deviation	5.44 m	8.98 m	6.06 m
constant a	1.0 m	3.0 m	3.0 m
median	3.40 m	6.00 m	8.50 m
upper decile	12.35 m	21.32 m	17.85 m
lower decile	0.46 m	0.30 m	3.35 m

Table II c

1.2. Characteristics of Distribution Function - Dependence of Damage Length on Length of Ships; Collisions only.
(c.f.Fig. 1.2.01 -1.2.03 and 1.2.11 - 1.2.20).

range of Lpp	130 m - 140 m	140 m - 150 m
range c.f. Fig. 1.2.01	g	h
location of casualty	all	all
number of ships	41	23
90% confidence limits	18.8 %	24.7%
mean	10.40 m	7.60 m
standard deviation	7.78.m	6.00 m
constant a	3.00 m	3.00 m
median	9.00 m	6.10 m
upper decile	18.88 m	15.45 m
lower decile	3.58 m	1.49 m

Table II d

1.2. Characteristics of Distribution Function - Dependence of Damage Length on Length of Ships; Collisions only.
(c.f. Fig. 1.2.01 - 1.2.03 and 1.2.11 - 1.2.20).

range of Lpp	150 - 170 m	170 m
range C.f. Fig. 1.2.01	i	k
location of casualty	all	all
number of ships	29	17
90 % confidence limits	22.0 %	28.6 %
mean	10.40 m	12.30 m
standard deviation	6.51 m	10.11 m
constant a	3.00 m	3.00 m
median	9.10 m	7.00 m
upper decile	18.58 m	30.89 m
lower decile	3.79 m	0.0 m

Table III

1.3.Characteristics of Distribution Function - Length of Damage in Dependence on Place of Casualty ; Collisions only.
(c.f. Fig. 1.3.01 - 1.3.12).

range of L_{pp}	<100 m	<100 m	<100 m
location of casualty	harbours	coast areas	open sea
number of ships	65	39	19
90 % confidence limits	14.8 %	19.2 %	27.2 %
mean	5.21 m	5.10 m	3.02 m
standard deviation	5.71 m	5.51 m	3.90 m
constant a	1.00 m	1.00 m	0.0 m
median	3.00 m	3.00 m	1.10 m
upper decile	12.27 m	11.78 m	6.74 m
lower decile	0.21 m	0.23 m	0.20 m

Table IV

1.3.Characteristics of Distribution Function - Length of Damage in Dependence on Place of Casualty ; Collisions only.
(c.f.Fig. 1.3.01 - 1.3.12).

range of Lpp	>100 m	>100 m	>100 m
location of casualty	habours	coast areas	open sea
number of ships	80	88	22
90% confidence limits	13,7%	12.8%	25,2%
mean	8.88 m	11.07 m	9.85 m
standard deviation	7.93 m	9.98 m	7.97 m
constant a	2.00 m	2.00 m	0.0 m
median	6.70 m	8.50 m	11.00 m
upper decile	19.40 m	22.50 m	20 28 m
lower decile	1.55 m	2.51 m	2.42 m

Table V

1.4. Characteristics of Distribution Function of Damage Length Strandings and Groundings only . (c.f. Fig. 1.4.01 - 1.4.06)

range of Lpp	all	<100 m	>100 m
location of casualty	all	all	all
number of ships	77	25	52
90 % confidence limits	13,6 %	23,7 %	16.6 %
mean	18.50 m	7.47 m	23.80 m
standard deviation	25.40 m	11.50 m	28.60 m
constant a	1.0 m	1.0 m	0.0 m
median	6.00 m	3.00 m	7.60 m
upper decile	42.70 m	18.10 m	52.50 m
lower decile	0.10 m	0.00 m	1.10 m

Table VI

2.1. Characteristics of Distribution Function - Penetration of Damage in Dependence on Lpp ; Collisions only.
(c.f. Fig. 2.0.01 - 2.0.04).

range of Lpp	<100 m	>100 m
location of casualty	all	all
number of ships	104	141
90 % confidence limits	11.95 %	10.30 %
mean	2.23 m	4.61 m
standard deviation	2.20 m	3.87 m
constant a	0.75 m	10.00 m
median	1.60 m	4.30 m
upper decile	4.90 m	8.45 m
lower decile	0.23 m	0.98 m

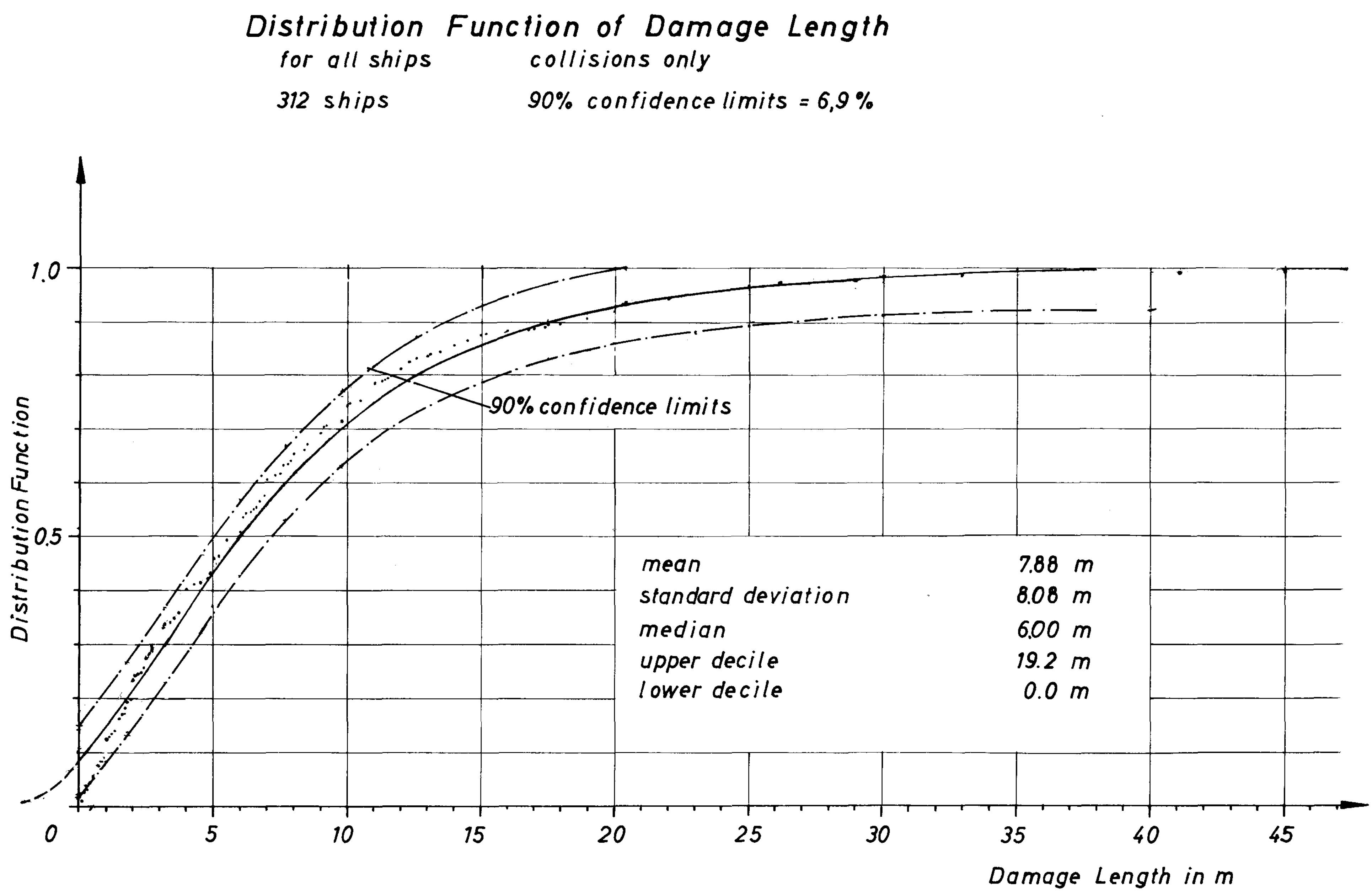
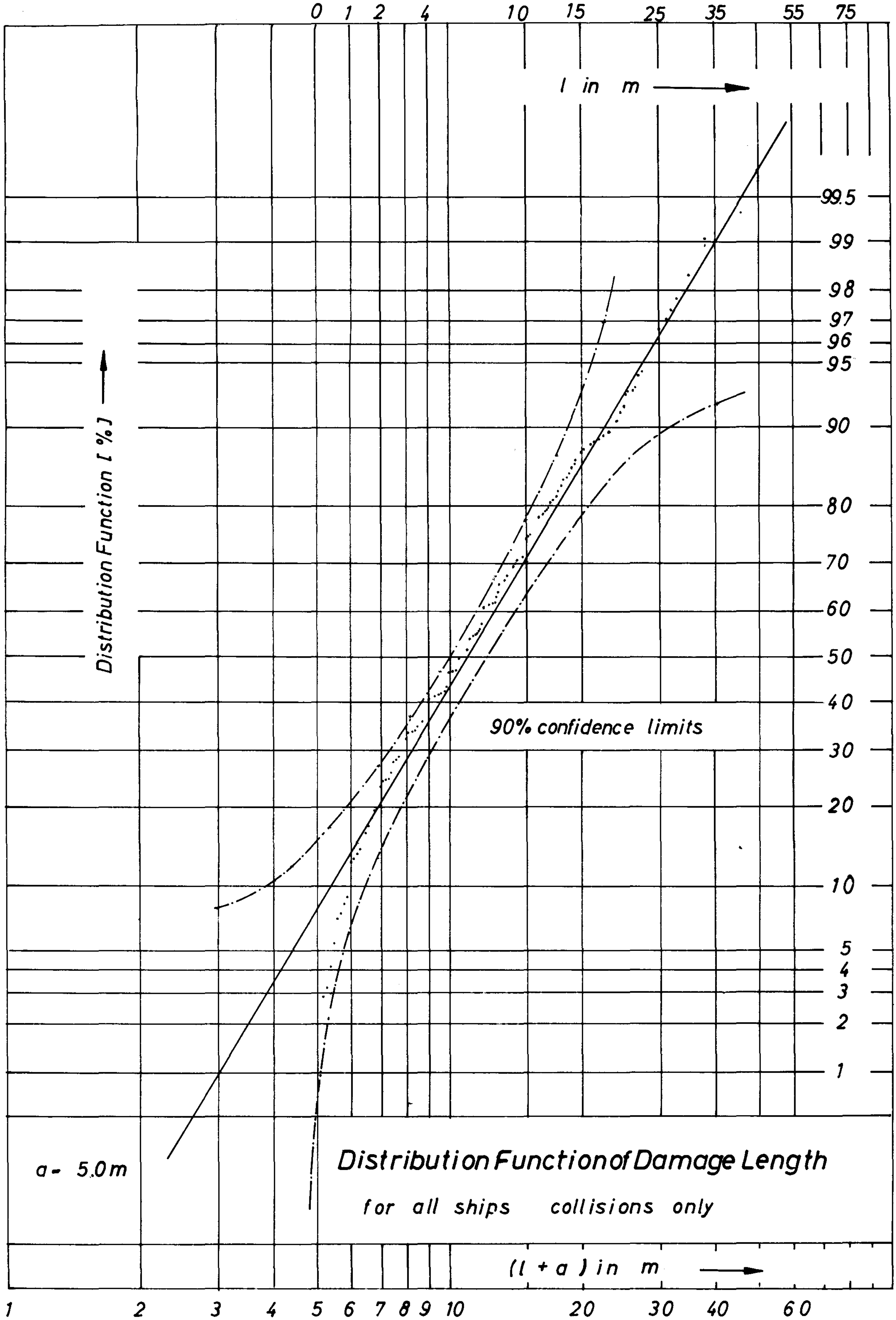

Distribution Function of Damage Length
for all ships
collisions only
312 ships
90% confidence limits = 6,9 %
1.0
0.5
Distribution Function
0
5
10
15
20
25
30
35
40
45
Damage Length in m
90% confidence limits
mean 7.88 m
standard deviation 8.08 m
median 6.00 m
upper decile 19.2 m
lower decile 0.0 m

Fig. 1.1. 01



0 1 2 4 10 15 25 35 55 75
l in m
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
Distribution Function [%]
90% confidence limits
a = 5.0m
Distribution Function of Damage Length
for all ships collisions only
(l + a) in m
1 2 3 4 5 6 7 8 9 10 20 30 40 60

Fig. 1.1.02

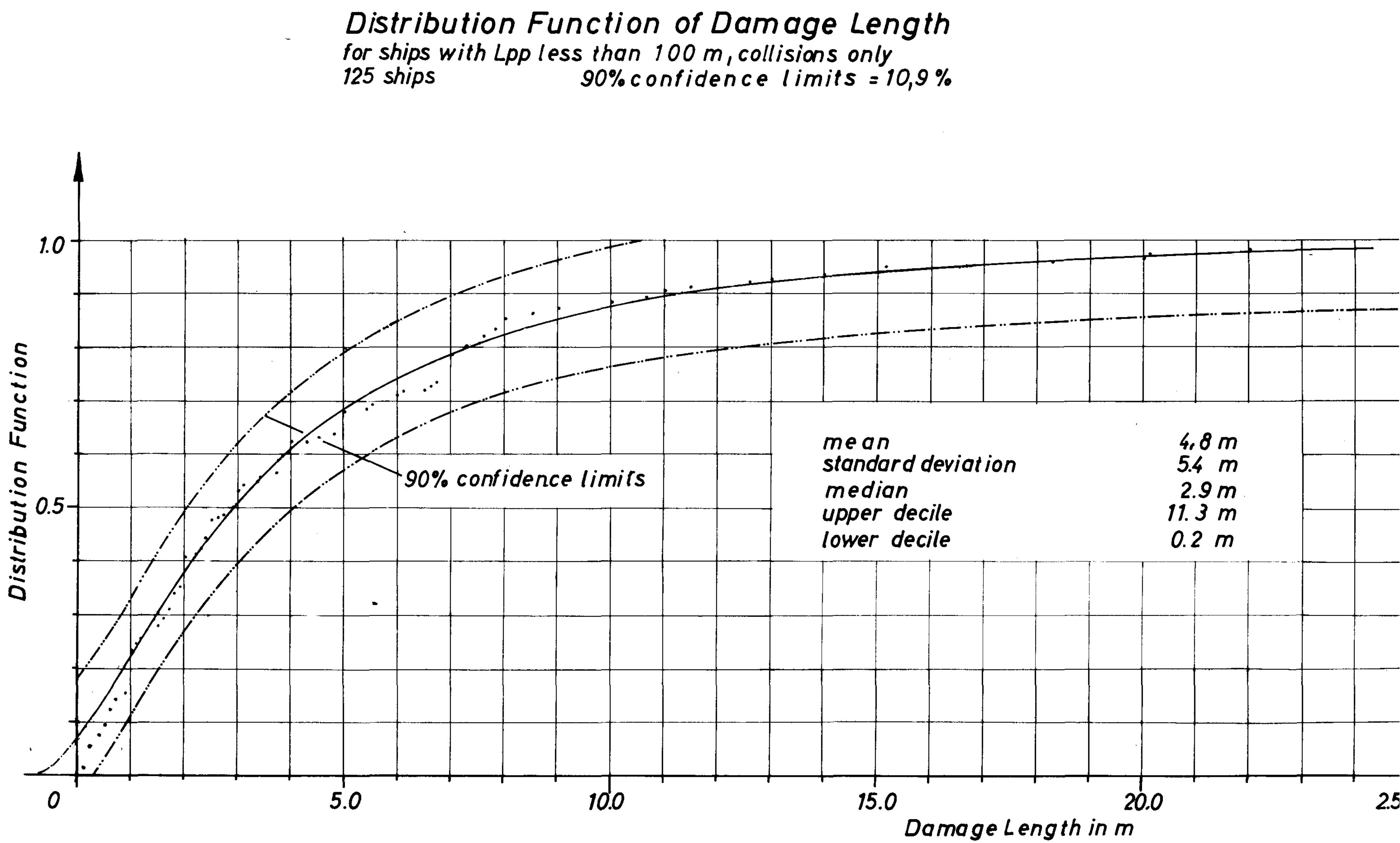
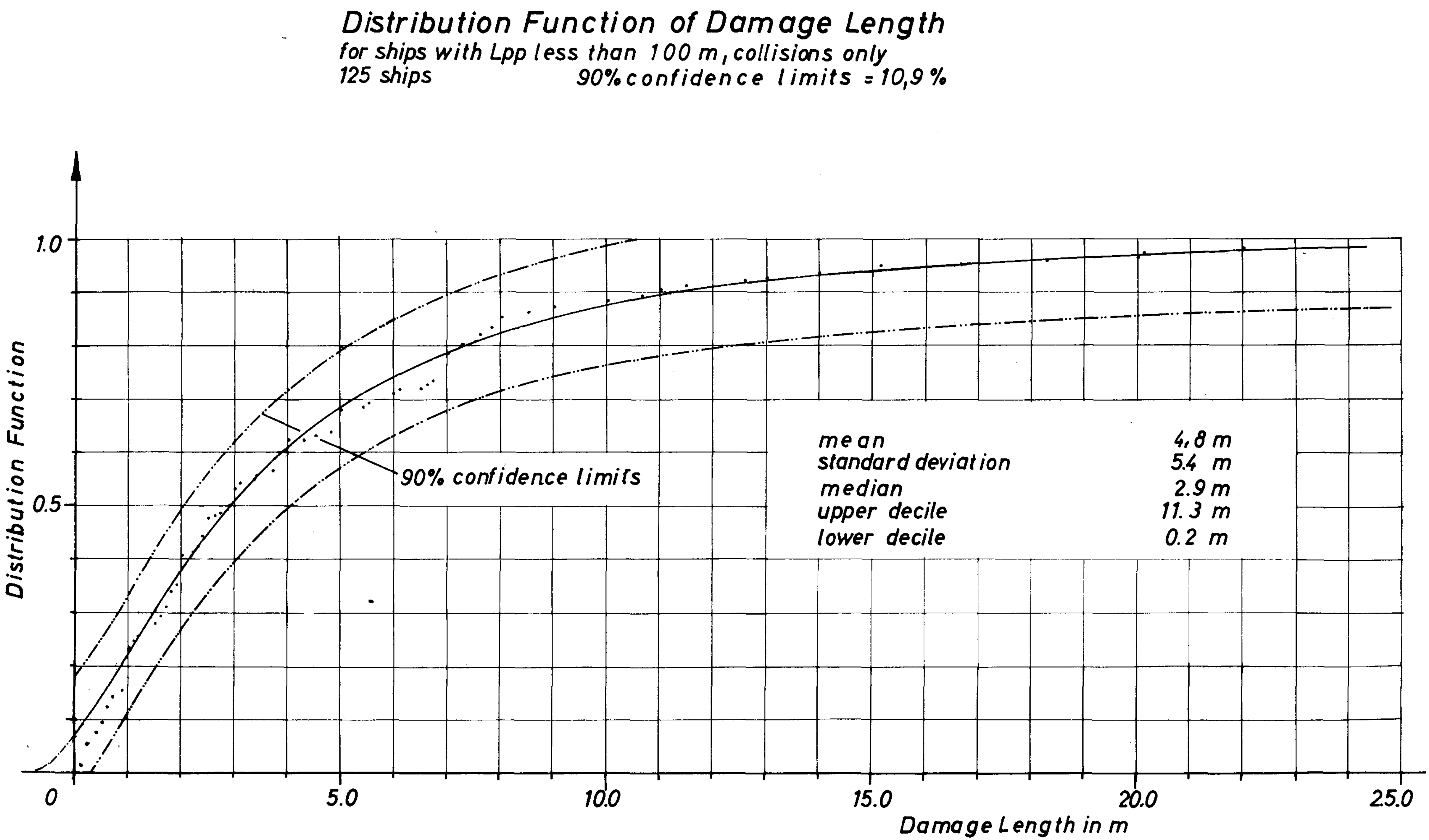

Distribution Function of Damage Length
for ships with Lpp less than 100 m, collisions only
125 ships
90% confidence limits = 10,9 %
Distribution Function
1.0
0.5
0
5.0
10.0
15.0
20.0
25
Damage Length in m
90% confidence limits
mean 4,8 m
standard deviation 5.4 m
median 2.9 m
upper decile 11.3 m
lower decile 0.2 m

Fig. 1.1. 03



Distribution Function of Damage Length
for ships with Lpp less than 100 m, collisions only
125 ships
90% confidence limits = 10,9 %
Distribution Function
1.0
0.5
0
5.0
10.0
15.0
20.0
25.0
Damage Length in m
90% confidence limits
mean 4,8 m
standard deviation 5.4 m
median 2.9 m
upper decile 11.3 m
lower decile 0.2 m

Fig. 1.1. 03

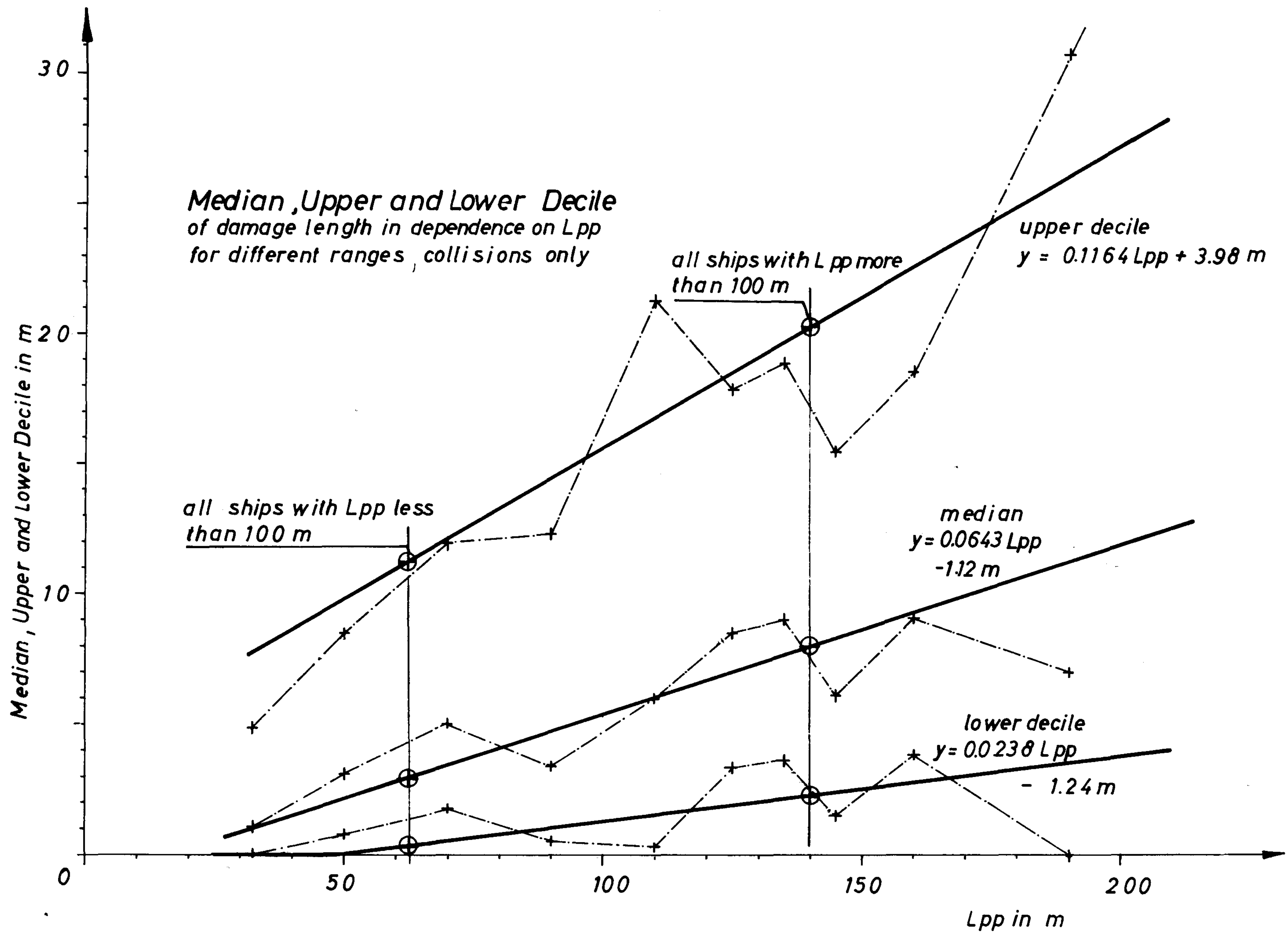
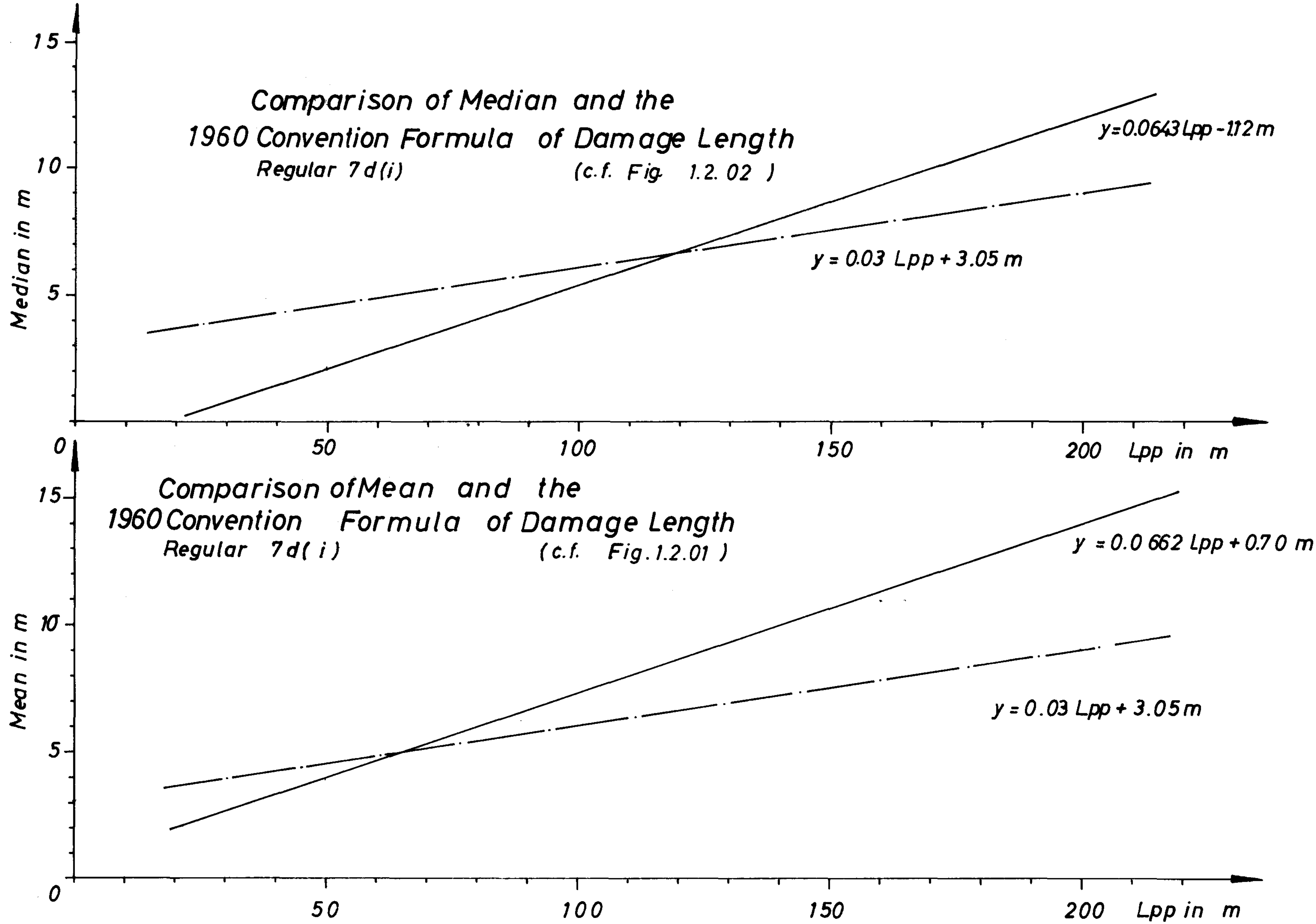
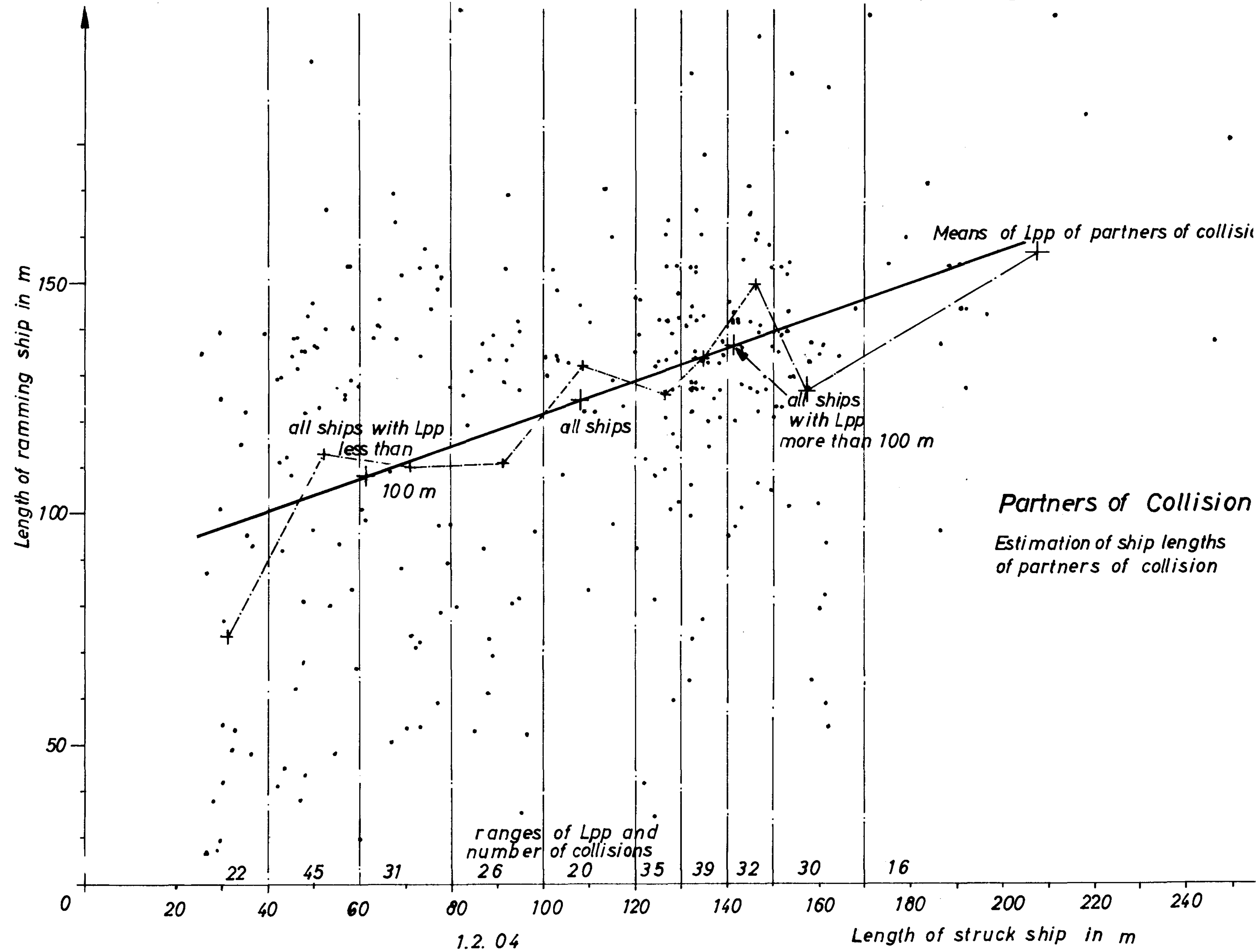

Median ,Upper and Lower Decile
of damage length in dependence on Lpp
for different ranges , collisions only
all ships with Lpp less
than 100 m
all ships with L pp more
than 100 m
upper decile
y = 0.1164 Lpp + 3.98 m
median
y= 0.0643 Lpp
-1.12 m
lower decile
y= 0.0238 Lpp
- 1.24 m
Median , Upper and Lower Decile in m
Lpp in m
0
10
20
30
50
100
150
200

Fig. 1.2.02


Comparison of Median and the
1960 Convention Formula of Damage Length
Regular 7 d(i)
(c.f. Fig. 1.2. 02)
y=0.0643 Lpp -1.12 m
y = 0.03 Lpp + 3.05 m
Median in m
15
10
5
0
50
100
150
200
Lpp in m
Comparison of Mean and the
1960 Convention Formula of Damage Length
Regular 7 d(i)
(c.f. Fig. 1.2.01)
y = 0.0 662 Lpp + 0.7 0 m
y = 0.03 Lpp + 3.05 m
Mean in m
15
10
5
0
50
100
150
200
Lpp in m

1.2.03


Length of ramming ship in m
150
100
50
0
20
40
60
80
100
120
140
160
180
200
220
240
Length of struck ship in m
Means of Lpp of partners of collisi
all ships with Lpp less than 100 m
all ships
all ships with Lpp more than 100 m
ranges of Lpp and number of collisions
22
45
31
26
20
35
39
32
30
16
1.2.04
Partners of Collision
Estimation of ship lengths of partners of collision

Distribution Function of Damage Length

in dependence on place of casualty for ships with Lpp less than 100 m. Collisions in harbours, rivers, estuary tradings.

65 ships 90% confidence limits = 14,8 %

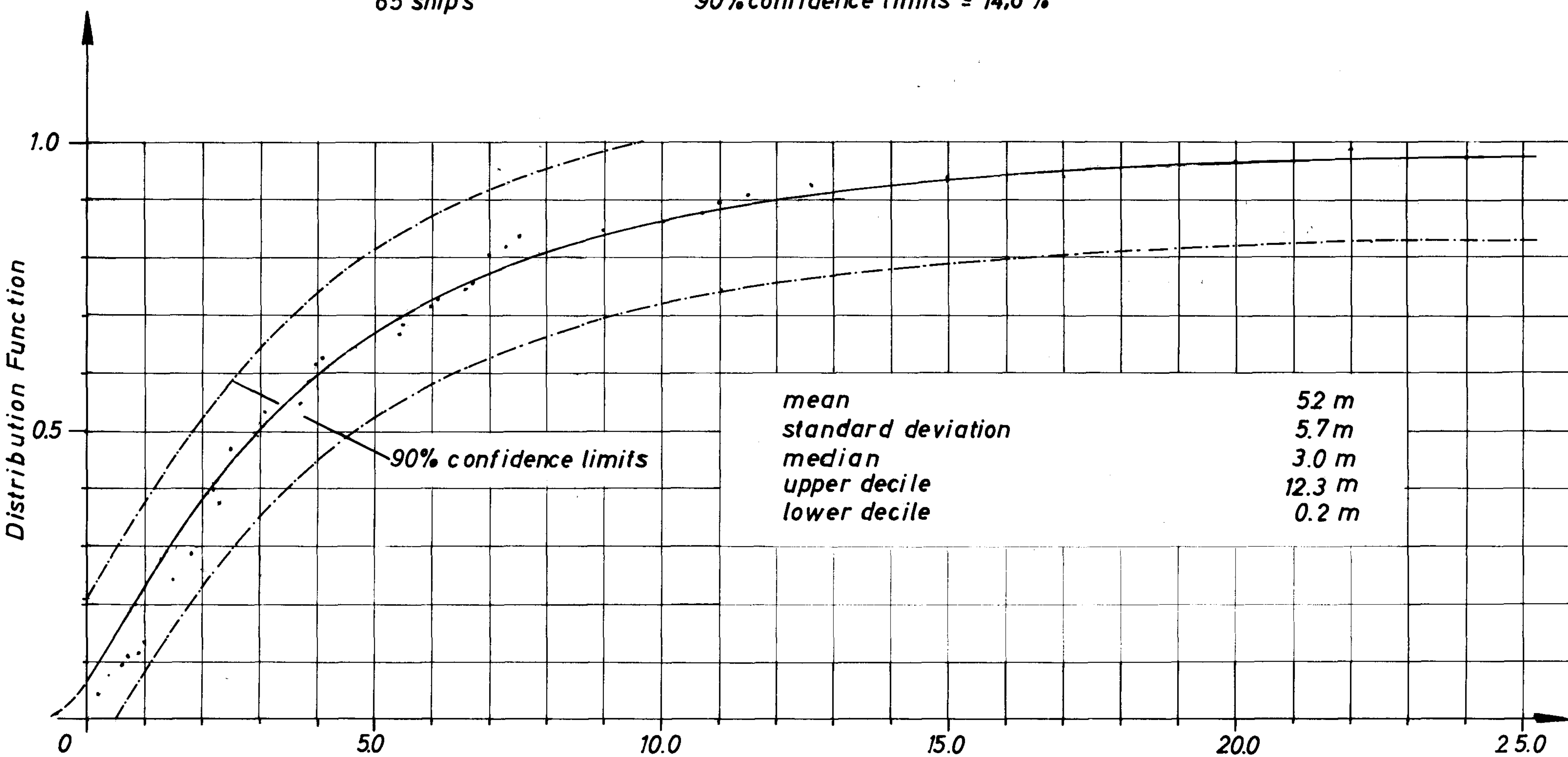


Fig. 1.3. 01

Distribution Function of Damage Length

in dependence on place of casualty for ships with Lpp more than 100 m. Collisions in harbours, rivers, estuary tradings.
80 ships 90% confidence limits = 13.4 %

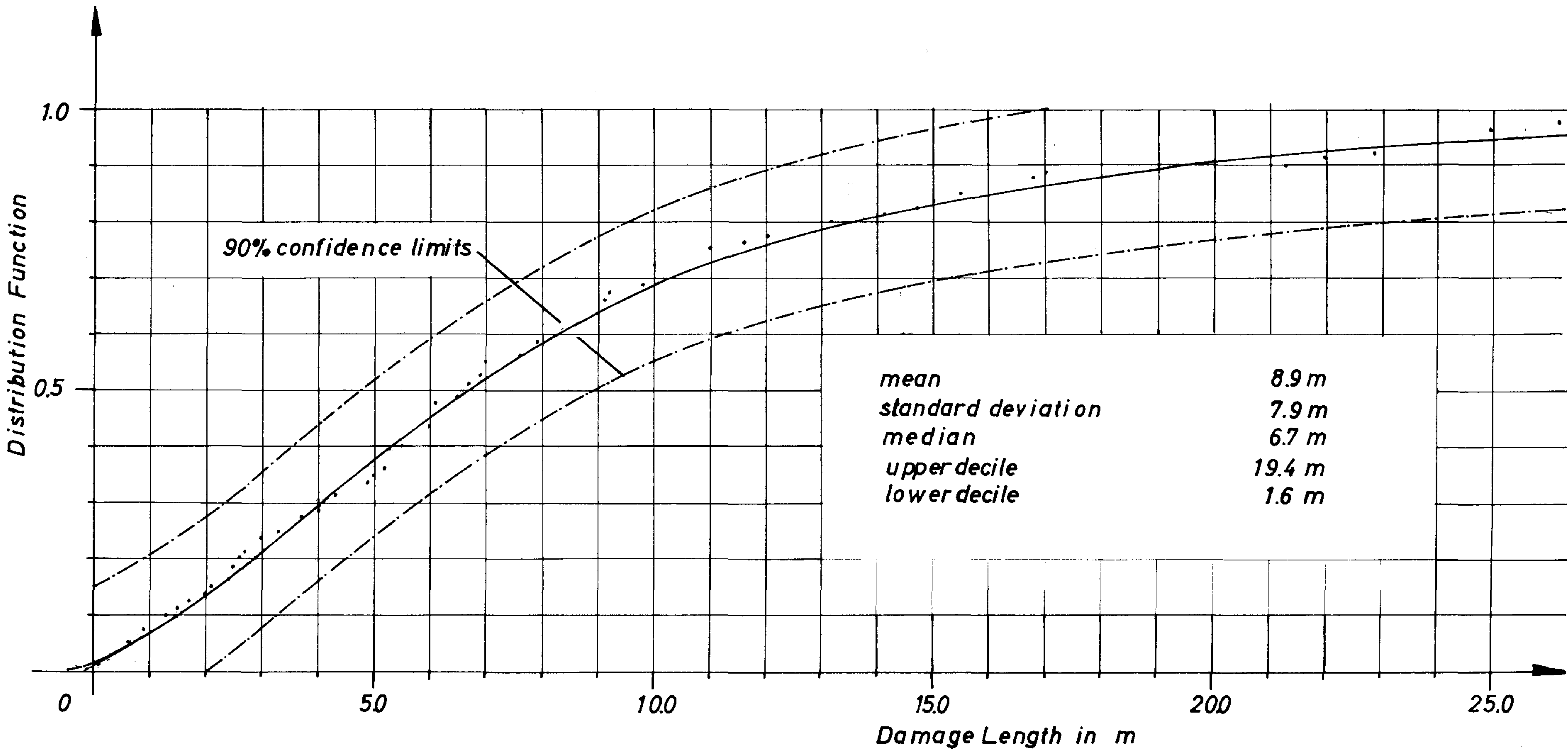


Fig. 1. 3. 03

Distribution Function of Damage Length

in dependence on place of casudty for ships with Lpp less than 100 m. Collisions in coastareas, swept channels, straits of sea.

39 ships 90% confidence limits = 19.2 %

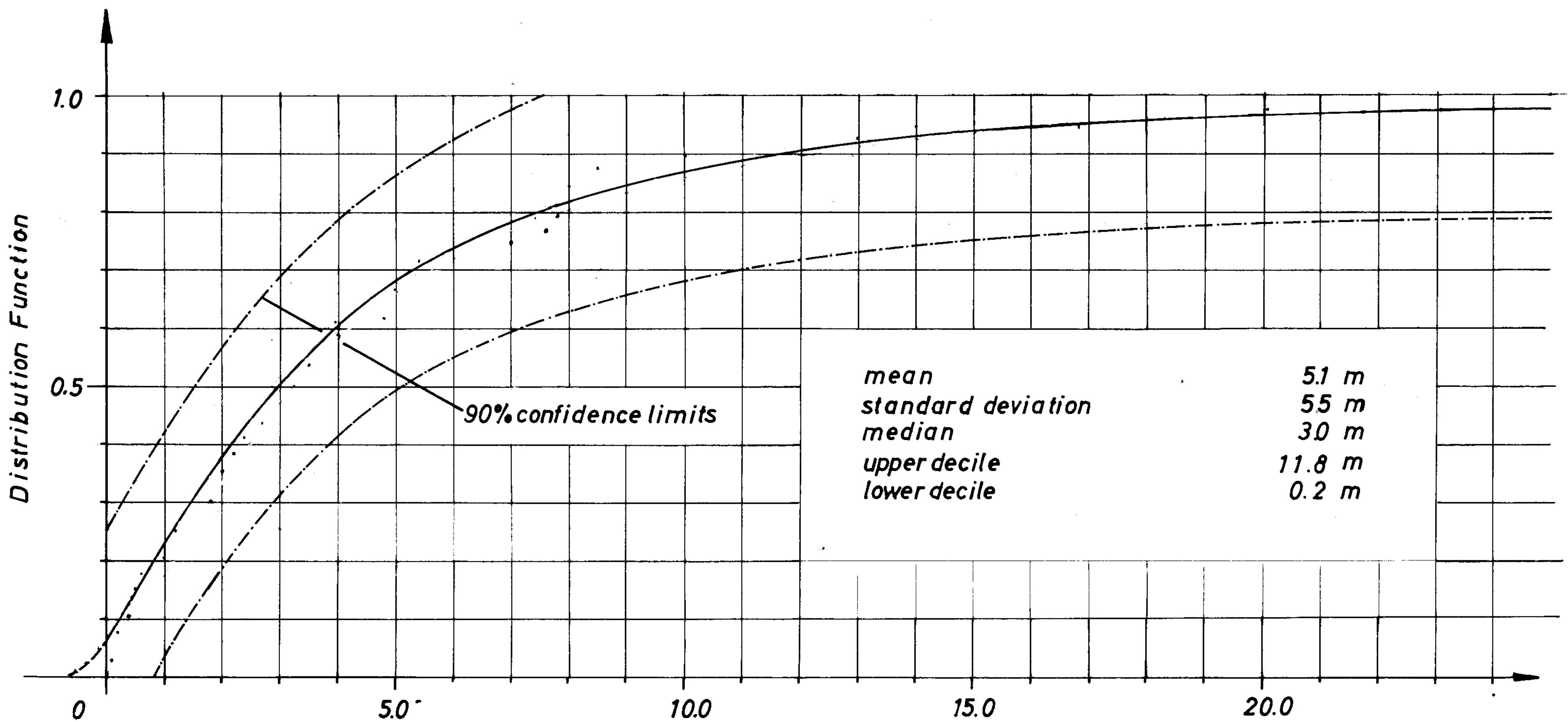


Fig. 1. 3. 05

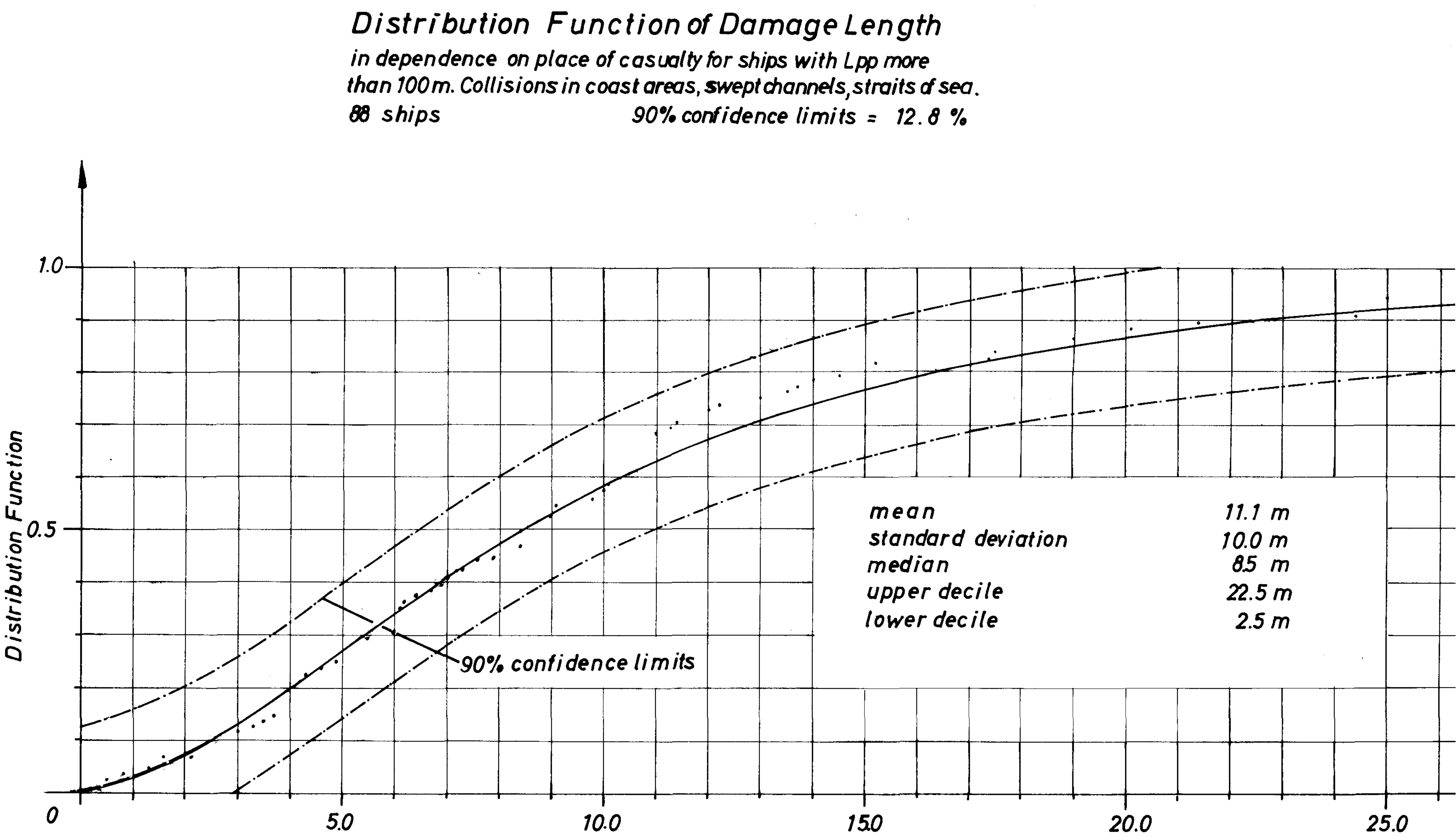

Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp more
than 100m. Collisions in coast areas, swept channels, straits of sea.
88 ships
90% confidence limits = 12.8 %
Distribution Function
1.0
0.5
0
5.0
10.0
15.0
20.0
25.0
Damage Length in m
90% confidence limits
mean 11.1 m
standard deviation 10.0 m
median 8.5 m
upper decile 22.5 m
lower decile 2.5 m

Fig. 1.3.07

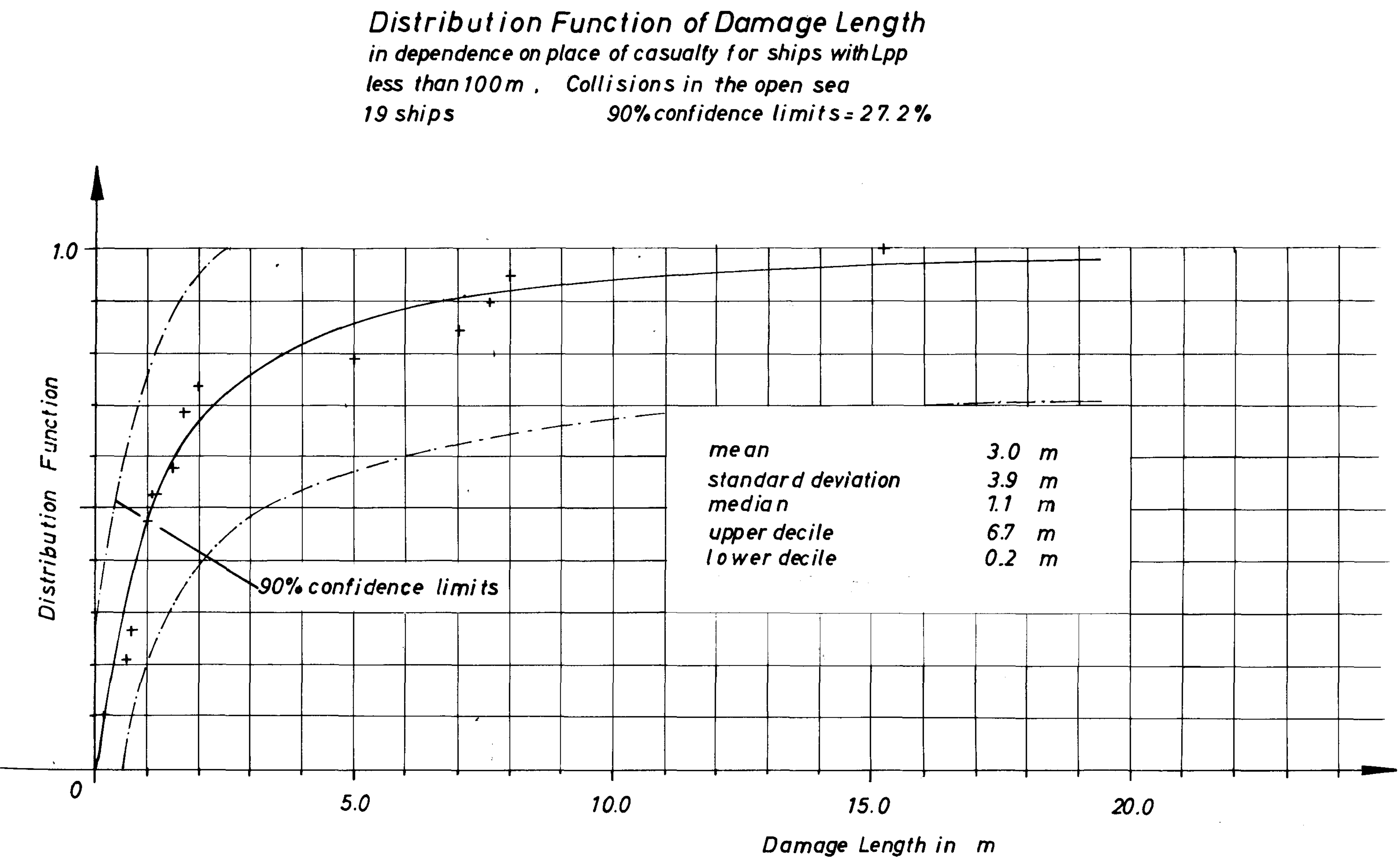

Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp
less than 100m , Collisions in the open sea
19 ships
90% confidence limits = 27.2 %
1.0
0
Distribution Function
90% confidence limits
mean 3.0 m
standard deviation 3.9 m
median 1.1 m
upper decile 6.7 m
lower decile 0.2 m
5.0
10.0
15.0
20.0
Damage Length in m

Fig. 1.3. 09

Distribution Function of Damage Length

in dependence on place of casualty for ships Lpp more than 100 m. Collisions in the open sea

22 ships 90% confidence limits = 25.2 %

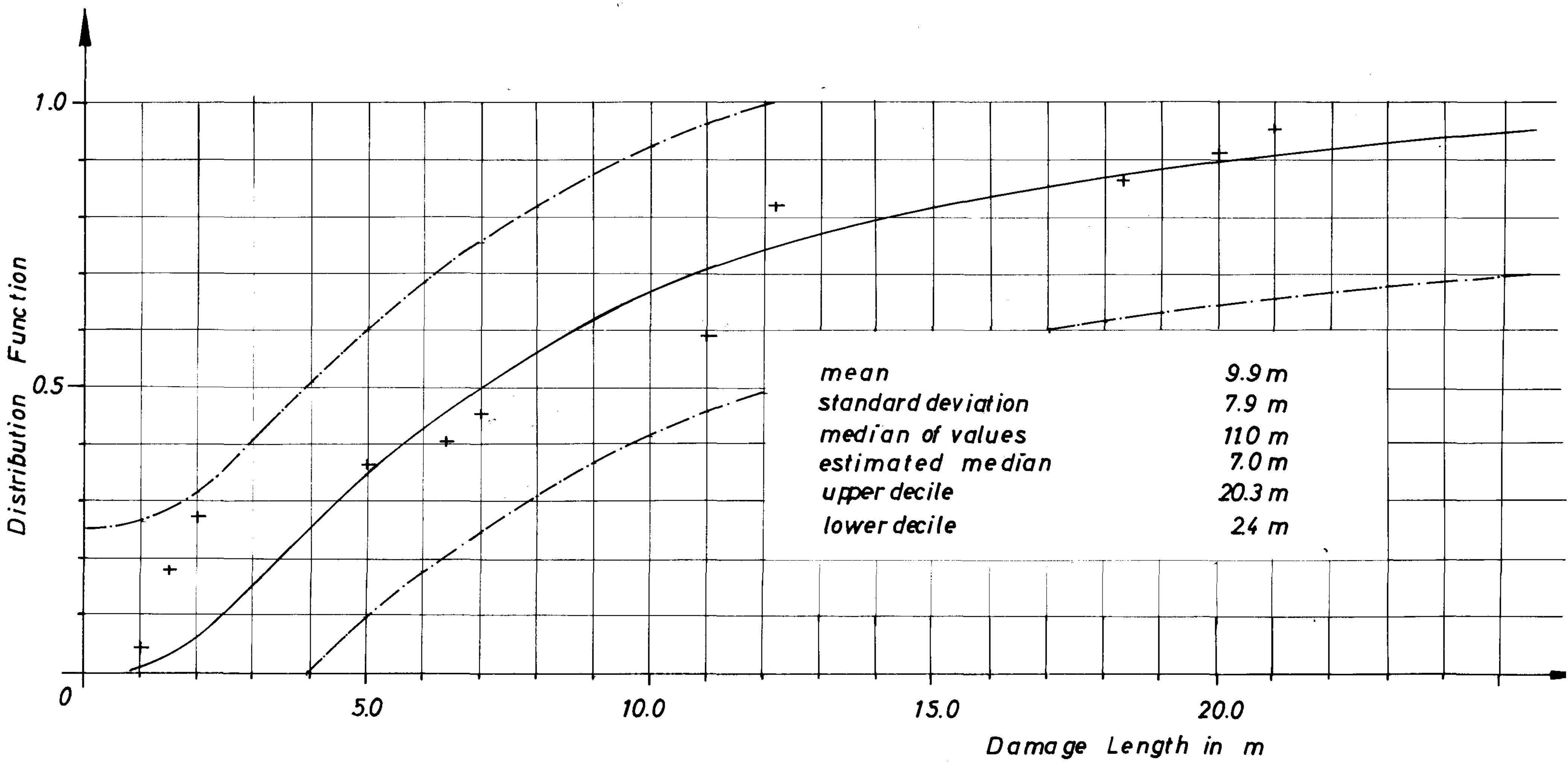


Fig. 1.3.11

Distribution Function of Damage Length

for all ship length, strandings and groundings only

77 ships — 90% confidence limits = 13.6 %

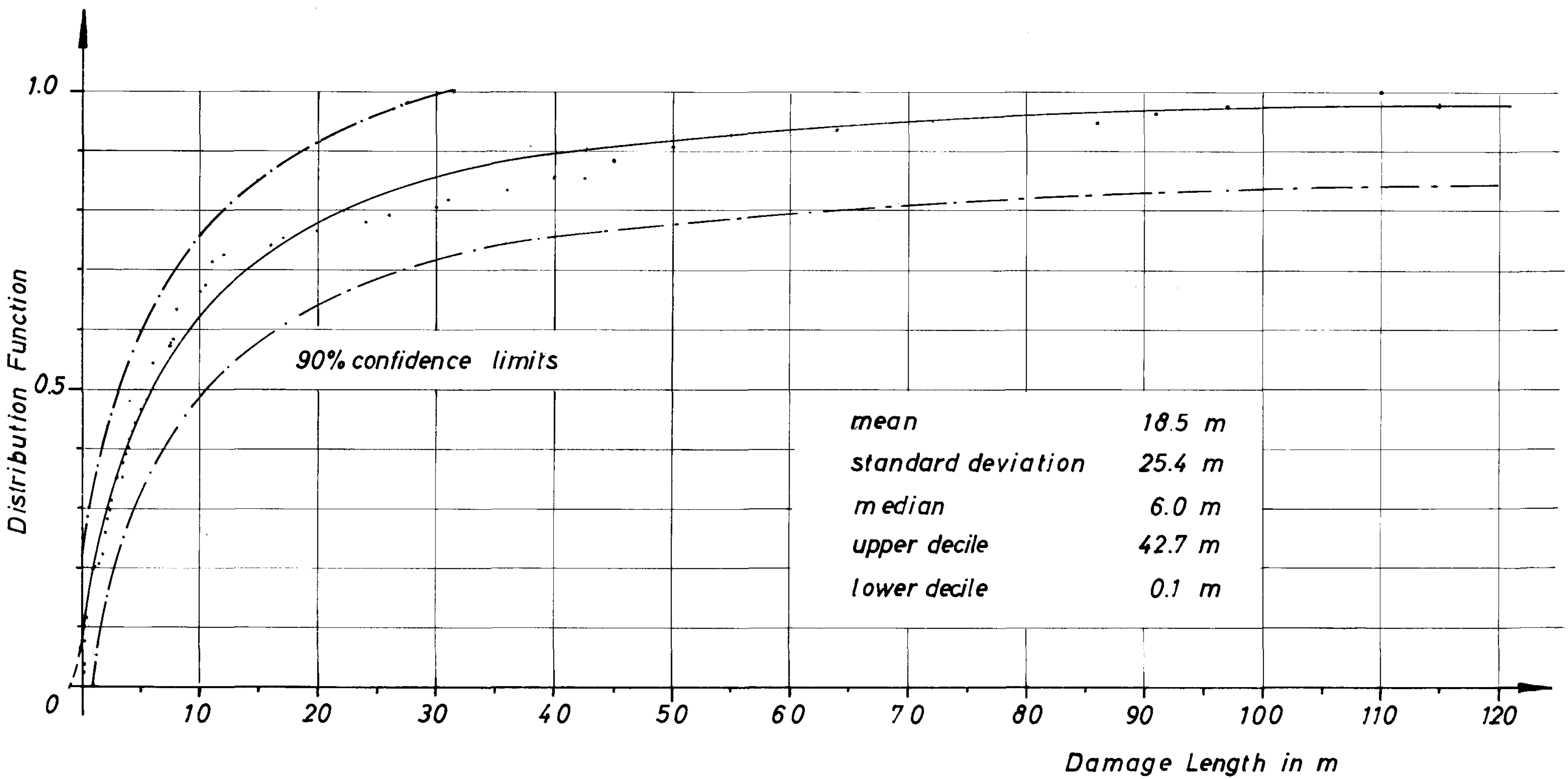


Fig. 14.01

Distribution Function of Damage Length

for ships with Lpp more than 100 m, collisions only
187 ships 90% confidence limits = 8.9 %

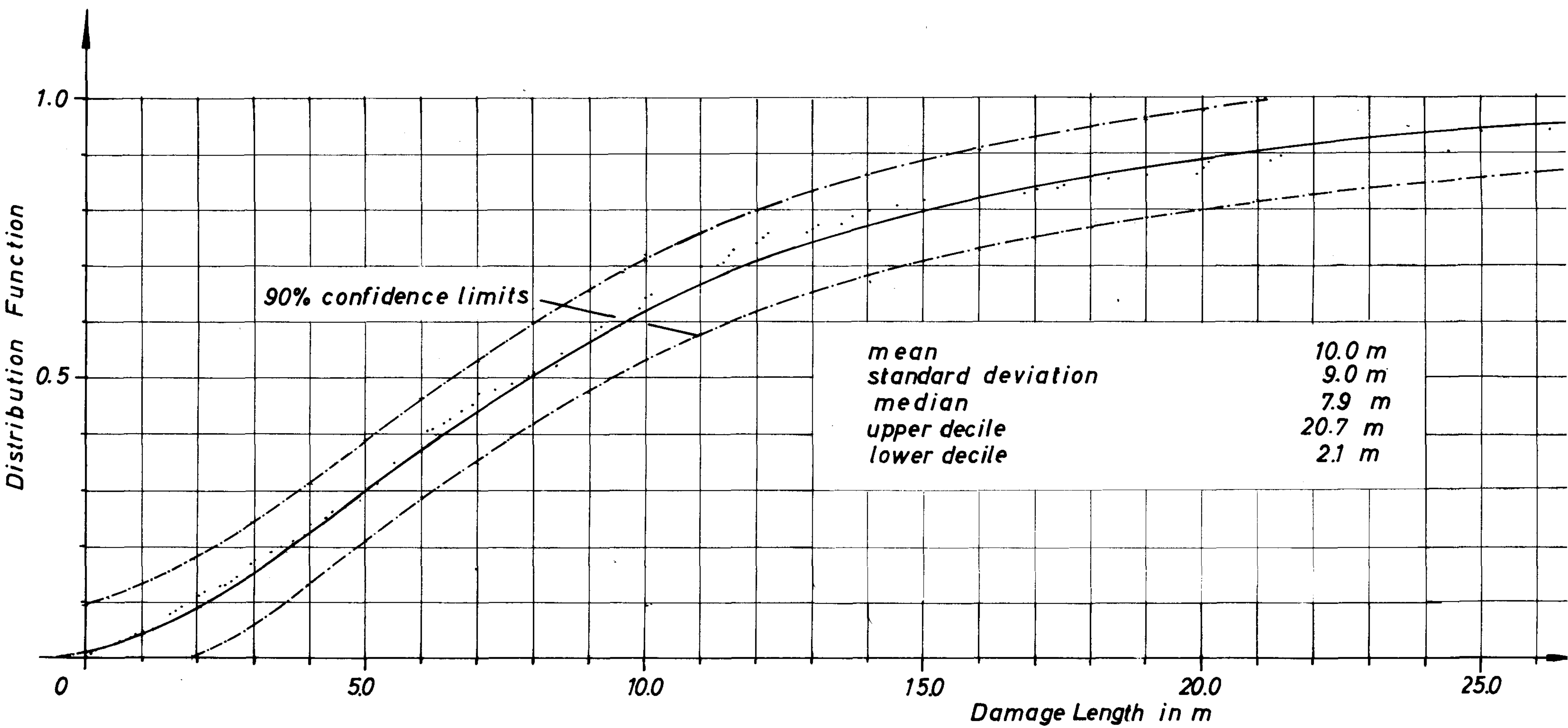


Fig. 1.1. 05

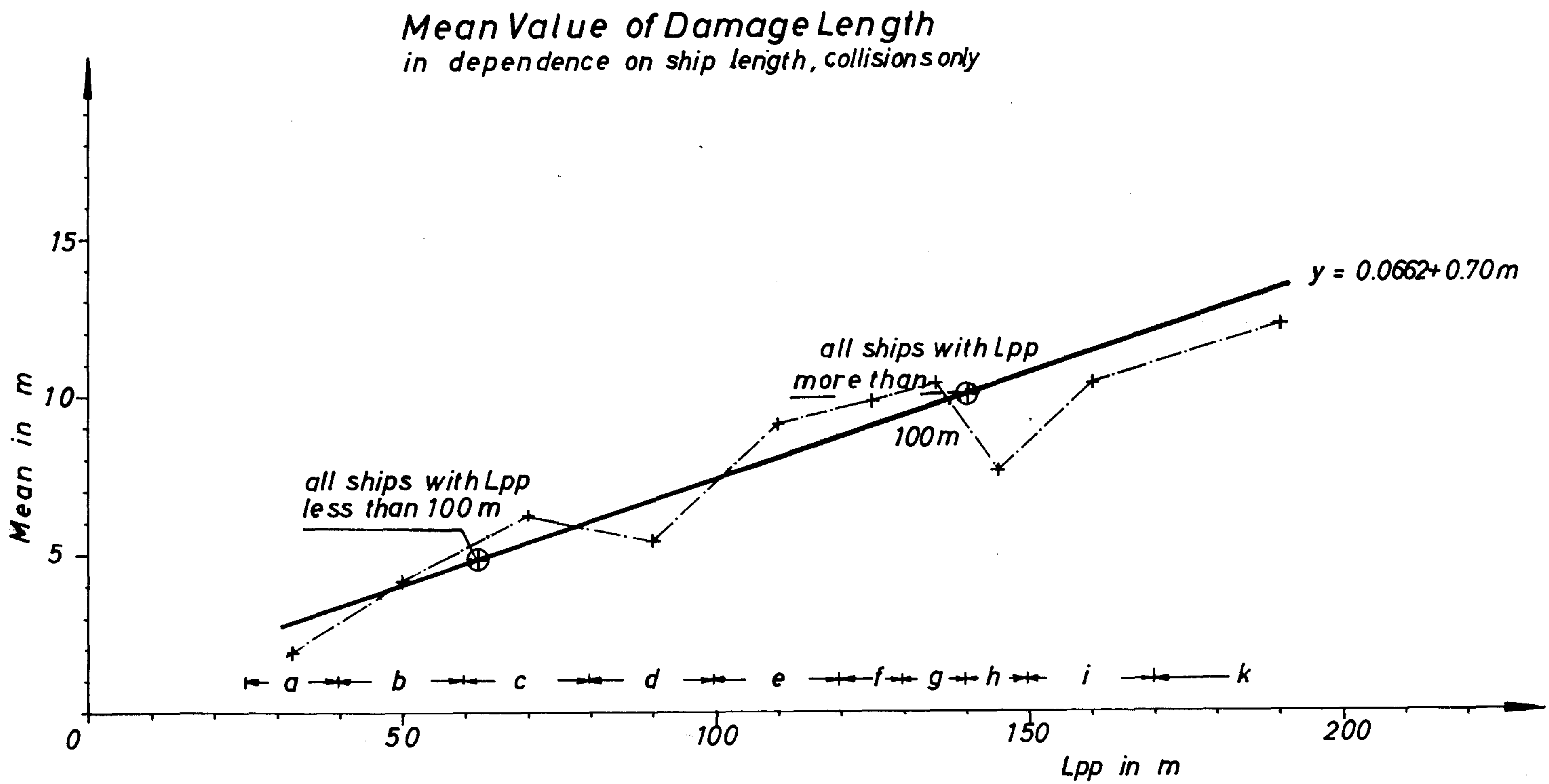
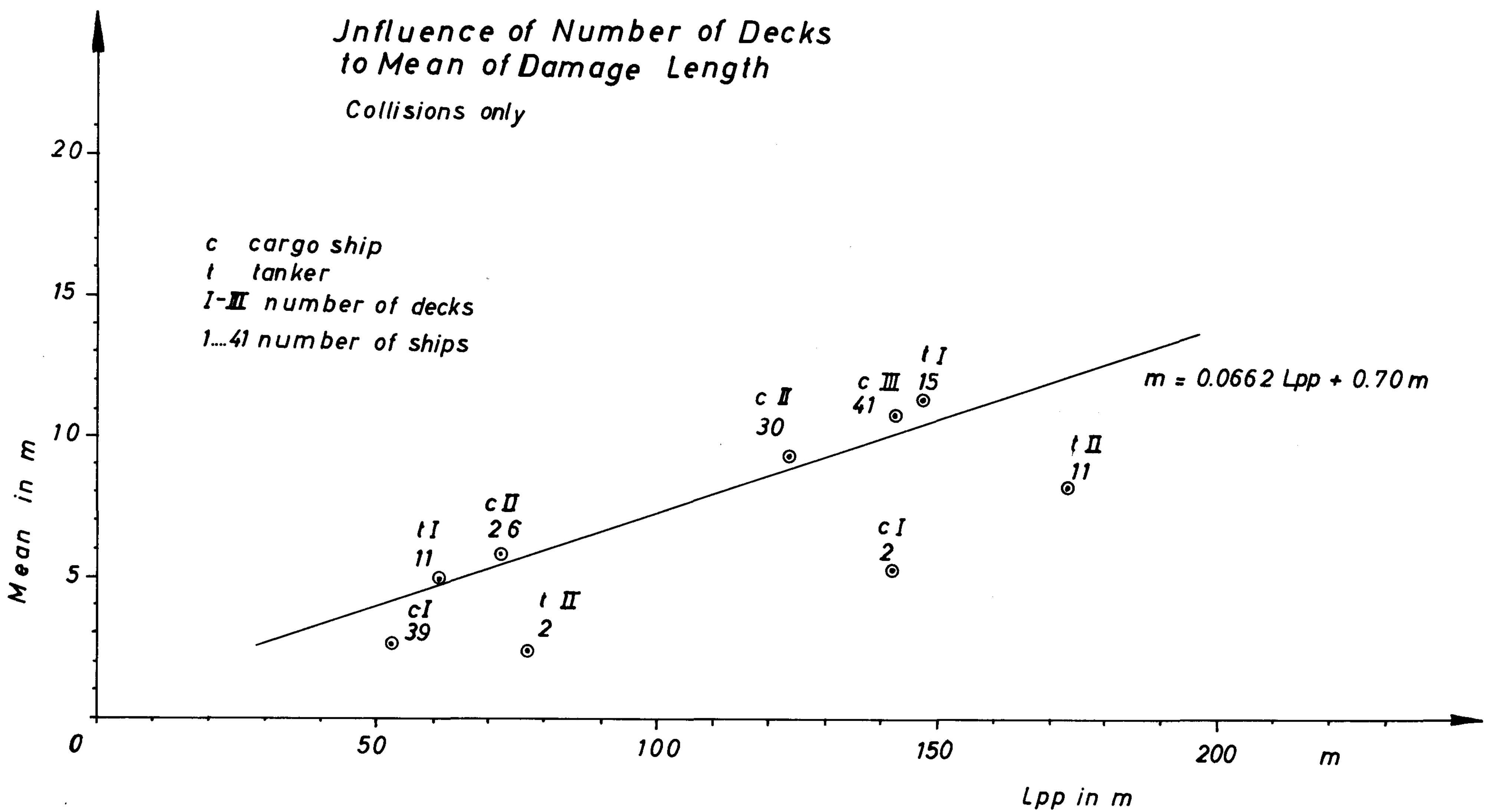

Mean Value of Damage Length
in dependence on ship length, collisions only
Mean in m
15
10
5
0
50
100
150
200
Lpp in m
y = 0.0662+0.70m
all ships with Lpp
less than 100 m
all ships with Lpp
more than
100m
a
b
c
d
e
f
g
h
i
k

Fig. 1.2.01


Jnfluence of Number of Decks
to Mean of Damage Length
Collisions only
c cargo ship
t tanker
I-III number of decks
1....41 number of ships
m = 0.0662 Lpp + 0.70 m
Mean in m
Lpp in m
0
5
10
15
20
50
100
150
200
m
cI 39
tI 11
cII 26
tII 2
cII 30
cIII 41
tI 15
cI 2
tII 11

6.0.01

Frequency and Cumulative Frequency

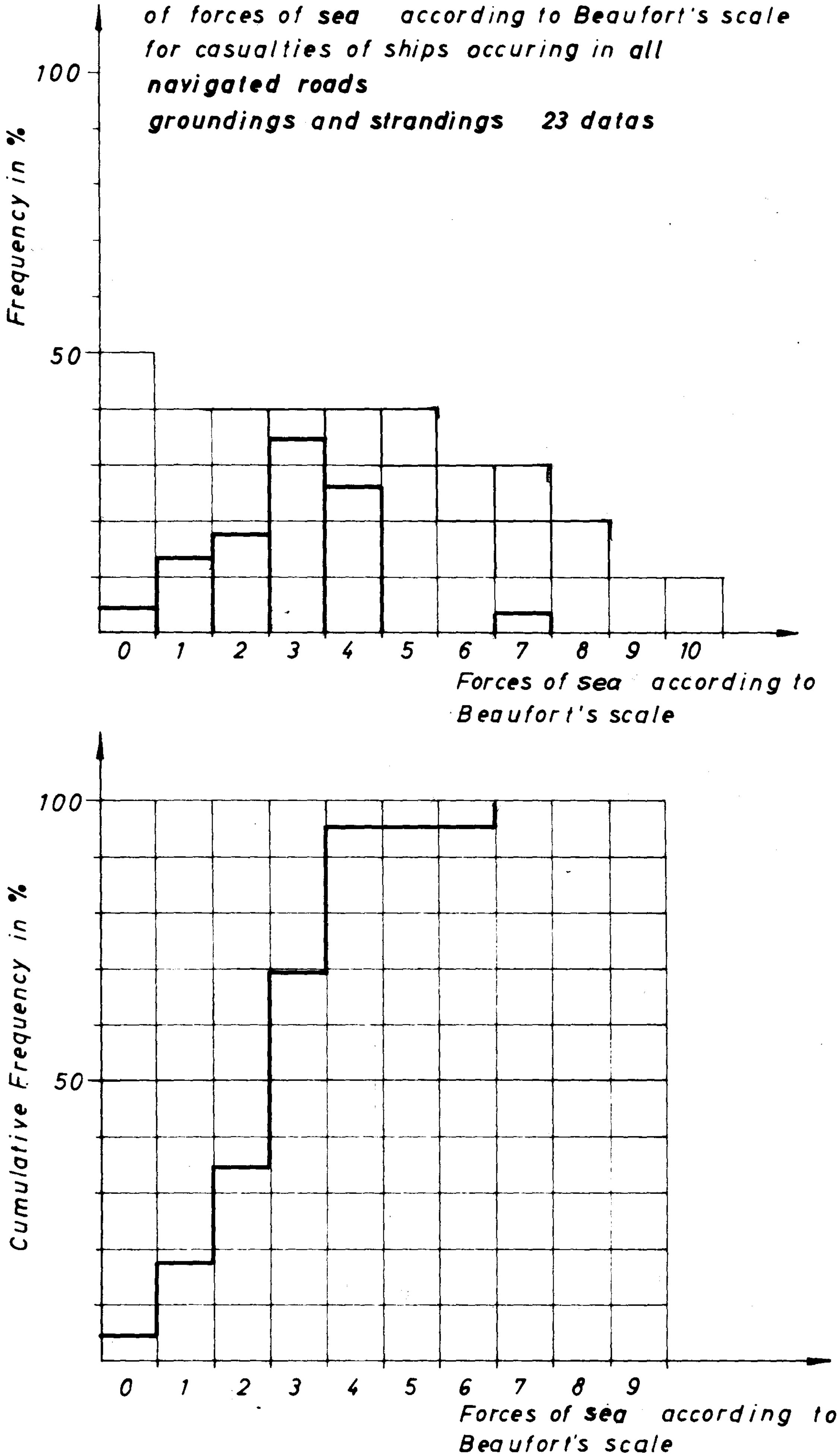


Fig.5.1.11

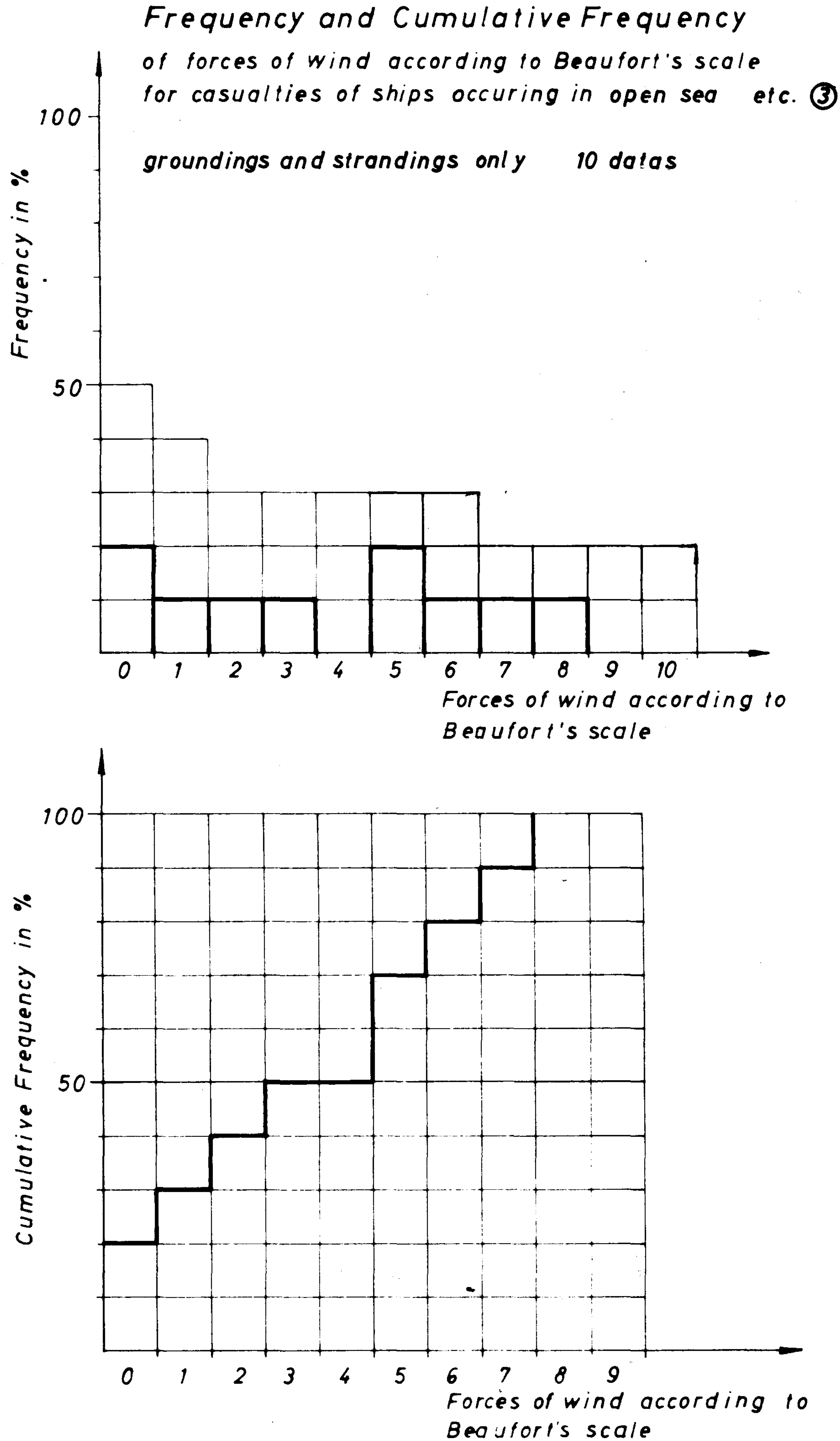

Frequency and Cumulative Frequency
of forces of wind according to Beaufort's scale
for casualties of ships occuring in open sea etc. ③
groundings and strandings only 10 datas
Frequency in %
100
50
0
1
2
3
4
5
6
7
8
9
10
Forces of wind according to Beaufort's scale
Cumulative Frequency in %
100
50
0
1
2
3
4
5
6
7
8
9
Forces of wind according to Beaufort's scale

Fig. 5.1.10

Frequency and Cumulative Frequency

of forces of wind according to Beaufort's scale
for casualties of ships occuring in coast areas ②
groundings and strandings only 24 datas

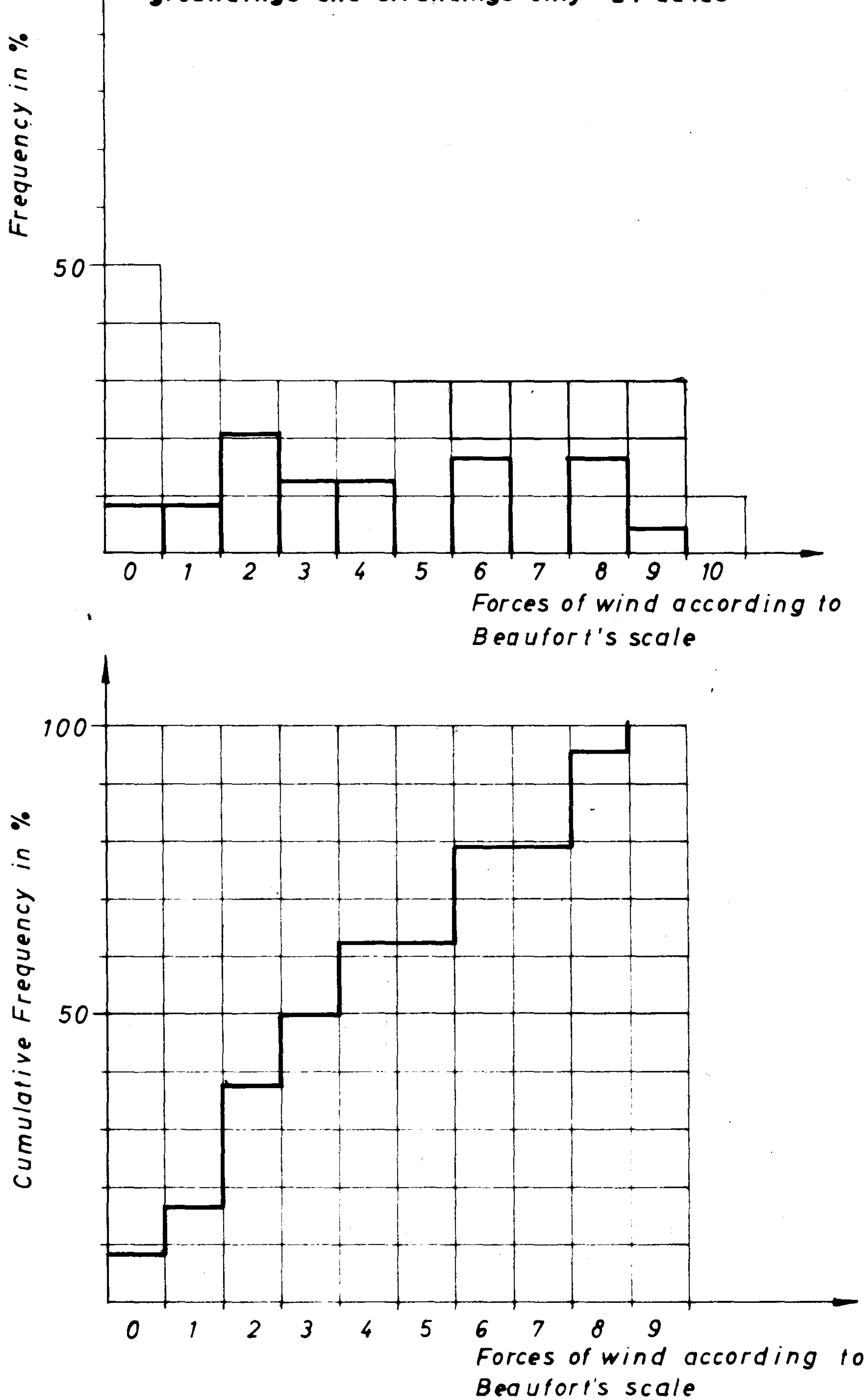


Fig. 5.1.09

Frequency and Cumulative Frequency

of forces of wind according to Beaufort's scale for casualties of ships occuring in habours ①

groundings and strandings only 36 datas

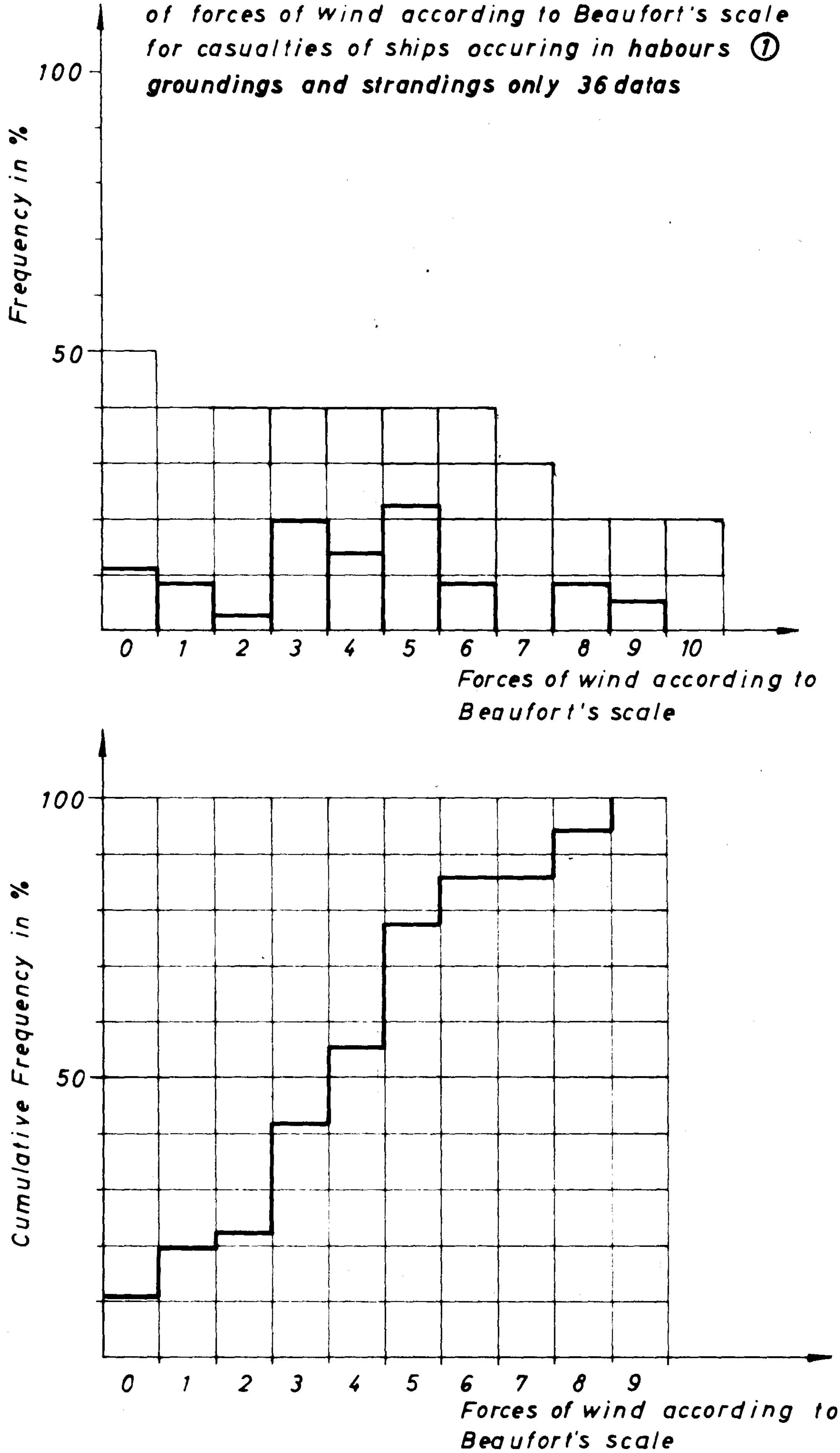


Fig. 5.1.08

Frequency and Cumulative Frequency

of forces of sea according to Beaufort's scale
for casualties of ships occuring in open seas ③

collisions only 24 datas

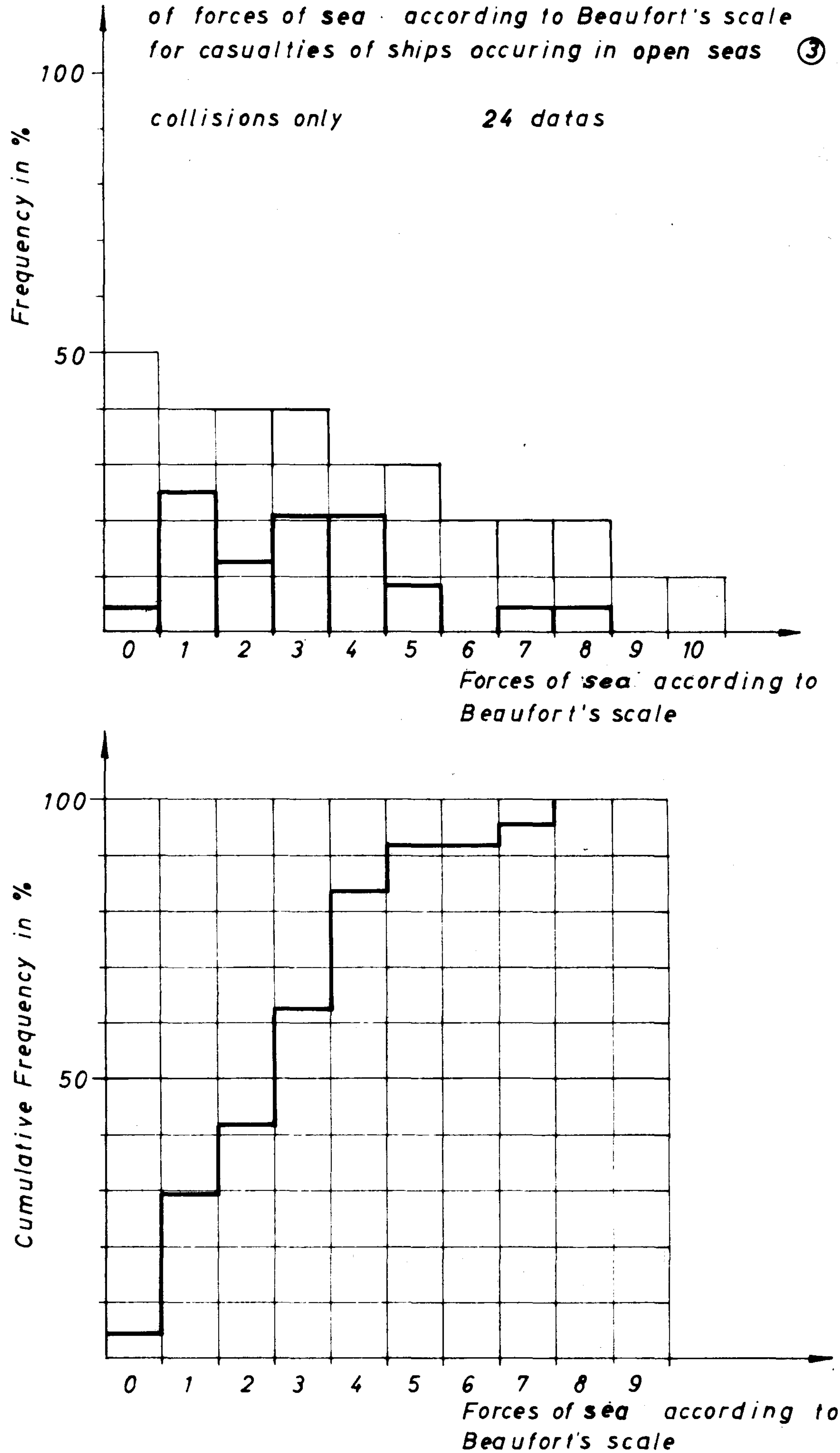


Fig. 5.1.07

Frequency and Cumulative Frequency

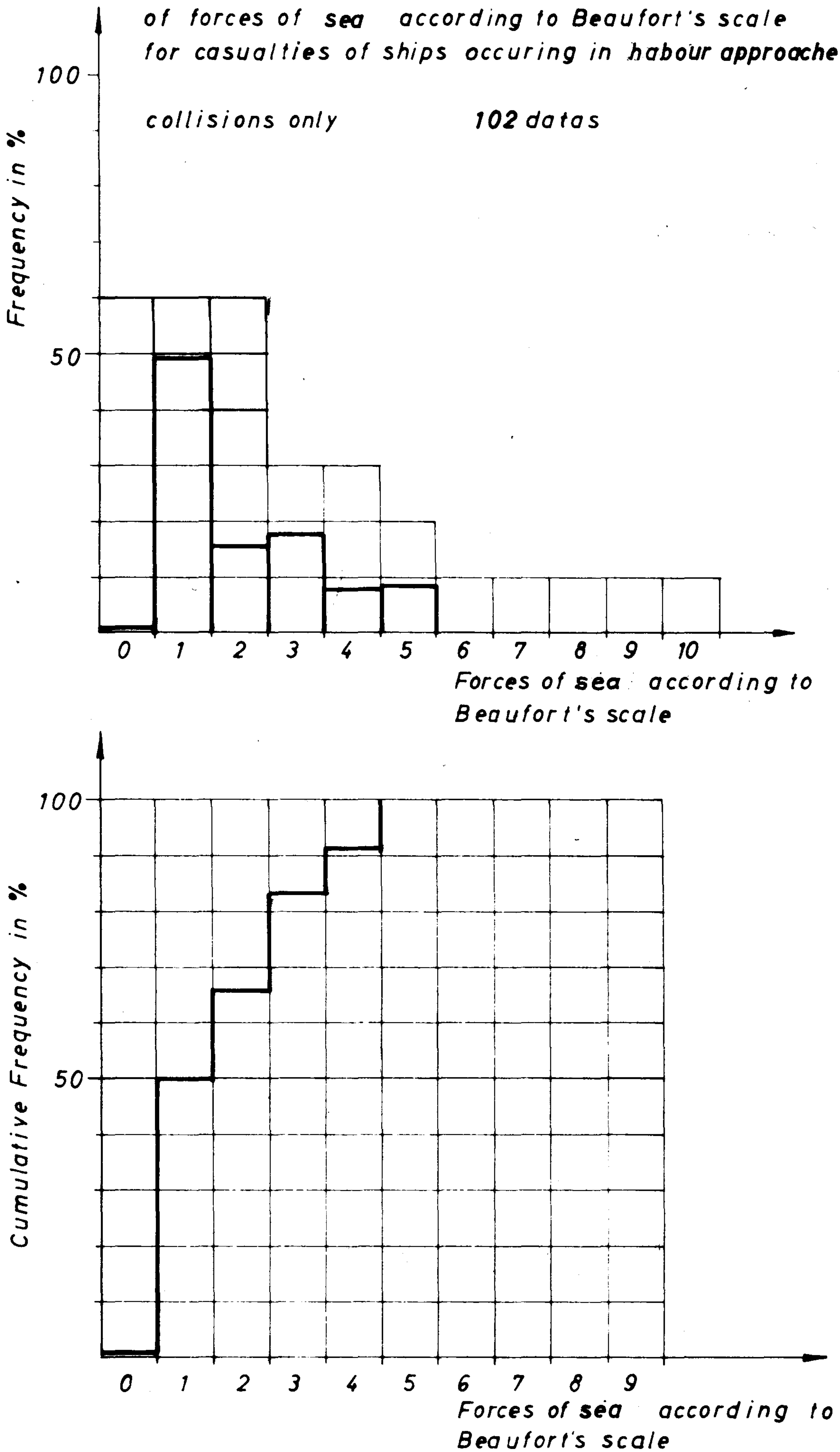
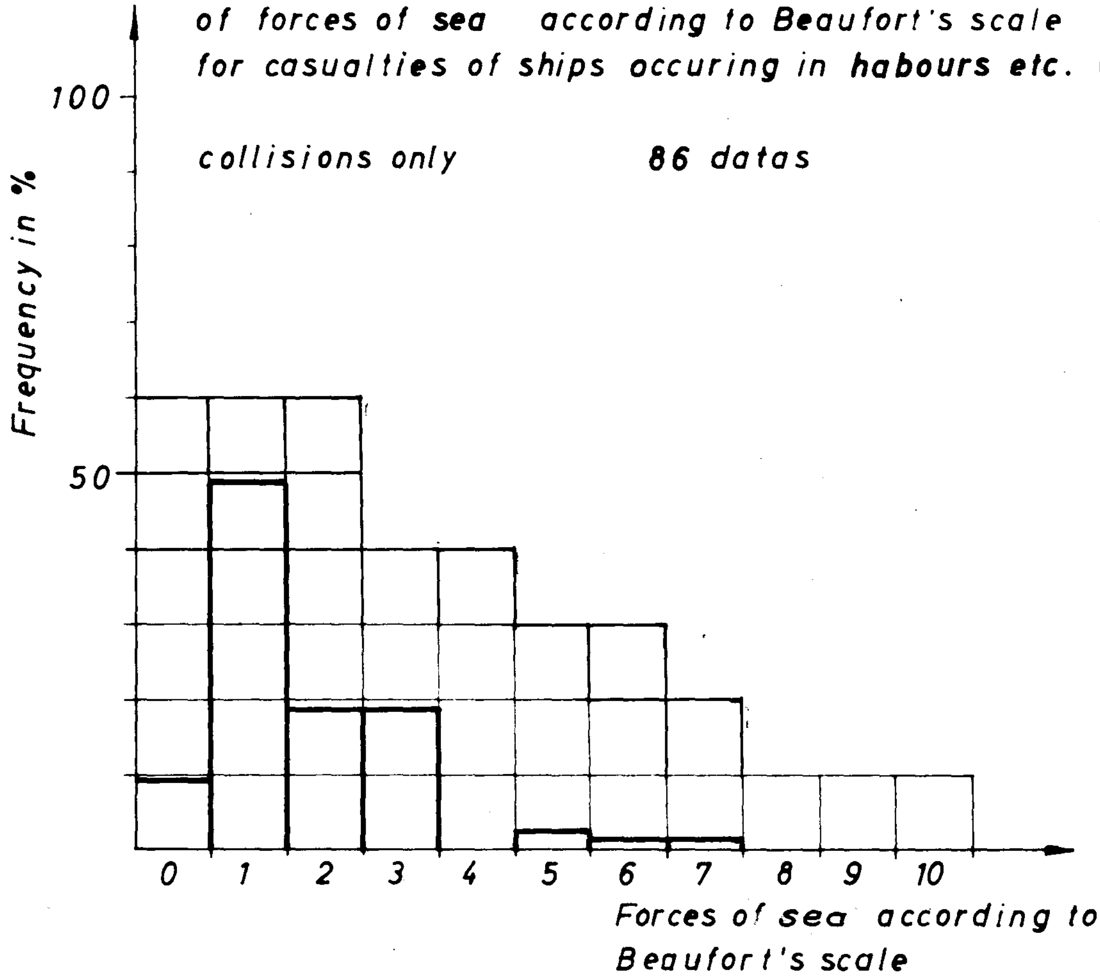


Fig. 5.1.06

Frequency and Cumulative Frequency

of forces of sea according to Beaufort's scale
for casualties of ships occuring in habours etc. (1)

collisions only 86 datas



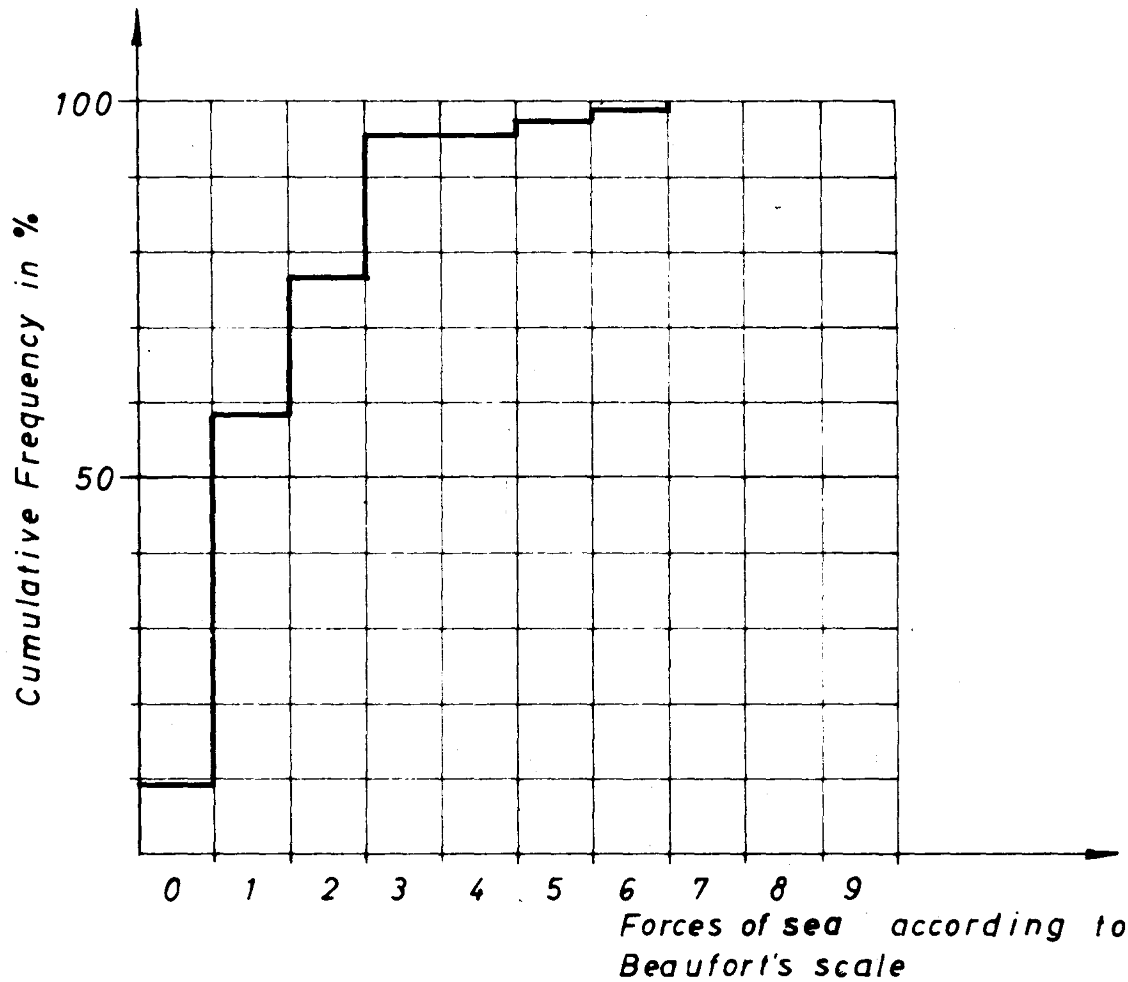


Fig. 5.1.05

Frequency and Cumulative Frequency

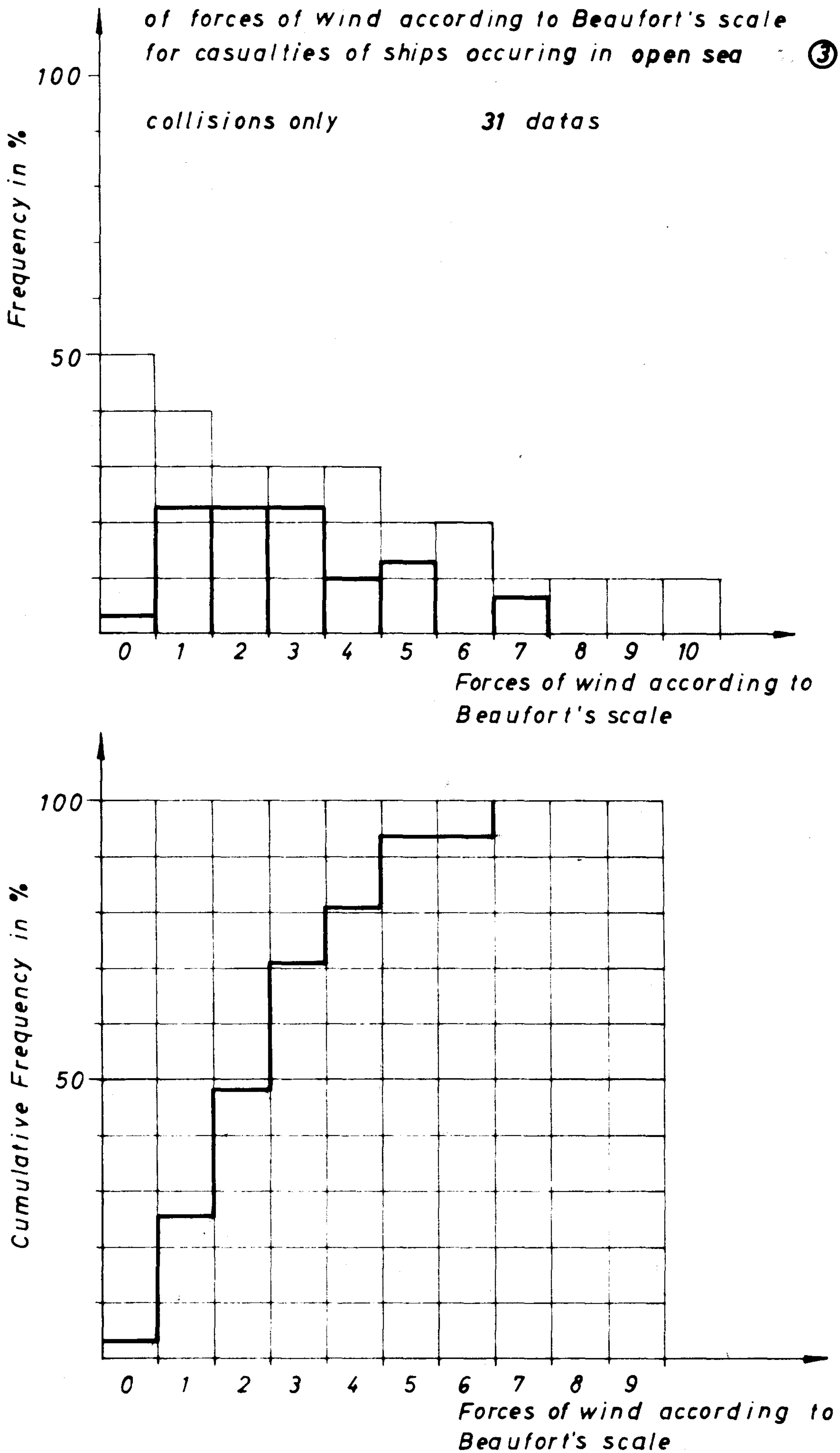


Fig. 5.1.04

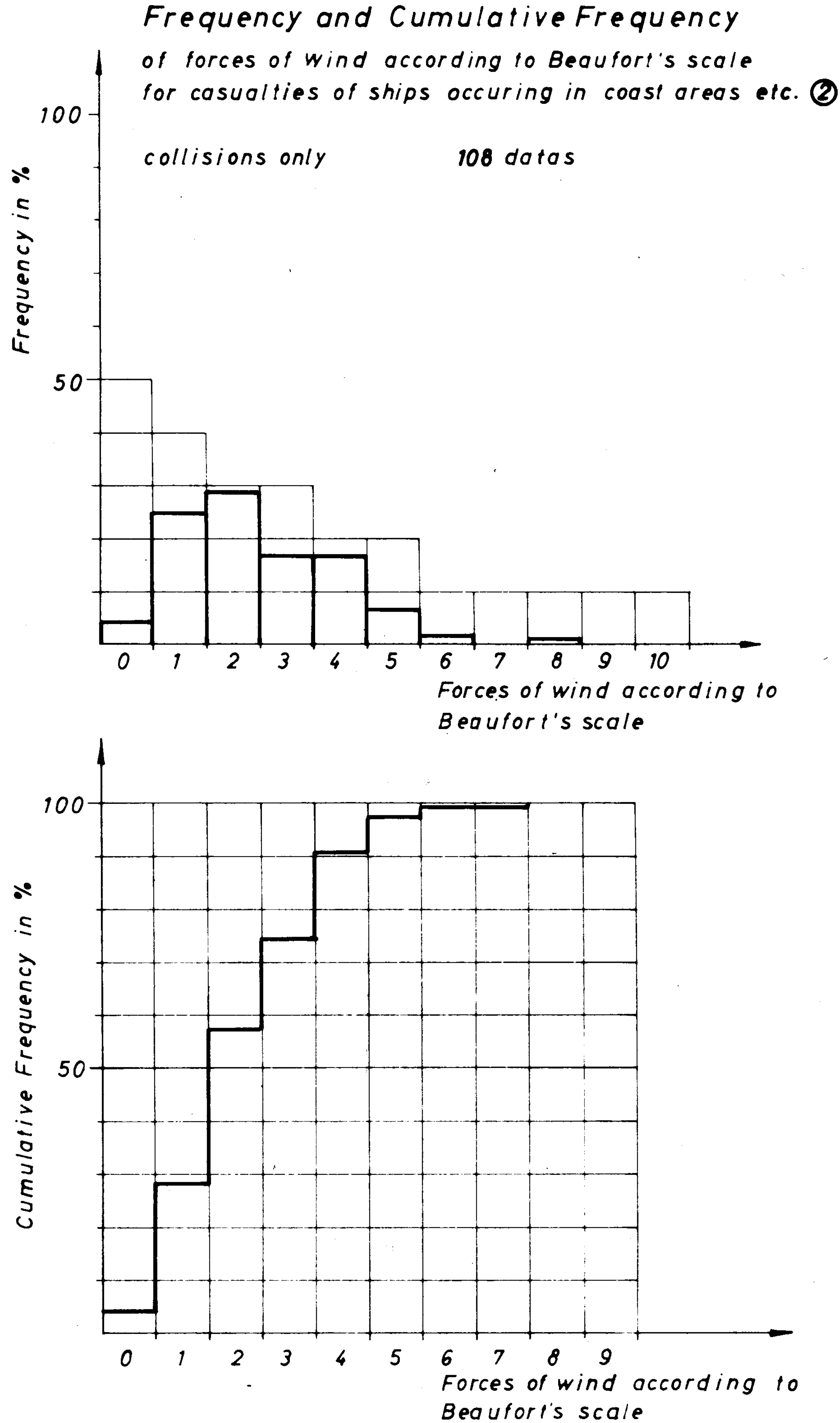

Frequency and Cumulative Frequency
of forces of wind according to Beaufort's scale
for casualties of ships occuring in coast areas etc. ②
collisions only
108 datas
Frequency in %
100
50
0 1 2 3 4 5 6 7 8 9 10
Forces of wind according to Beaufort's scale
Cumulative Frequency in %
100
50
0 1 2 3 4 5 6 7 8 9
Forces of wind according to Beaufort's scale

Fig. 5.1. 03

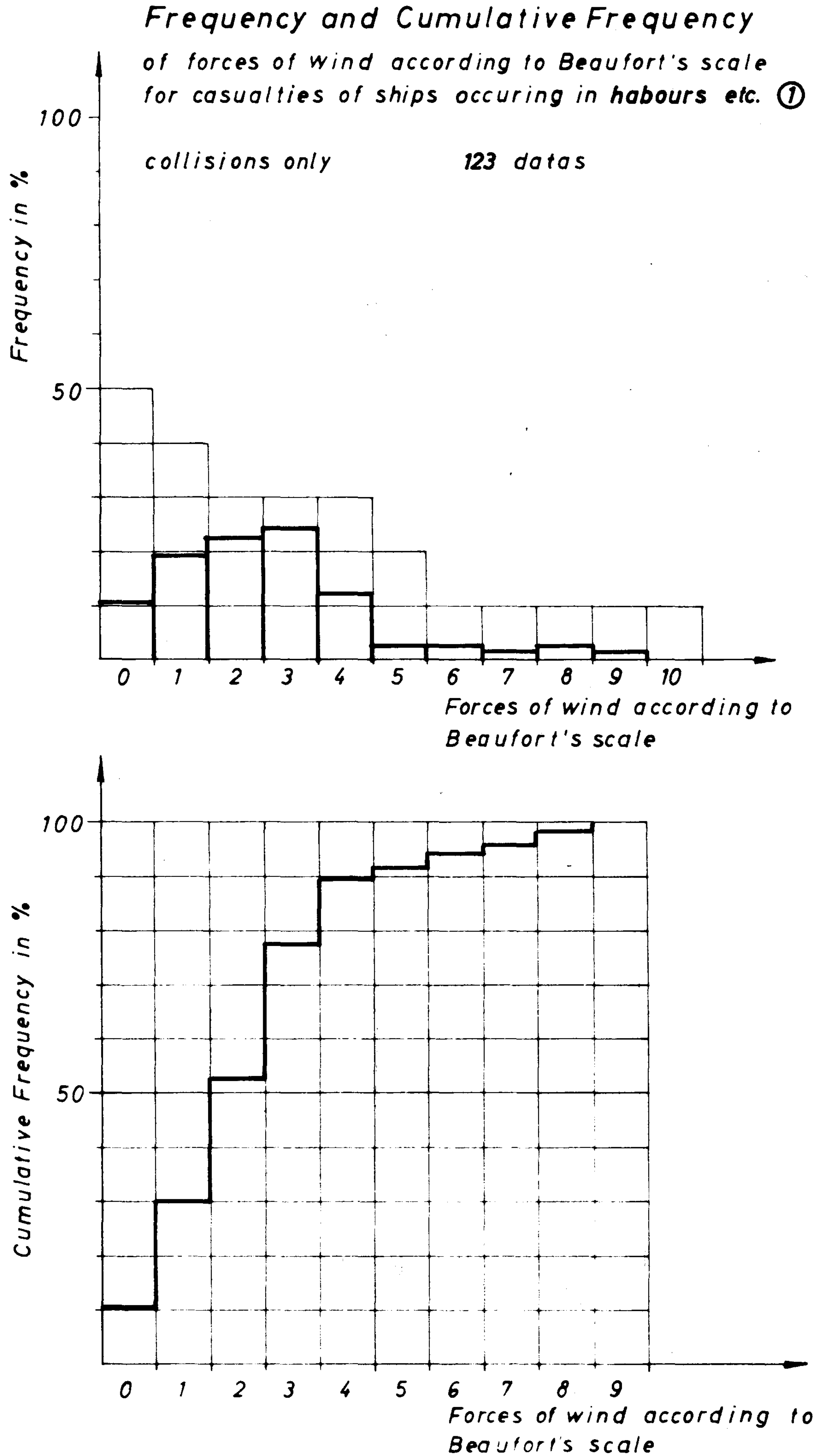
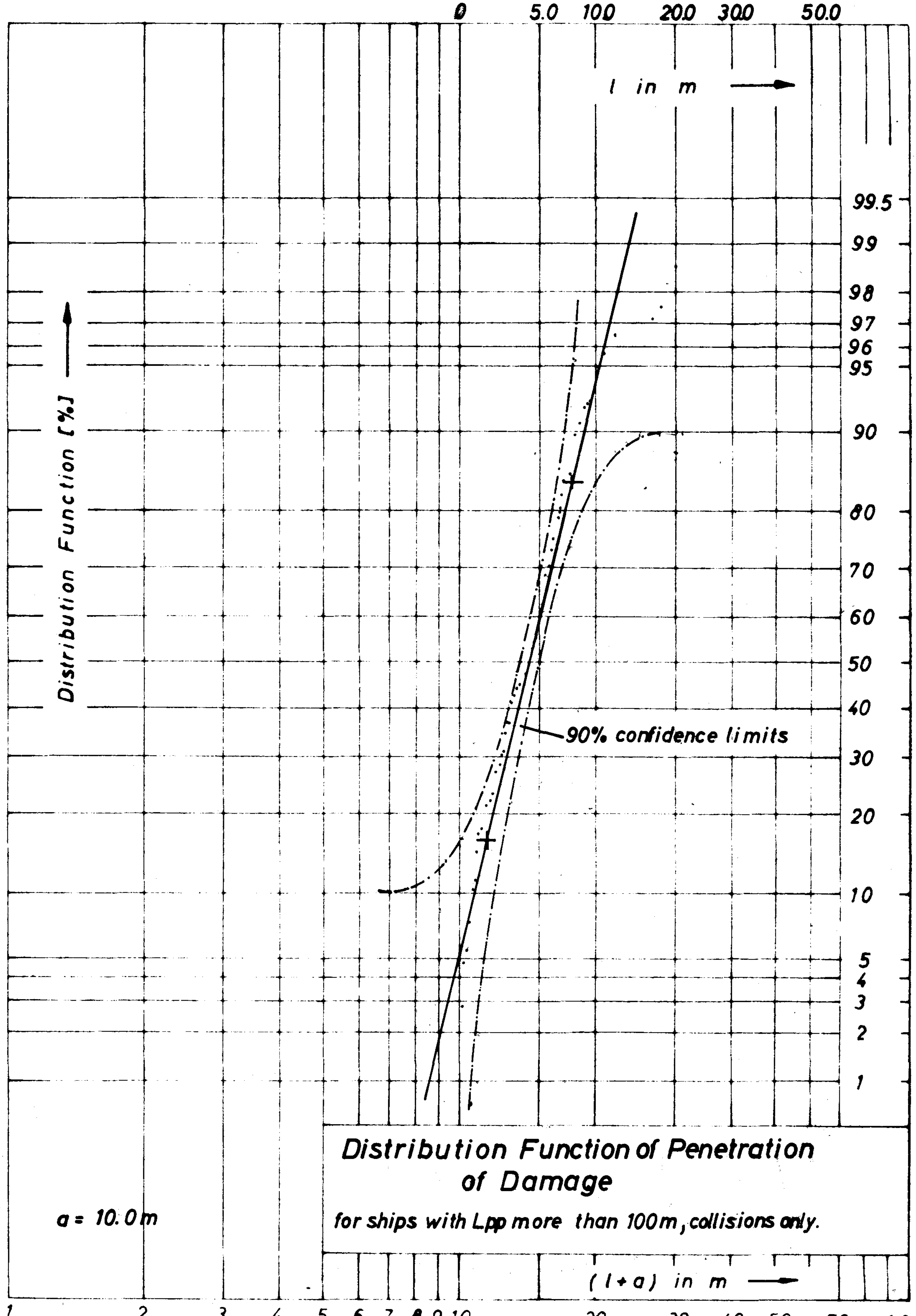

Frequency and Cumulative Frequency
of forces of wind according to Beaufort's scale
for casualties of ships occuring in habours etc. ①
collisions only
123 datas
100
50
Frequency in %
0 1 2 3 4 5 6 7 8 9 10
Forces of wind according to Beaufort's scale
100
50
Cumulative Frequency in %
0 1 2 3 4 5 6 7 8 9
Forces of wind according to Beaufort's scale

Fig. 5. 1. 02



0
5.0
10.0
20.0
30.0
50.0
l in m
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
Distribution Function [%]
90% confidence limits
Distribution Function of Penetration of Damage
for ships with Lpp more than 100m, collisions only.
a = 10.0 m
(l+a) in m
1
2
3
4
5
6
7
8
9
10
20
30
40
50
70
100

Fig. 2.0.04

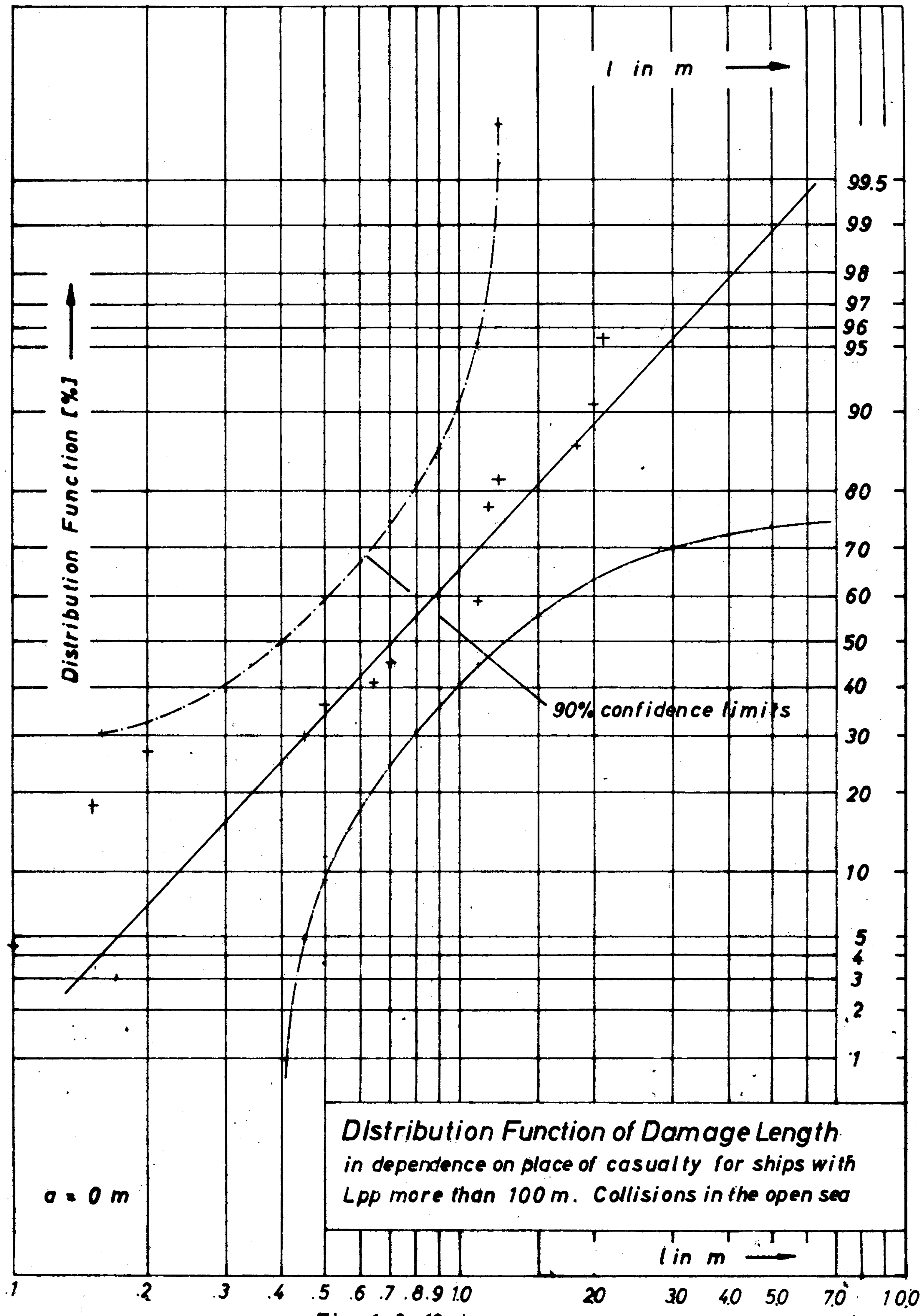
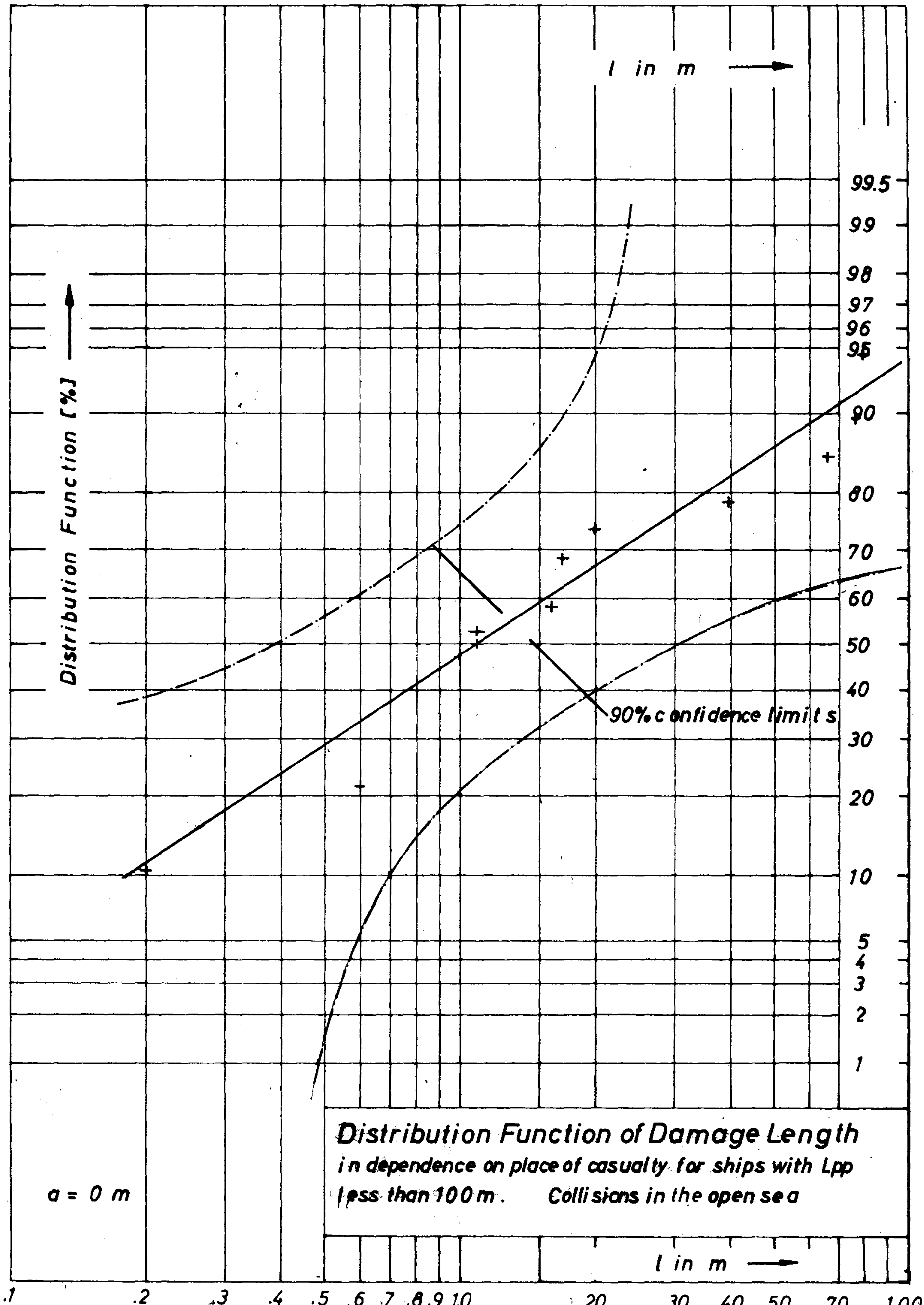

l in m
Distribution Function [%]
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
90% confidence limits
Distribution Function of Damage Length
in dependence on place of casualty for ships with
Lpp more than 100 m. Collisions in the open sea
a = 0 m
l in m
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
2.0
3.0
4.0
5.0
7.0
10.0

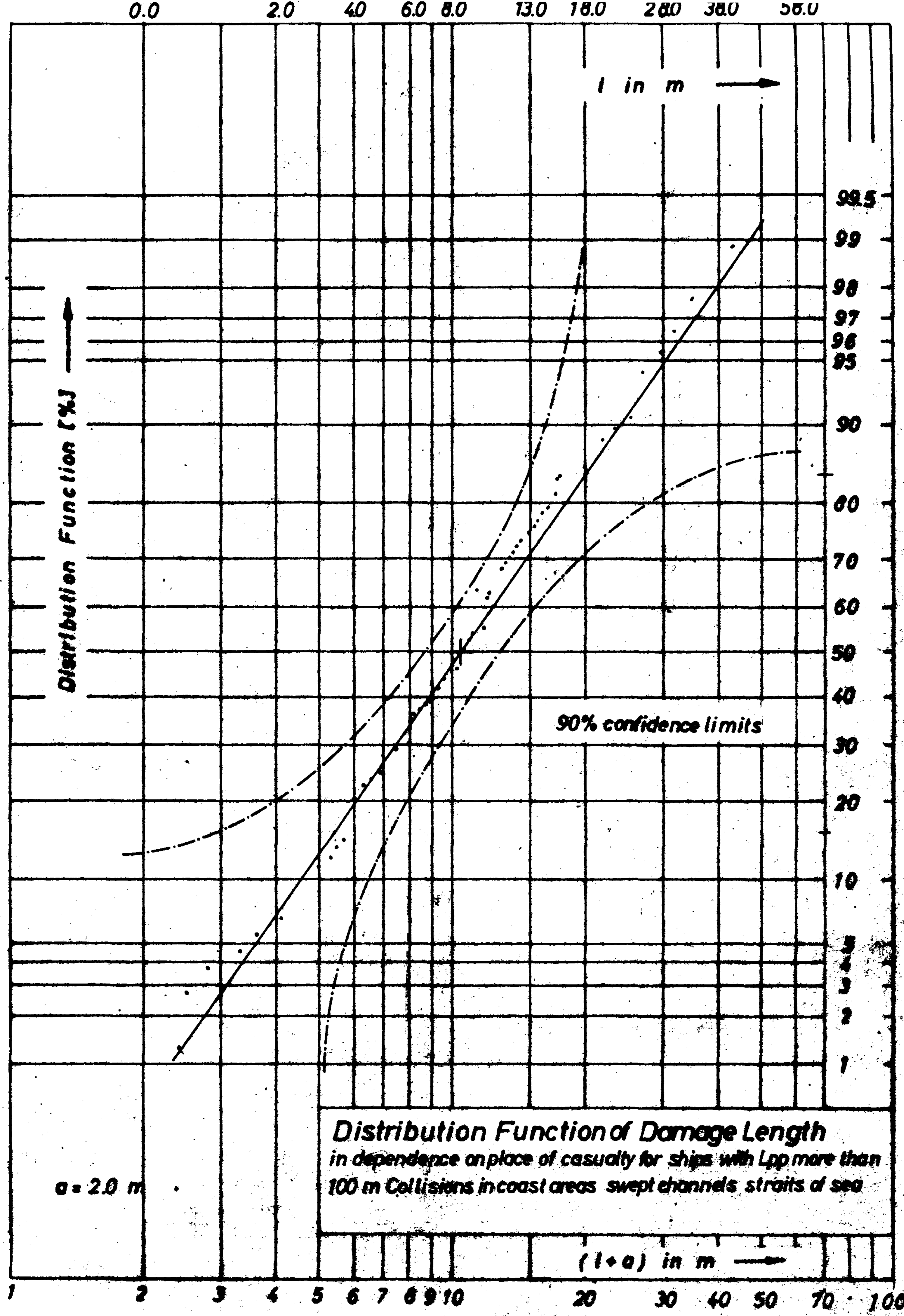
Fig. 1. 3. 12



Distribution Function of Damage Length

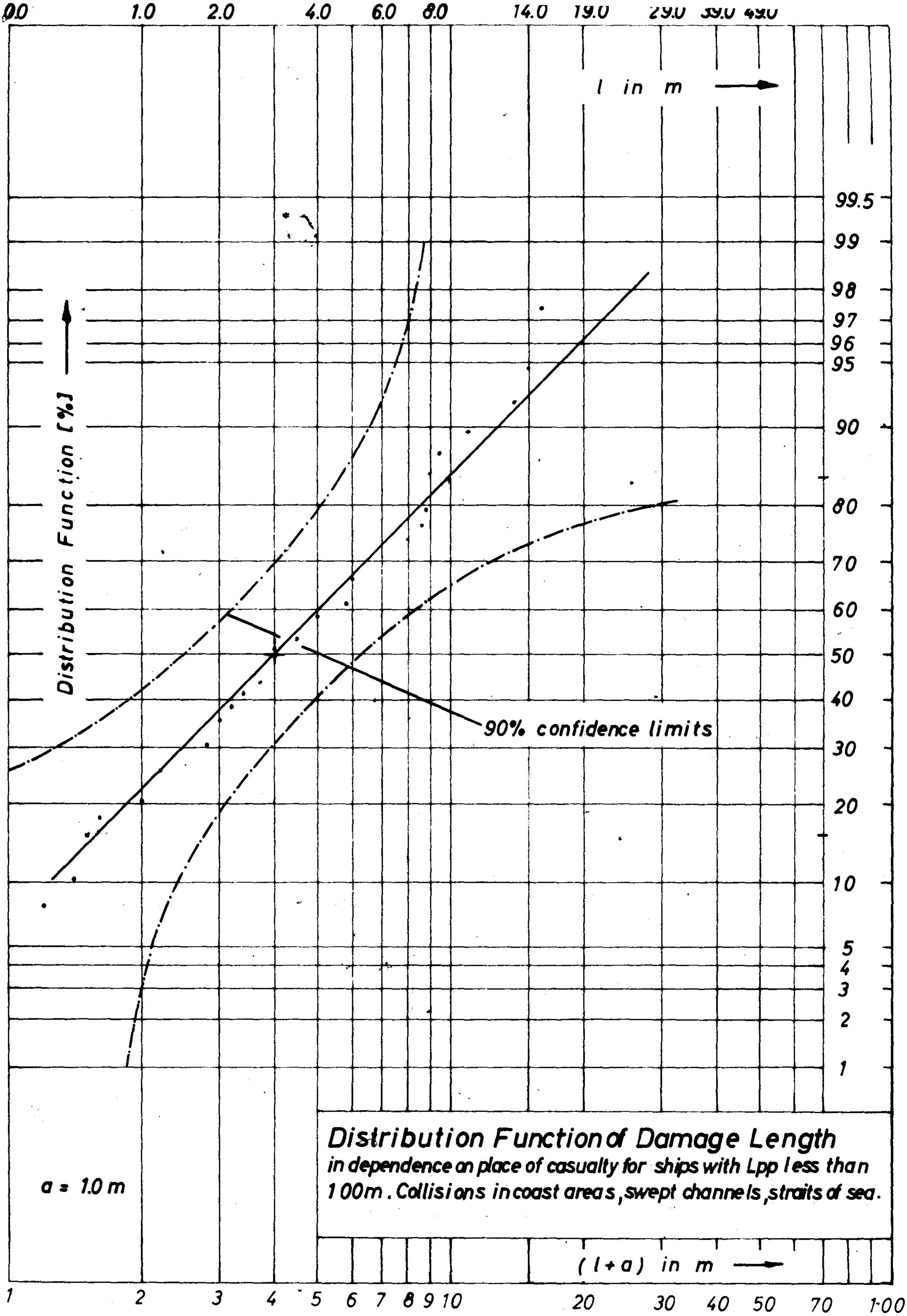
in dependence on place of casualty for ships with Lpp less than 100 m. Collisions in the open sea

Fig. 1.3.10



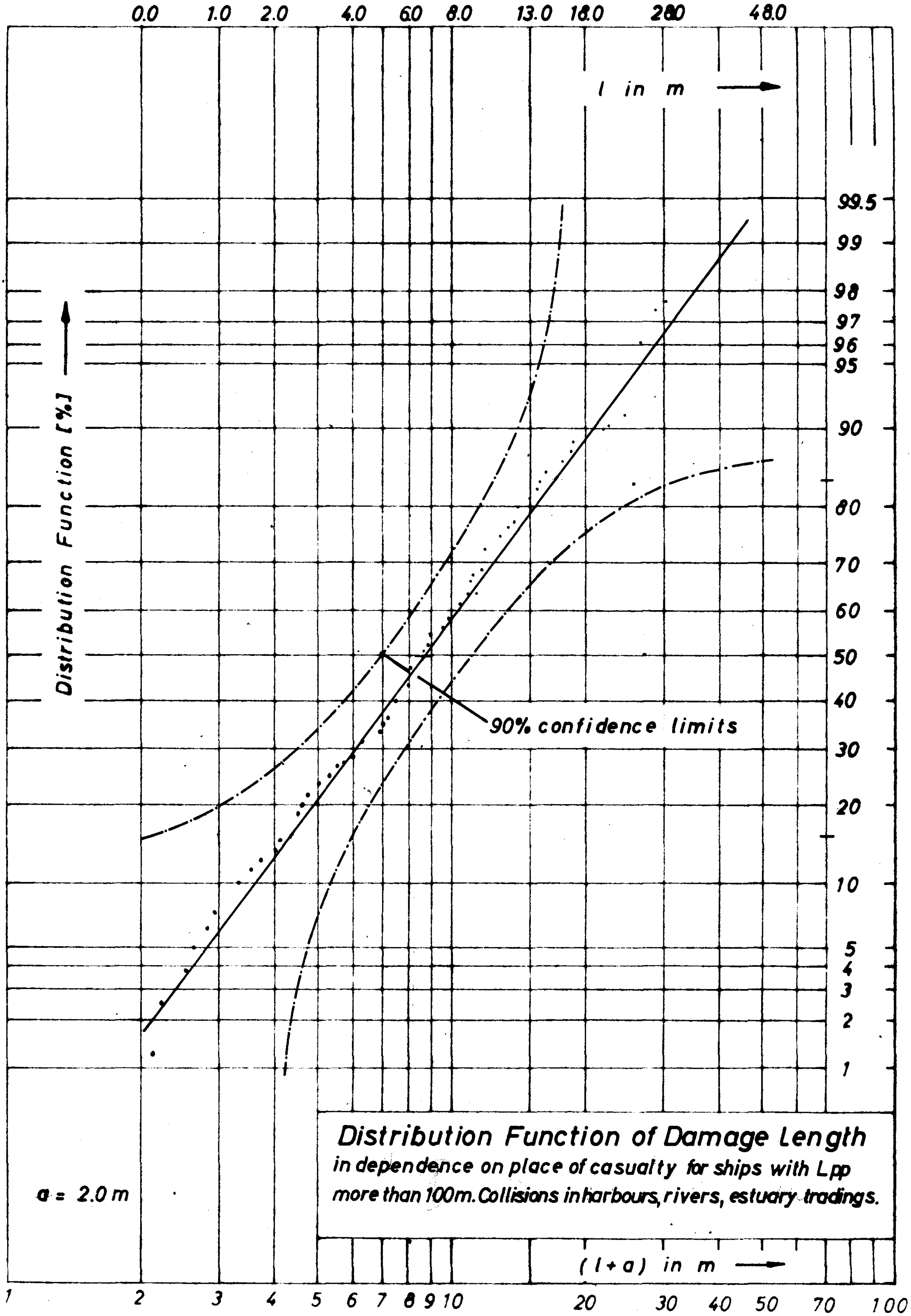
Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp more than 100 m Collisions in coast areas swept channels straits of sea

Fig. I.3.08



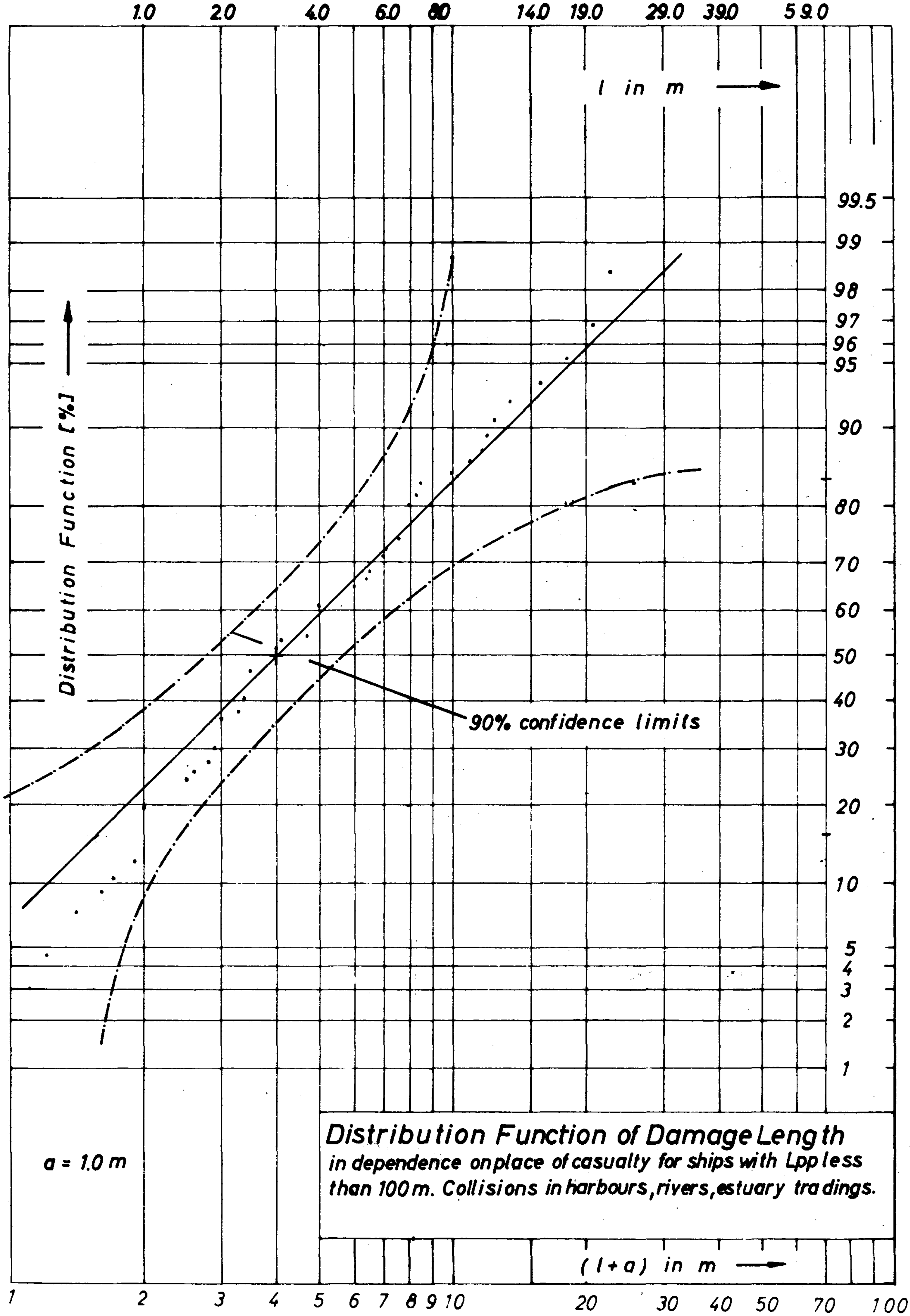
0.0
1.0
2.0
4.0
6.0
8.0
14.0
19.0
29.0
39.0
49.0
l in m
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
Distribution Function [%]
90% confidence limits
a = 1.0 m
Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp less than 100m. Collisions in coast areas, swept channels, straits of sea.
(l+a) in m
1
2
3
4
5
6
7
8
9
10
20
30
40
50
70
1·00

Fig. 1.3.06



0.0 1.0 2.0 4.0 6.0 8.0 13.0 18.0 28.0 48.0
l in m
Distribution Function [%]
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
90% confidence limits
Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp more than 100m. Collisions in harbours, rivers, estuary tradings.
a = 2.0 m
(l+a) in m
1 2 3 4 5 6 7 8 9 10 20 30 40 50 70 100

Fig.1.3.04



1.0 2.0 4.0 6.0 8.0 14.0 19.0 29.0 39.0 59.0
l in m
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
Distribution Function [%]
90% confidence limits
a = 1.0 m
Distribution Function of Damage Length
in dependence on place of casualty for ships with Lpp less than 100 m. Collisions in harbours, rivers, estuary tradings.
(l+a) in m
1 2 3 4 5 6 7 8 9 10 20 30 40 50 70 100

Fig. 1.3.02

Distribution Function of Damage Length

Lpp in a range from 150 to 170 m

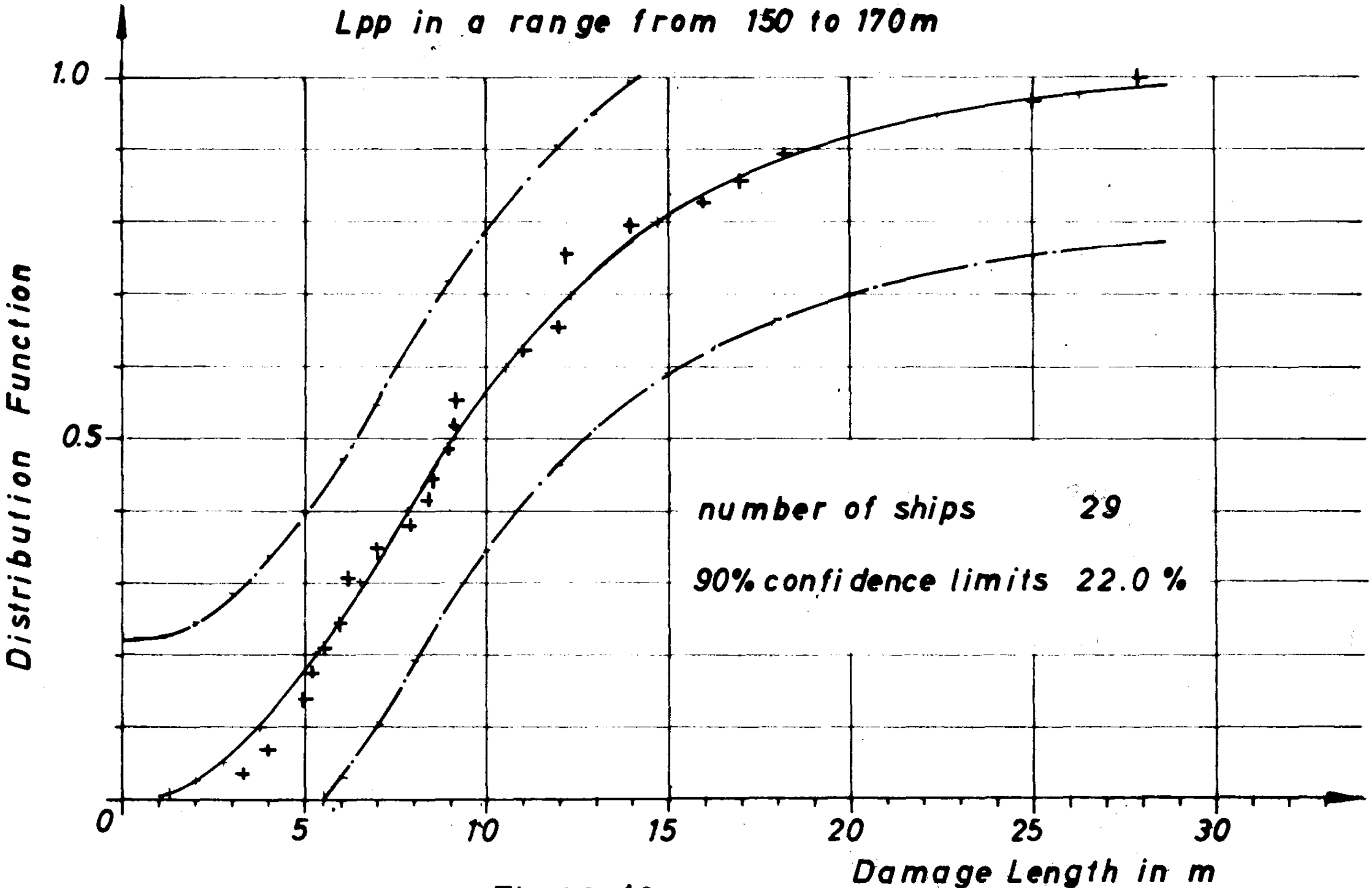


Fig. 1.2. 19

Distribution Function of Damage Length

Lpp more than 170 m

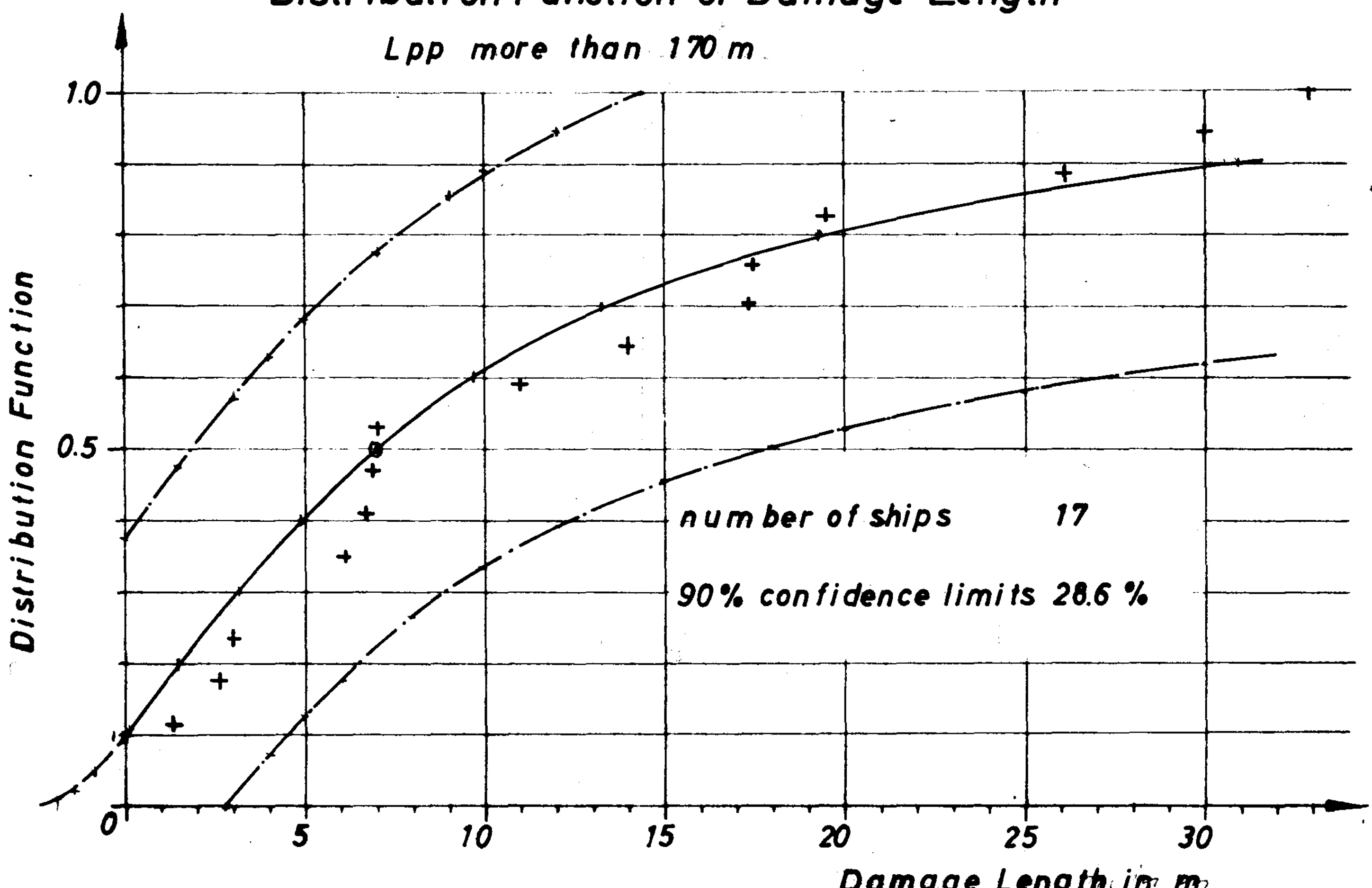


Fig. 1.2. 20

Distribution Function of Damage Length

Lpp in a range from 130 to 140 m

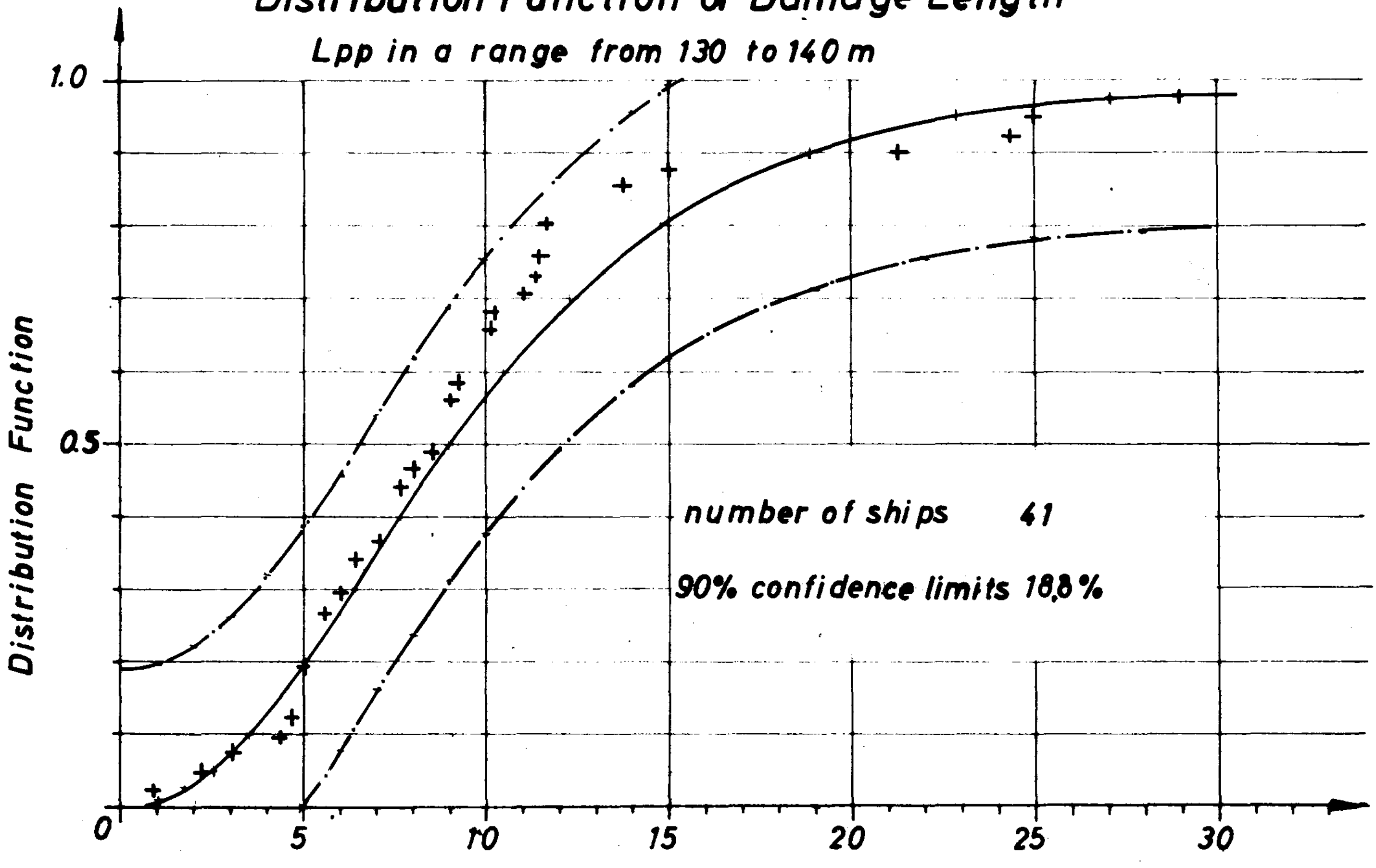


Fig. 1.2.17

Distribution Function of Damage Length

Lpp in a range from 140 to 150 m

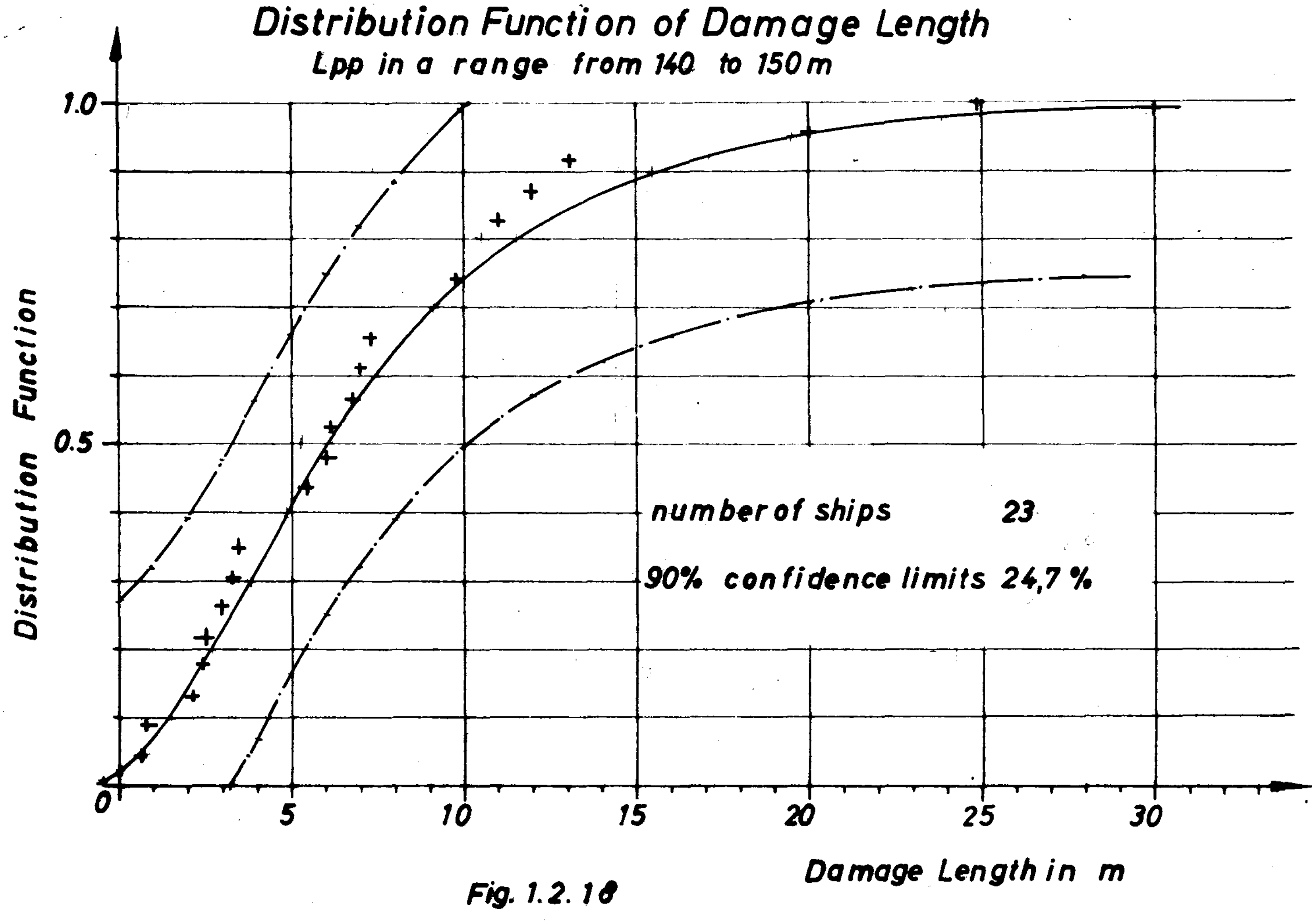


Fig. 1.2.18

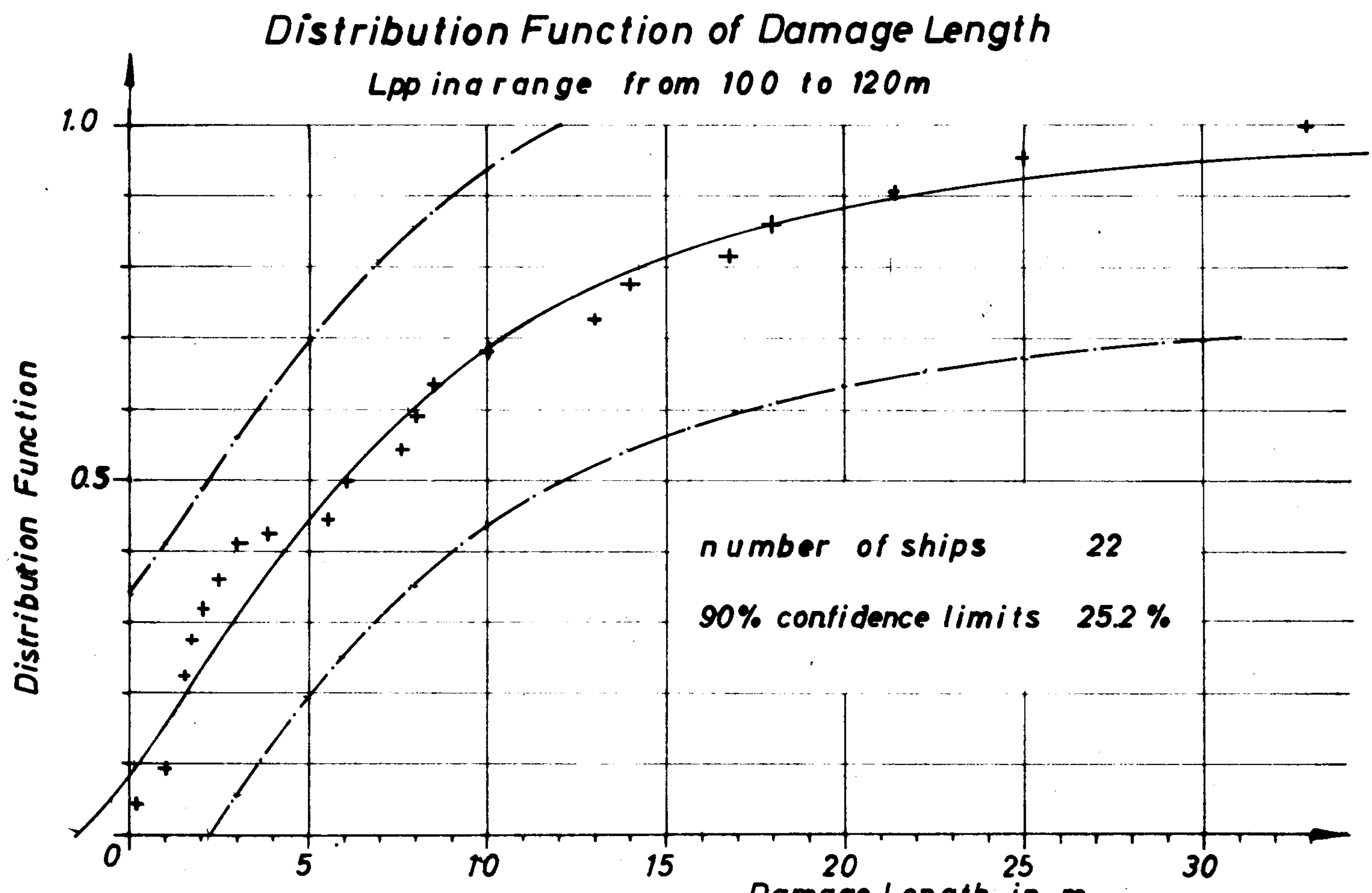


Fig. 1.2.15

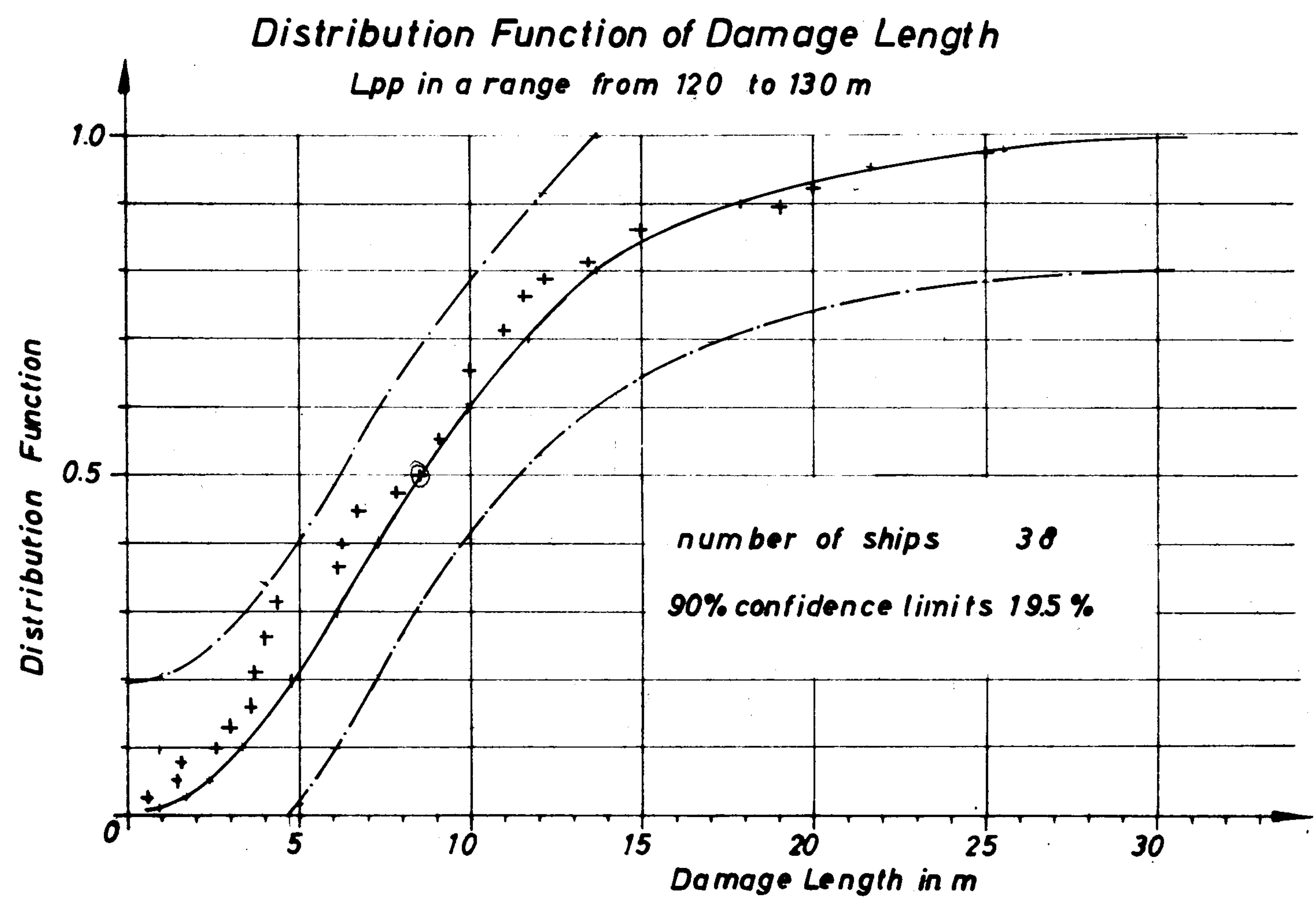


Fig. 1.2.16

Distribution Function of Damage Length

Lpp in a range from 60 to 80 m

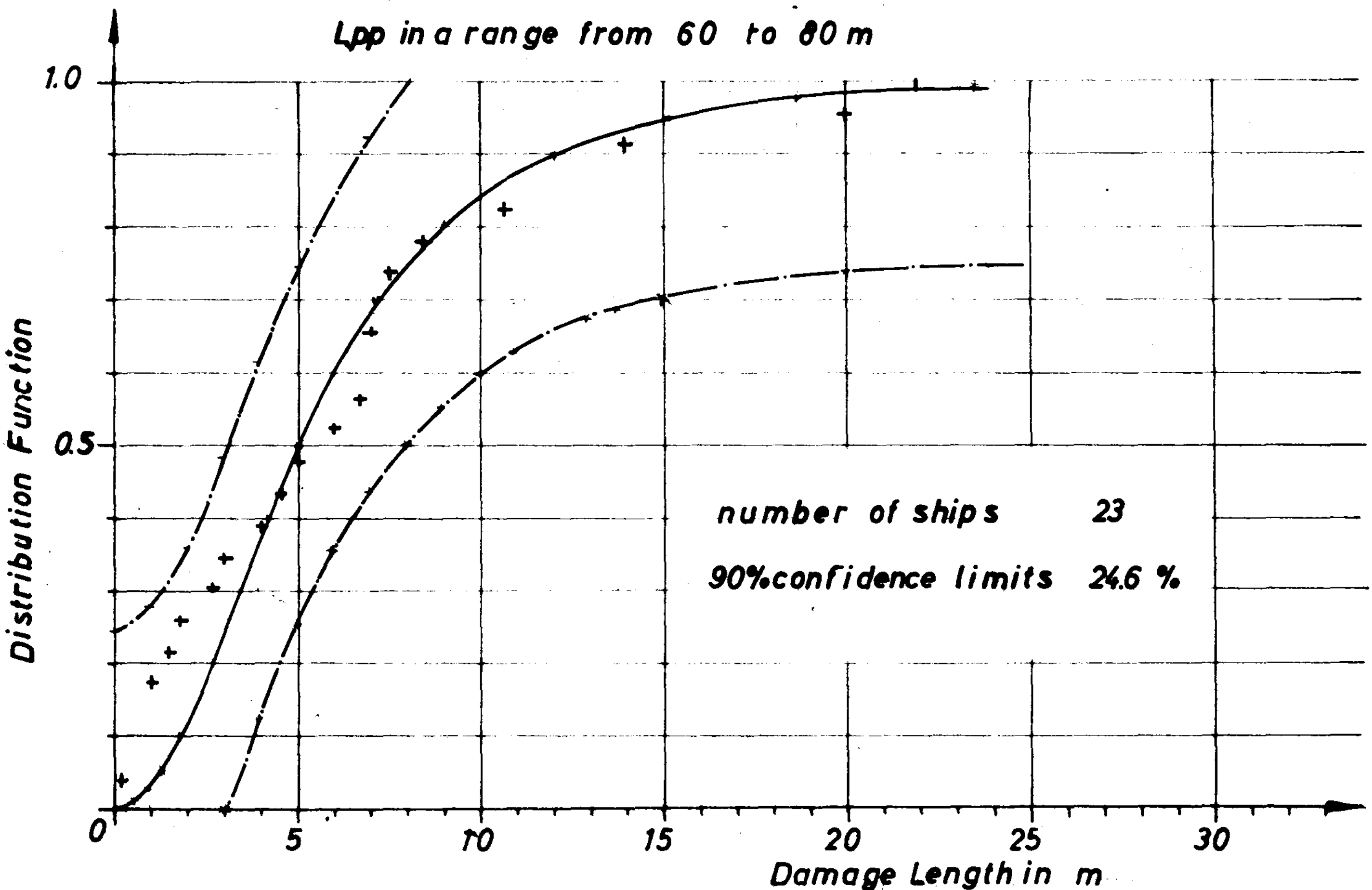


Fig. 1.2.13

Distribution Function of Damage Length

Lpp in a range from 80 to 100 m

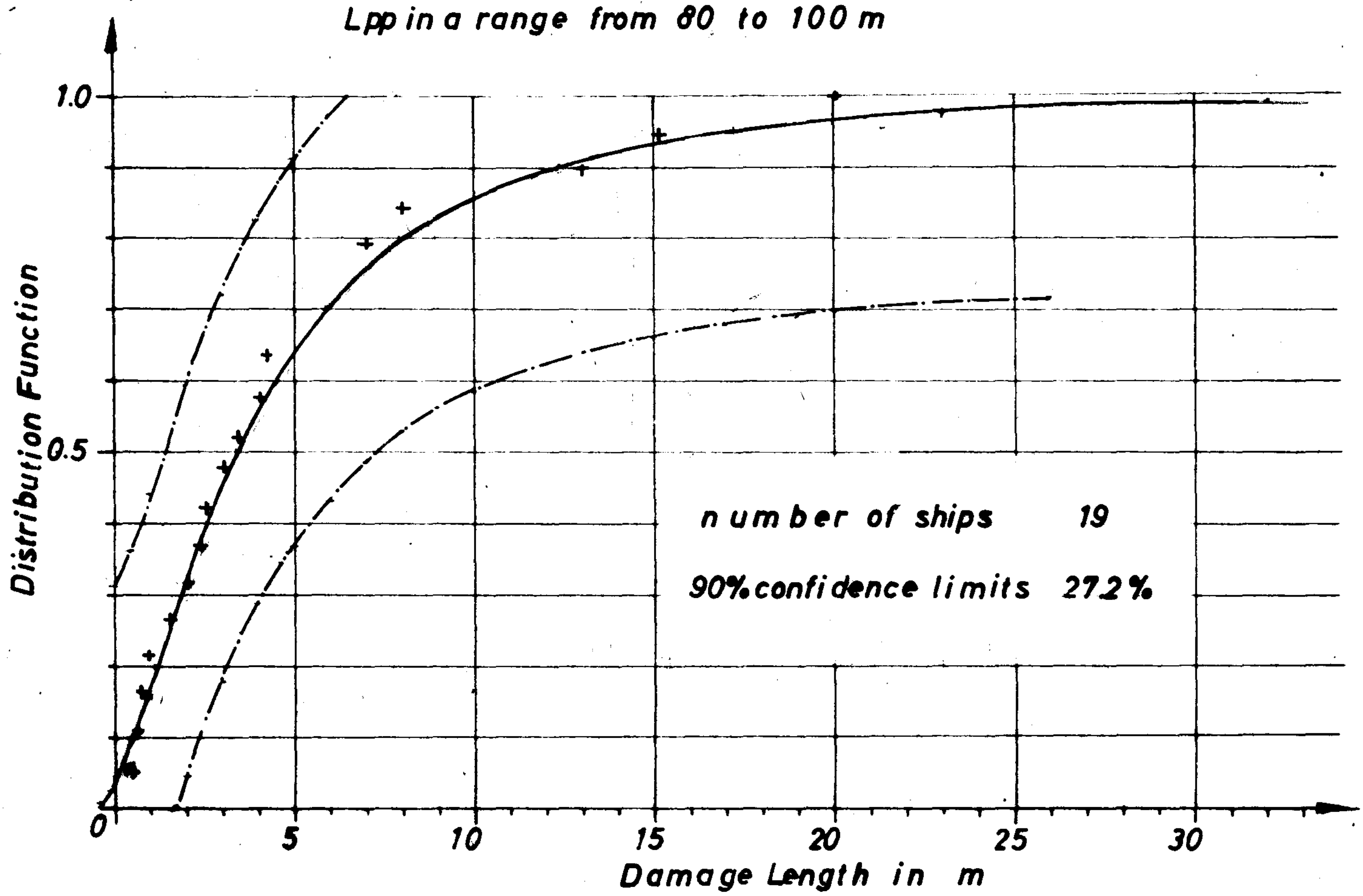


Fig. 1.2.14

Distribution Function of Damage Length

Lpp in a range from 2 5 to 40 m

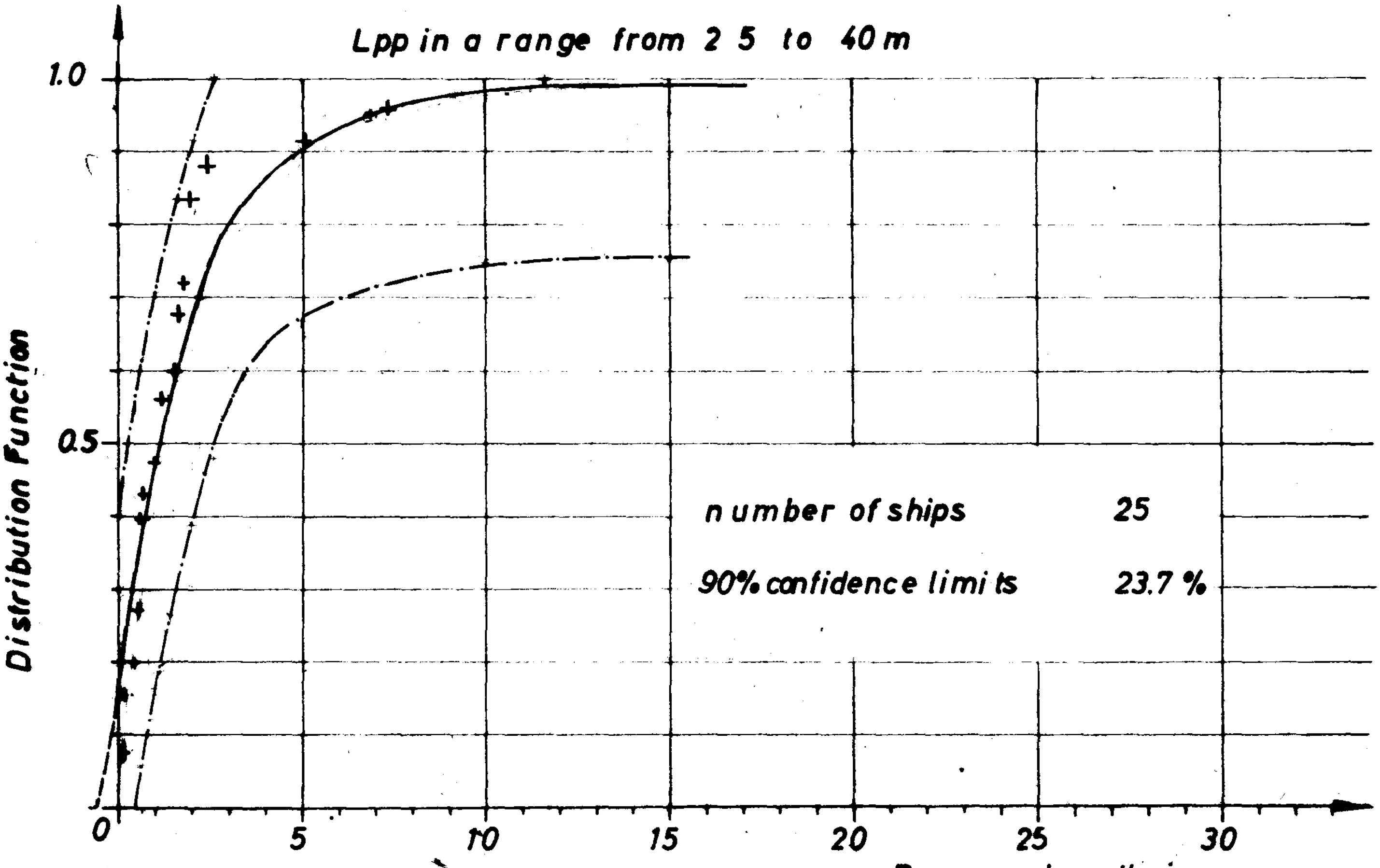


Fig. 1.2. 11

Distribution Function of Damage Length

Lpp in a range from 40 to 60 m

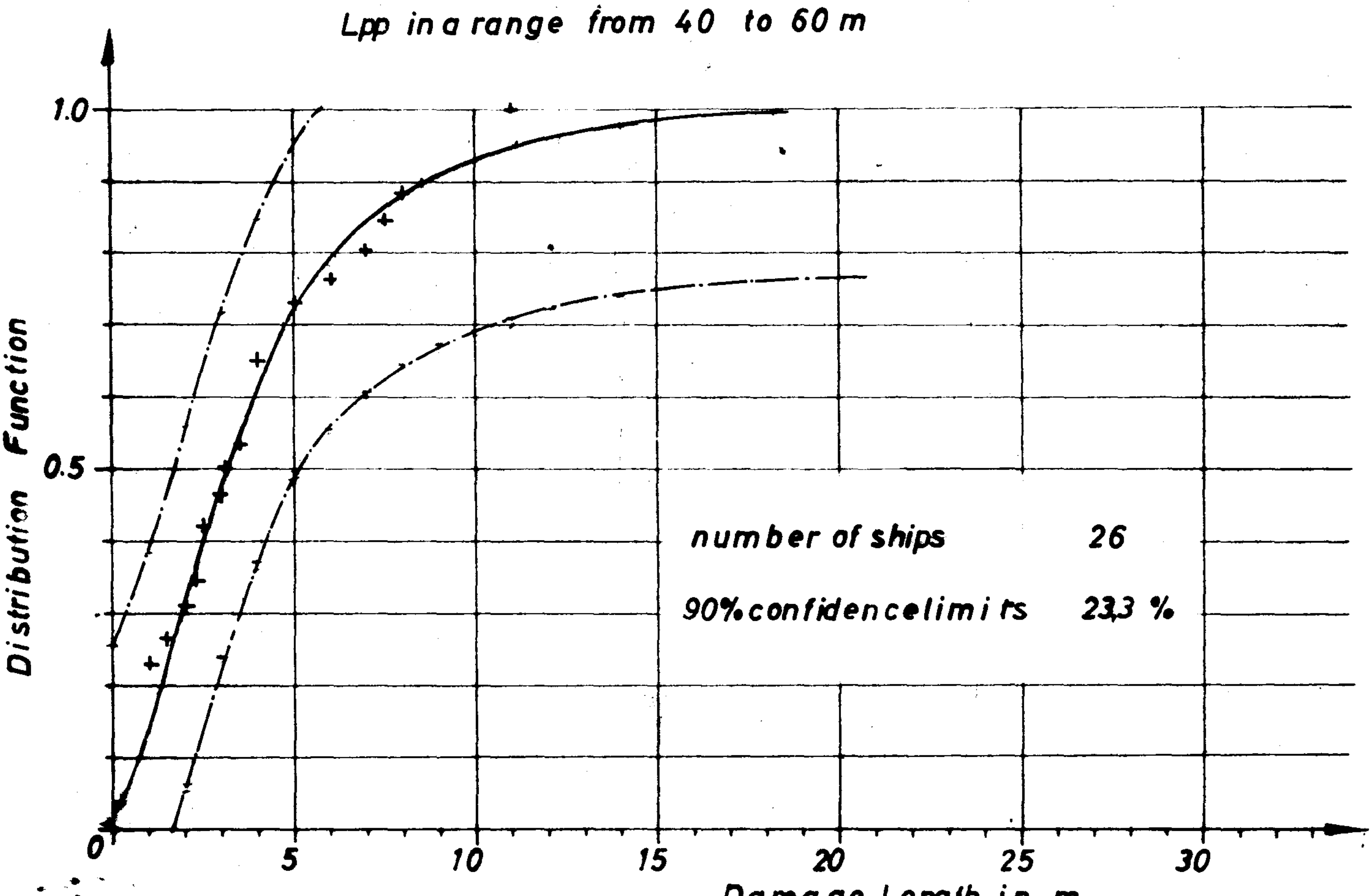


Fig. 1.2. 12

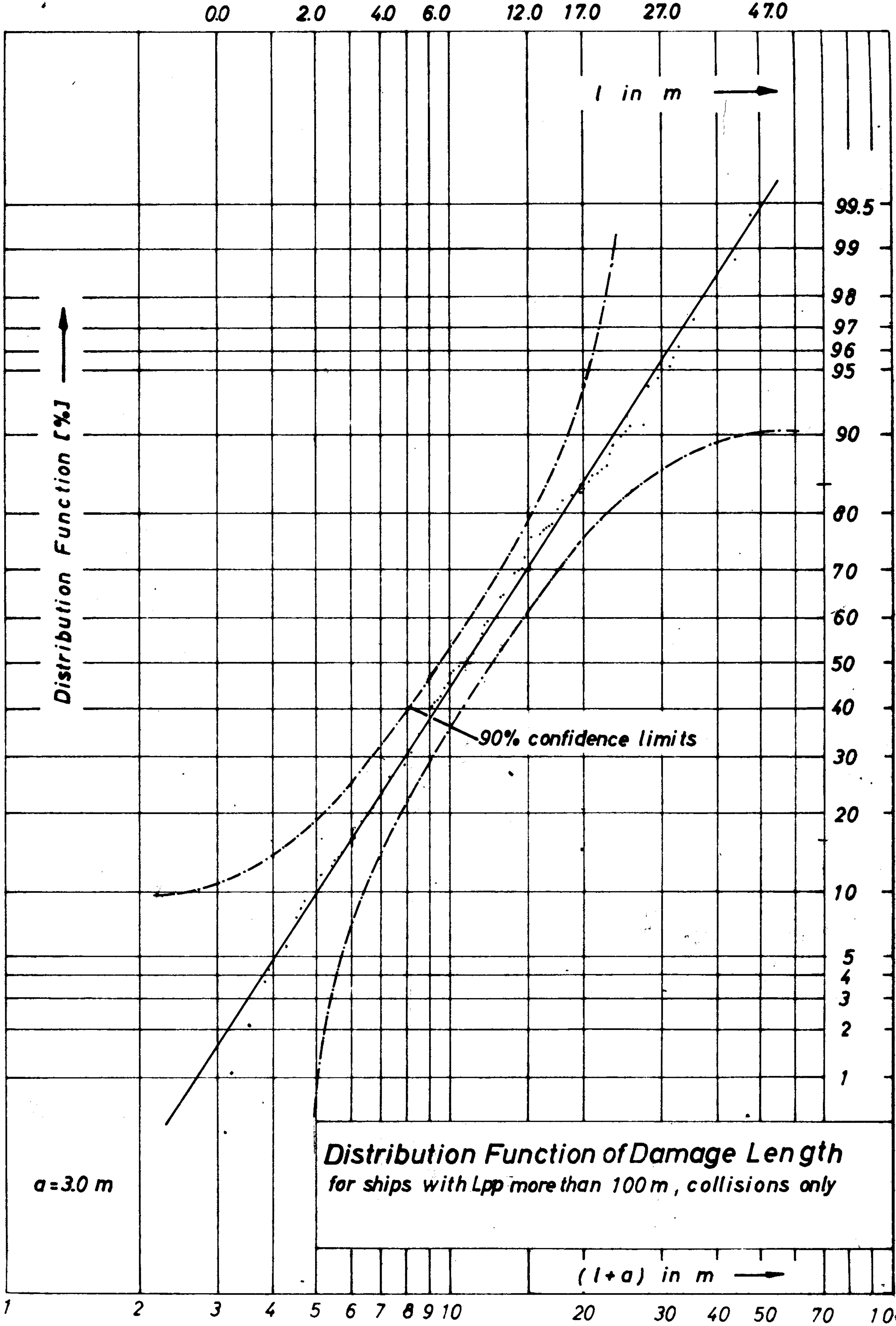

0.0
2.0
4.0
6.0
12.0
17.0
27.0
47.0
l in m
Distribution Function [%]
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
90% confidence limits
a=3.0 m
Distribution Function of Damage Length
for ships with Lpp more than 100 m, collisions only
(l+a) in m
1
2
3
4
5
6
7
8
9
10
20
30
40
50
70
100

Fig. 1.1. 06

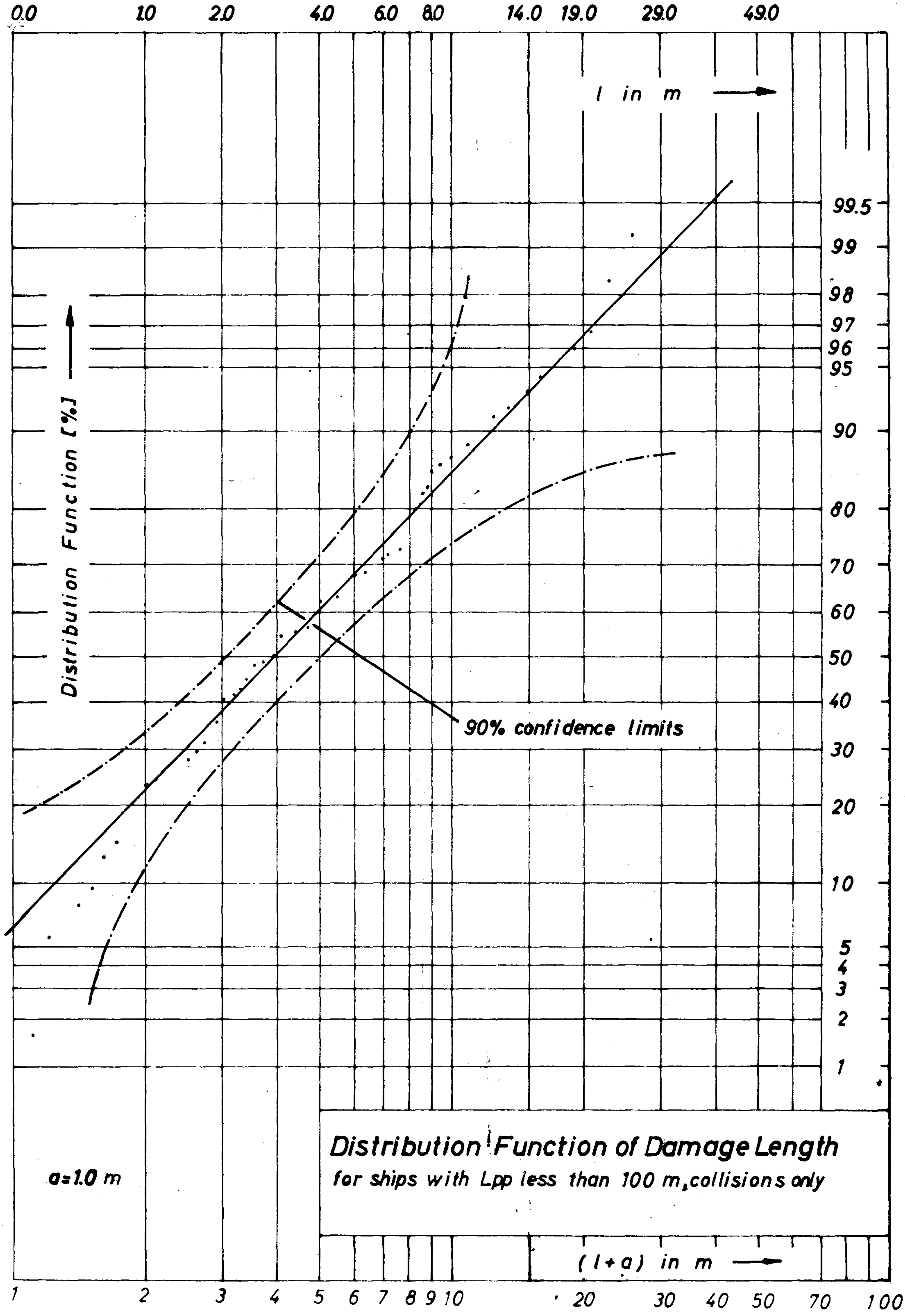

0.0 1.0 2.0 4.0 6.0 8.0 14.0 19.0 29.0 49.0
l in m
99.5 99 98 97 96 95 90 80 70 60 50 40 30 20 10 5 4 3 2 1
Distribution Function [%]
90% confidence limits
a=1.0 m
Distribution Function of Damage Length
for ships with Lpp less than 100 m, collisions only
(l+a) in m
1 2 3 4 5 6 7 8 9 10 20 30 40 50 70 100

Fig. 1.1. 04

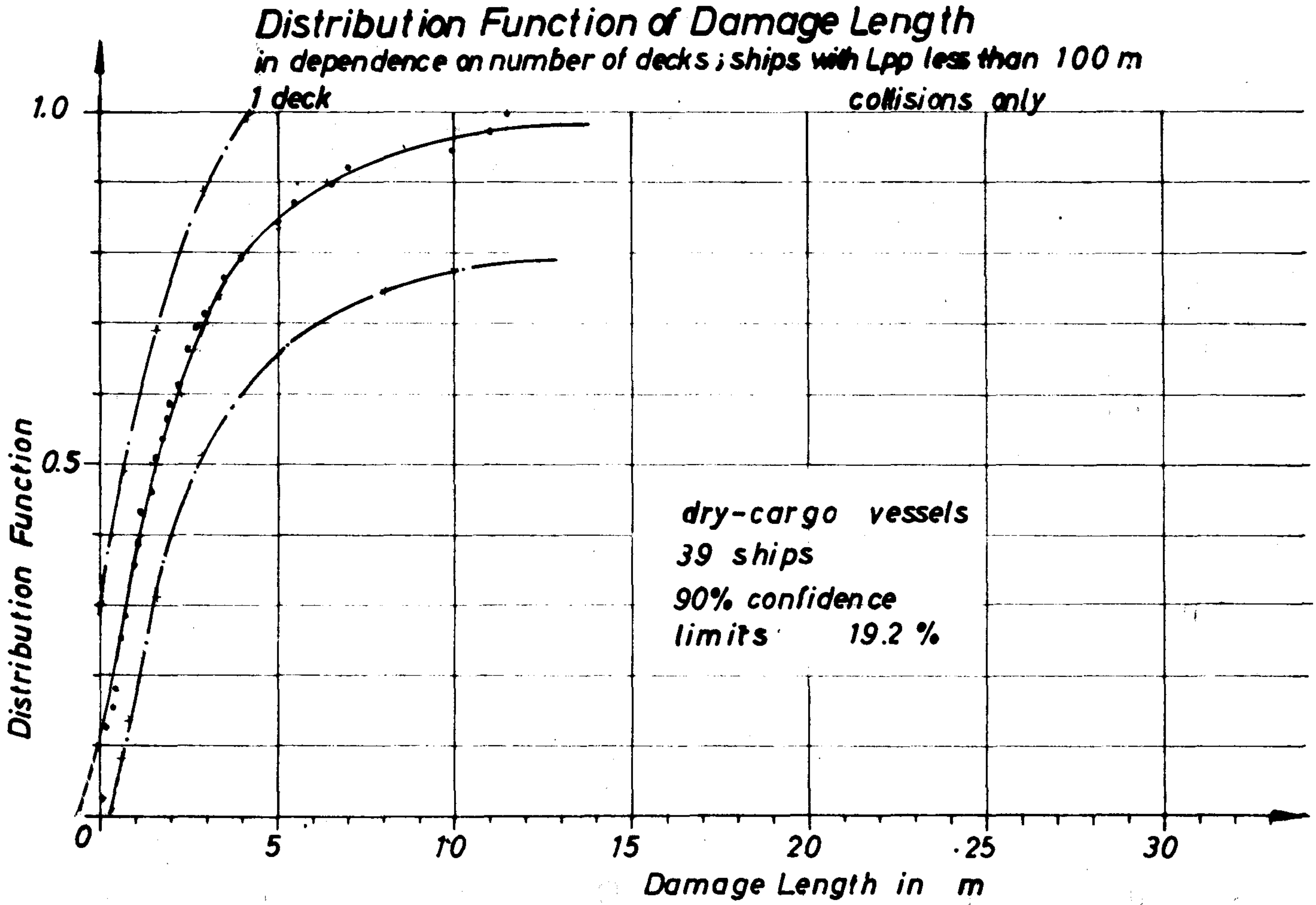


Fig. 6.0.02

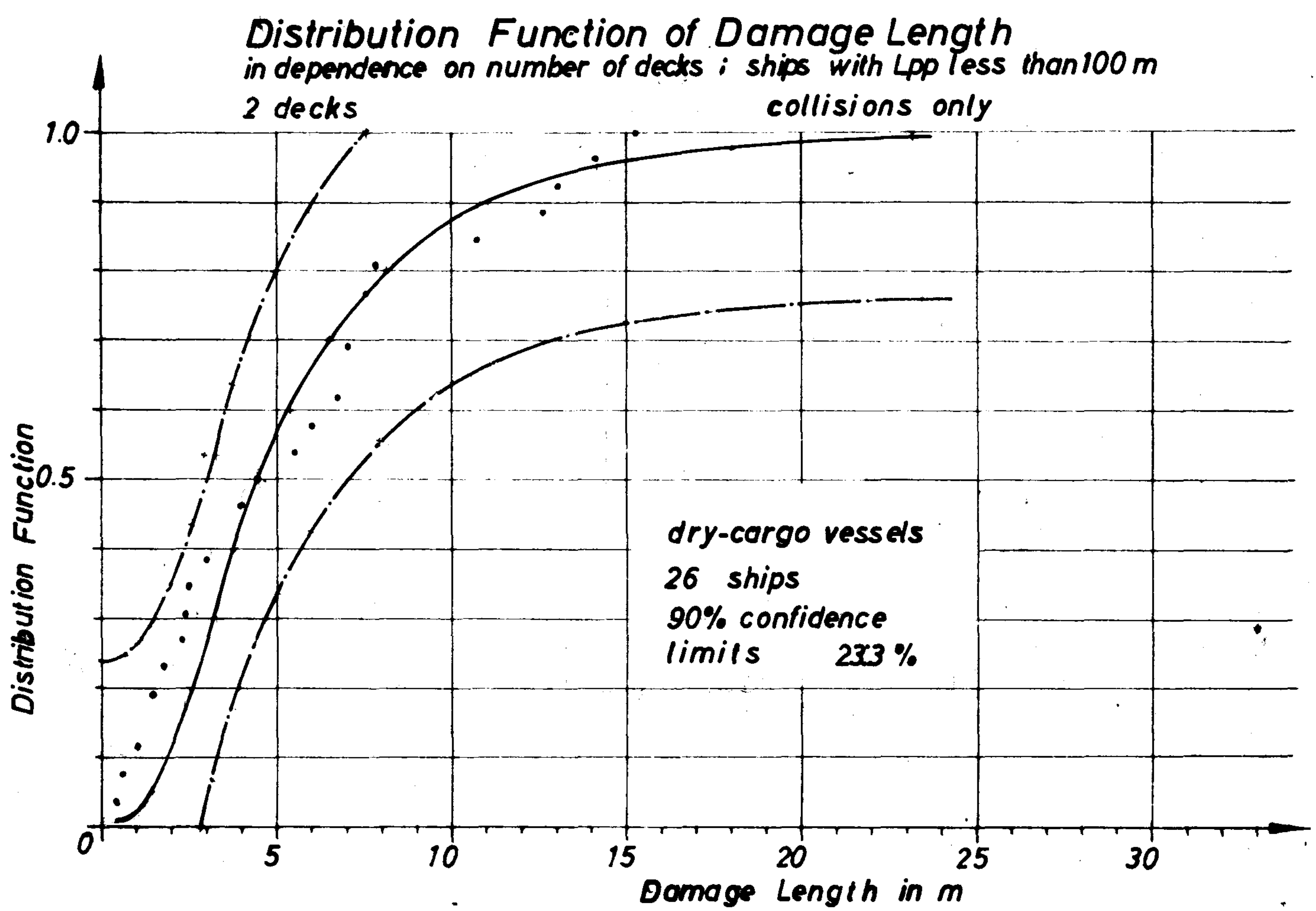


Fig. 6.0.03

Cumulative Frequency Polygon of Product l × b

Dependence of damage extension on number of decks ; Lpp less than 100 m

1 deck collisions only

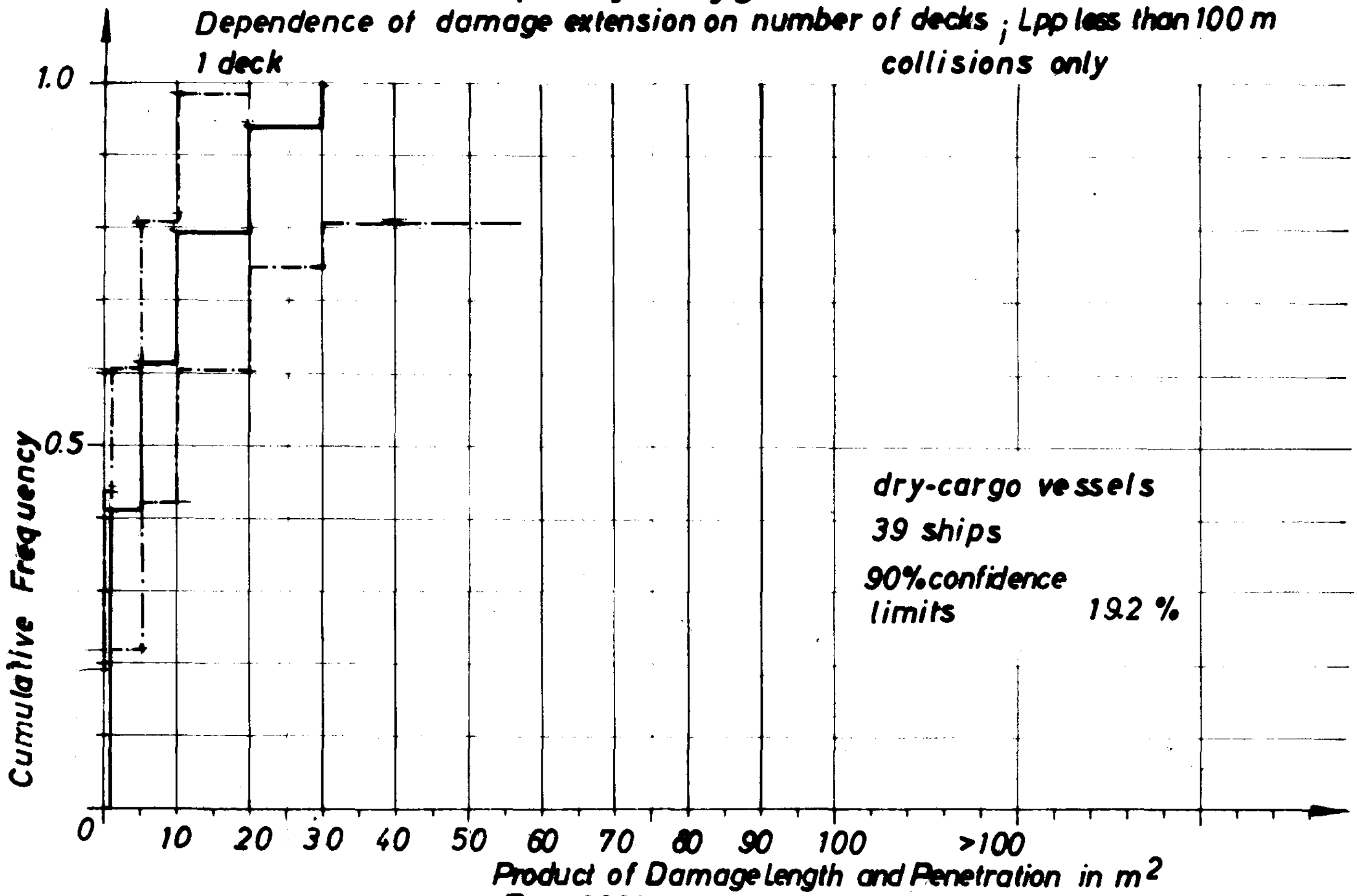


Fig. 6.0.04

Cumulative Frequency Polygon of Product l × b

Dependence of damage extension on number of decks; Lpp less than 100 m

2 decks collisions only

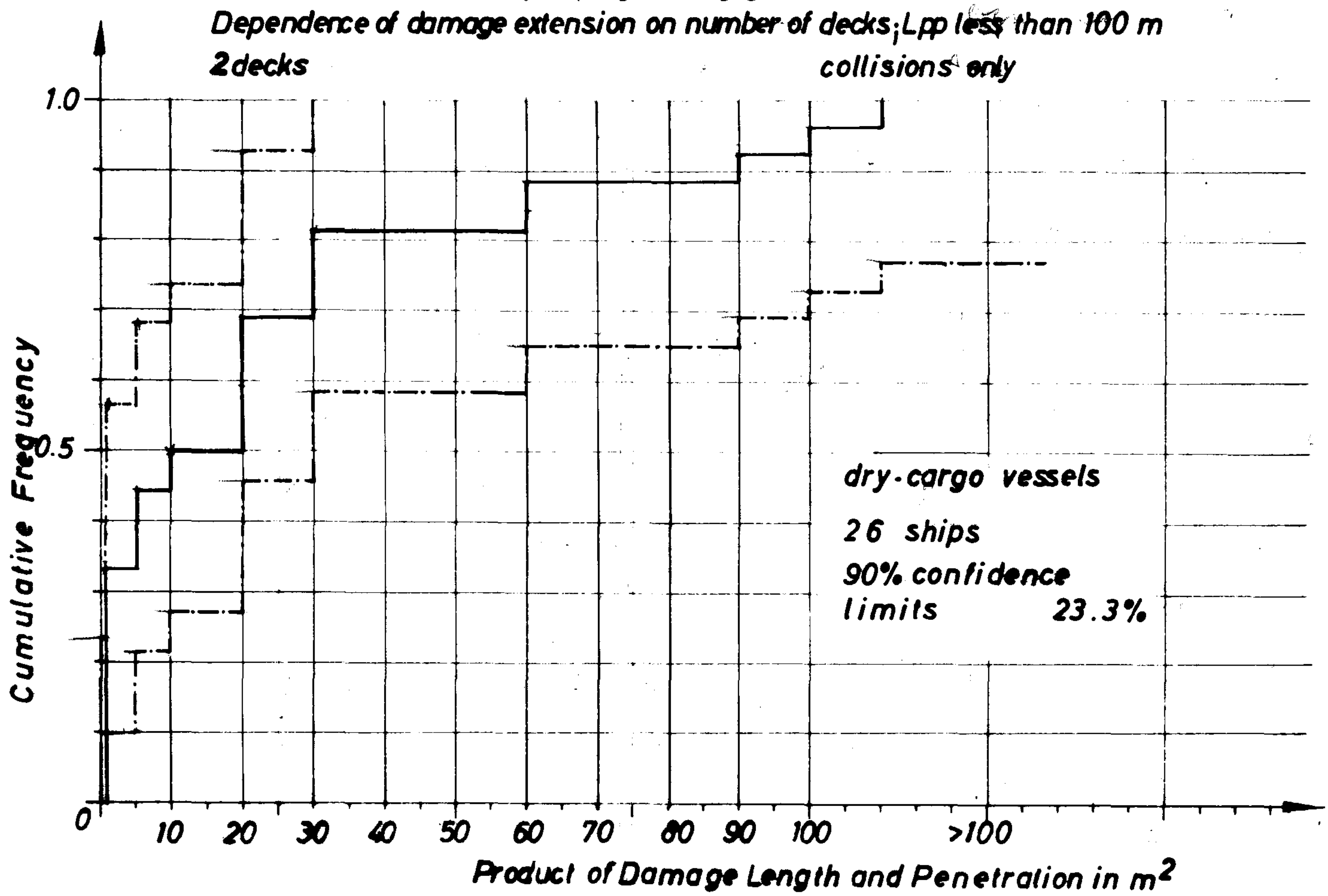
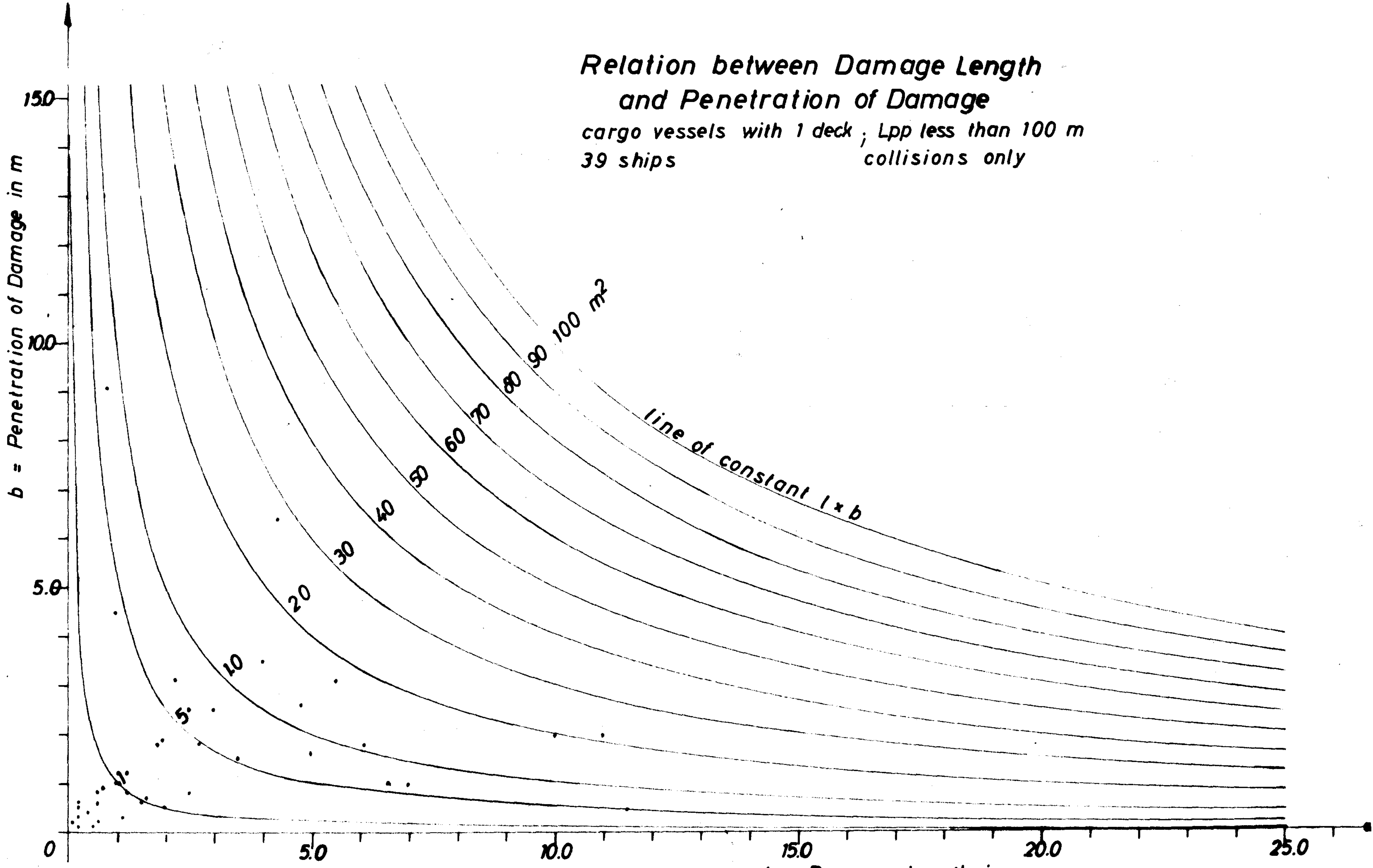


Fig. 6.0.05



Relation between Damage Length and Penetration of Damage
cargo vessels with 1 deck ; Lpp less than 100 m
39 ships
collisions only
b = Penetration of Damage in m
l = Damage Length in m
0
5.0
10.0
15.0
20.0
25.0
1
5
10
20
30
40
50
60
70
80
90
100 m²
line of constant l × b

Fig. 6.0.06

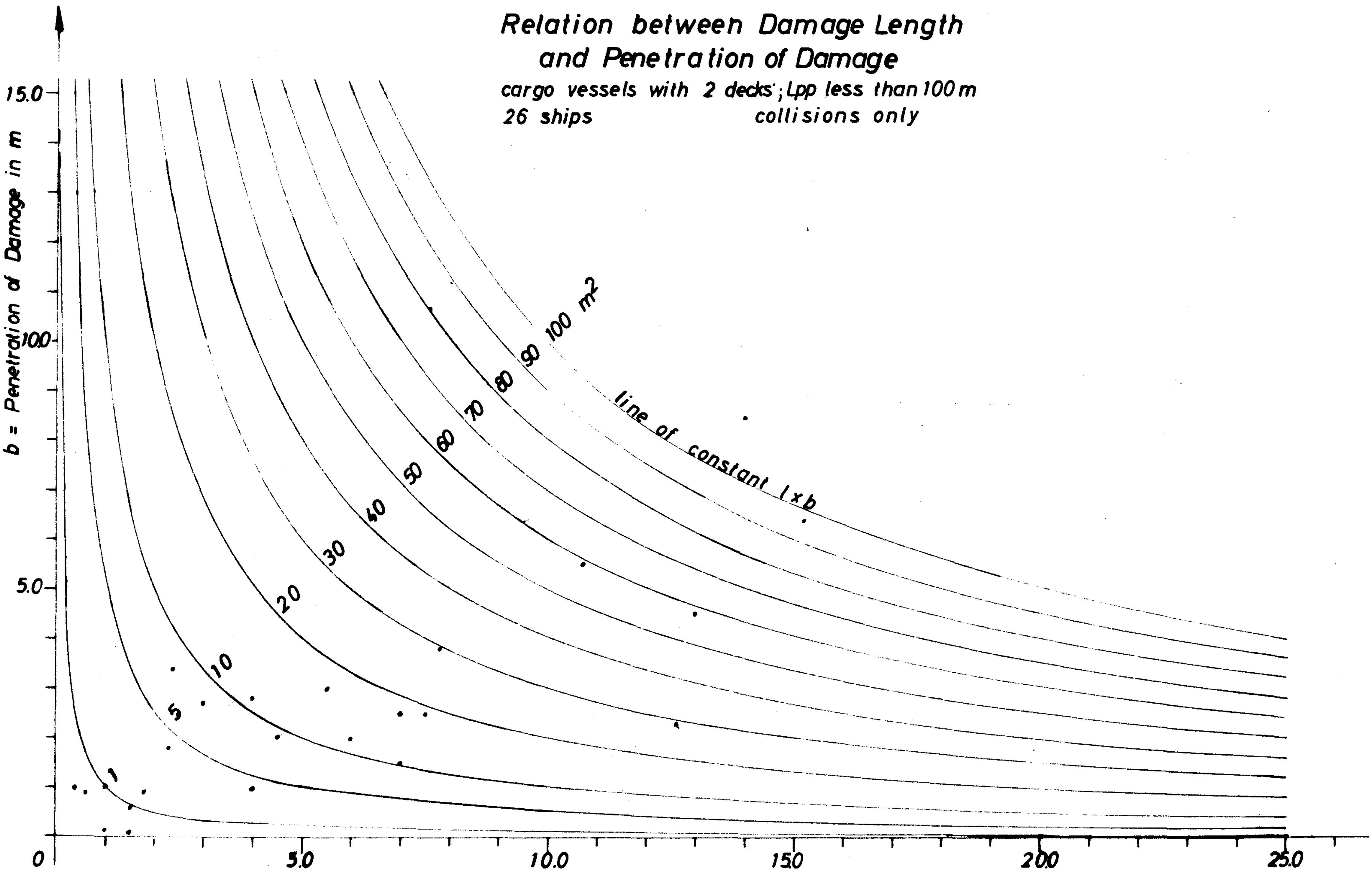

Relation between Damage Length
and Penetration of Damage
cargo vessels with 2 decks; Lpp less than 100 m
26 ships
collisions only
b = Penetration of Damage in m
15.0
10.0
5.0
0
1
5
10
20
30
40
50
60
70
80
90
100 m²
line of constant l x b
5.0
10.0
15.0
20.0
25.0
l = Damage Length in m

Fig 6.007

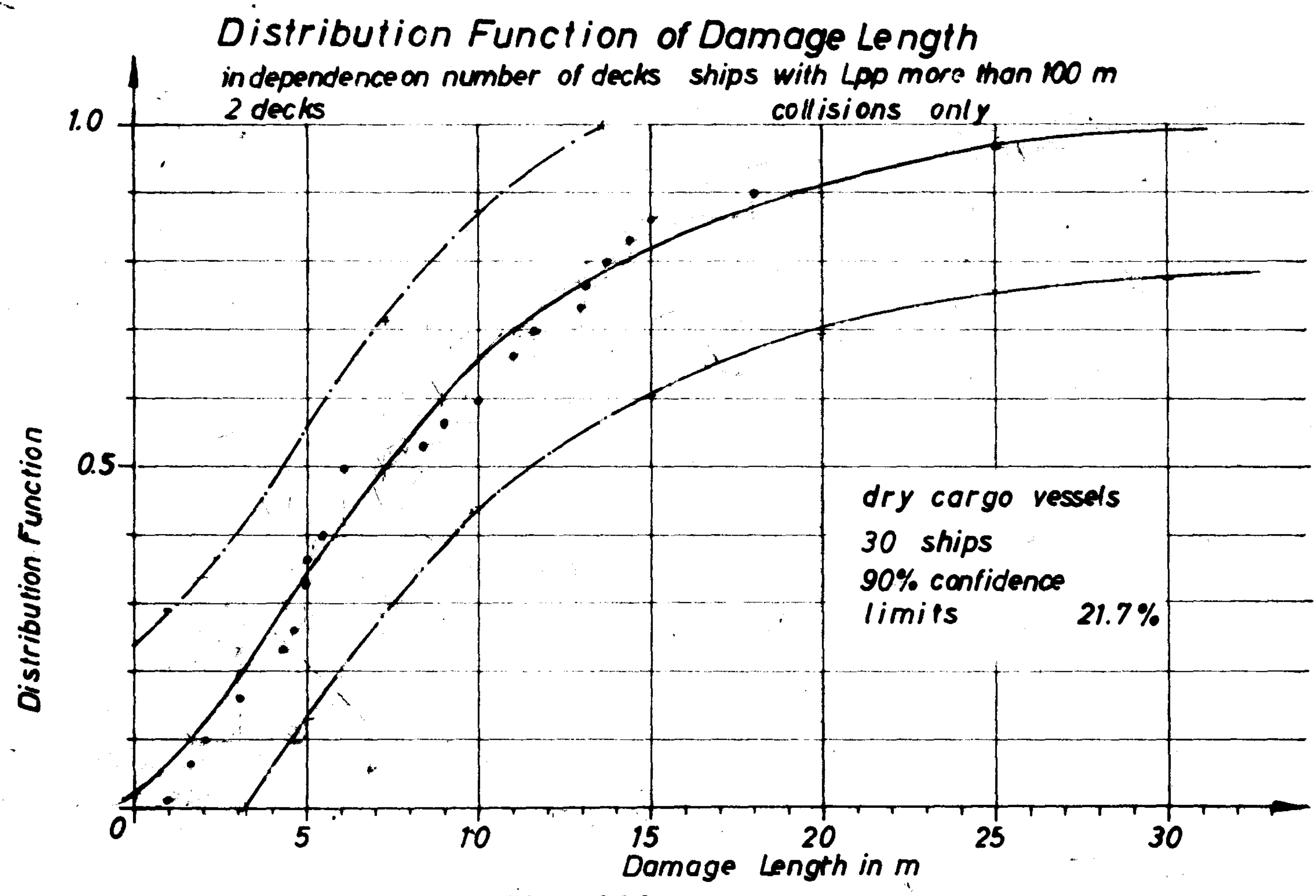


Fig. 6.0.08

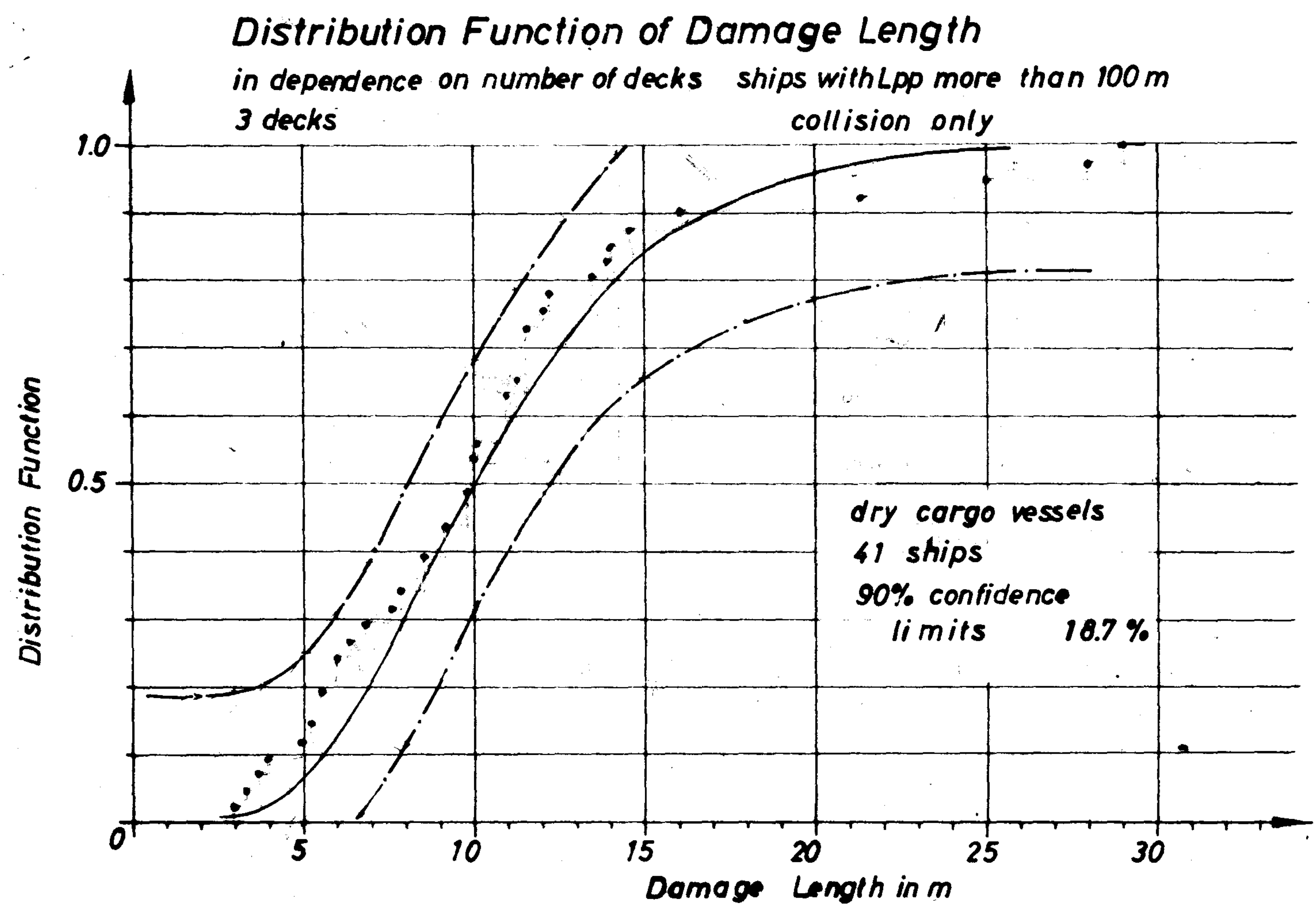


Fig. 6.0.09

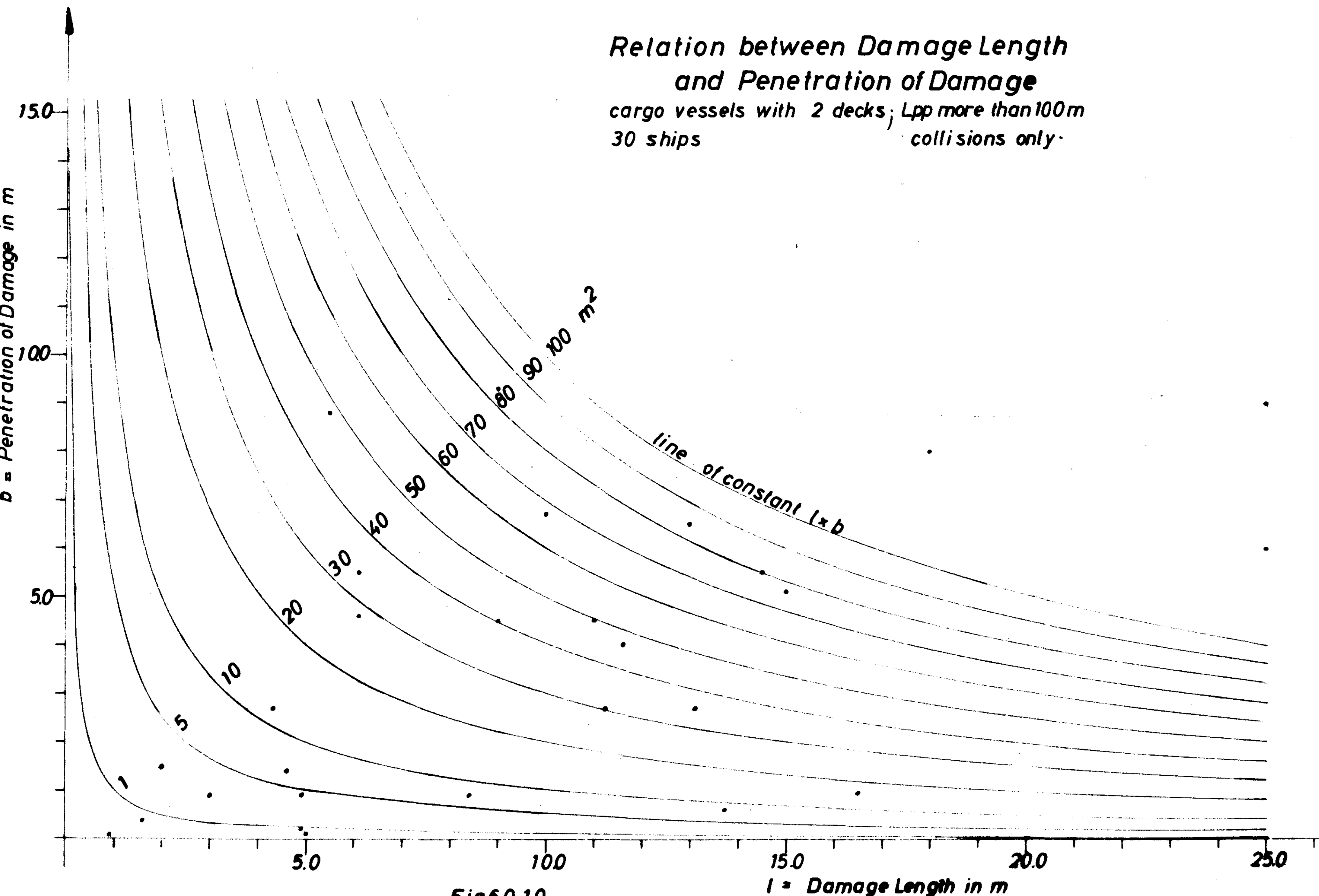

Relation between Damage Length
and Penetration of Damage
cargo vessels with 2 decks; Lpp more than 100m
30 ships
collisions only.
b = Penetration of Damage in m
l = Damage Length in m
line of constant l × b
1
5
10
20
30
40
50
60
70
80
90
100 m²
5.0
10.0
15.0
20.0
25.0

Fig.6.0.10

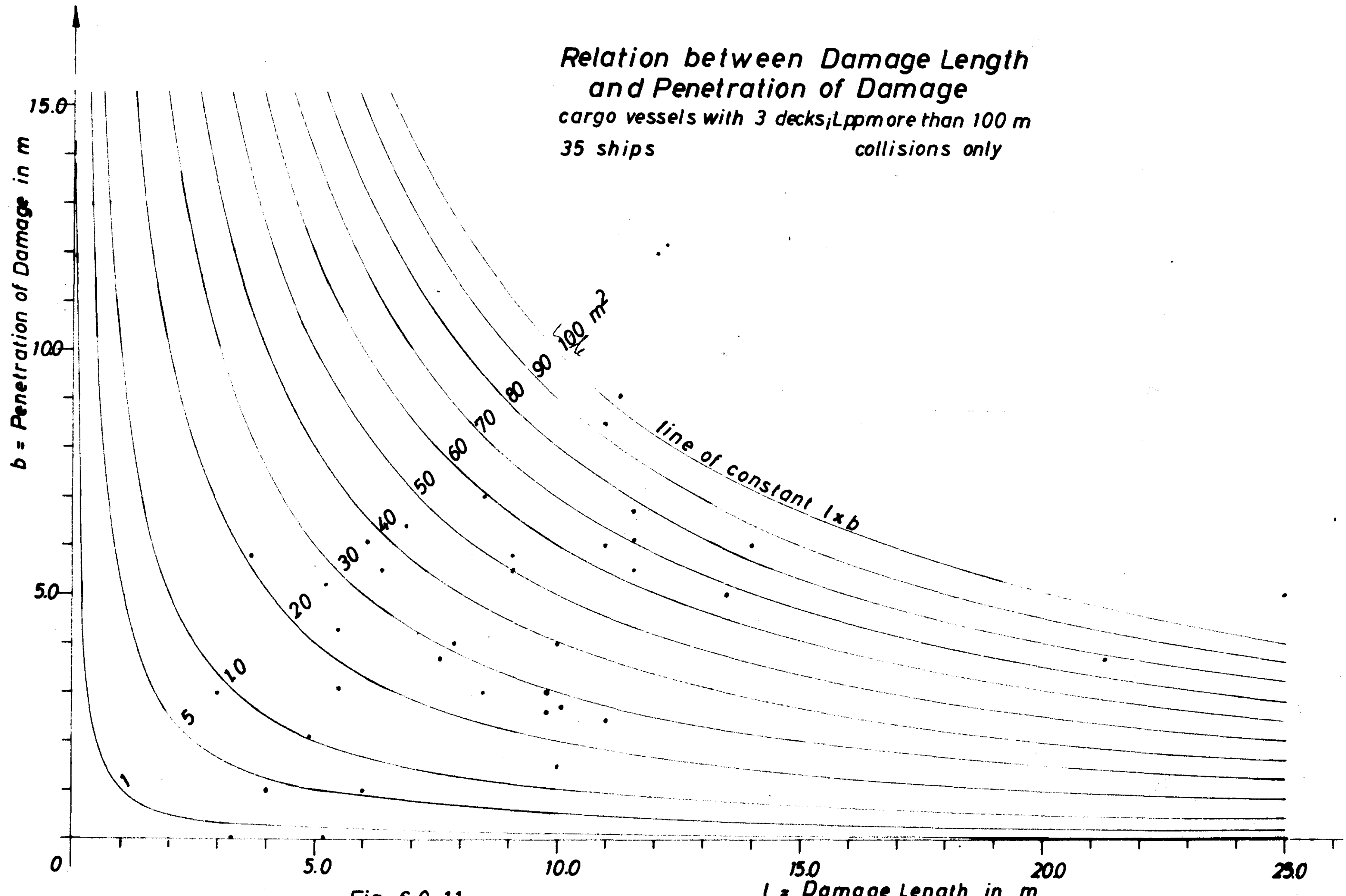
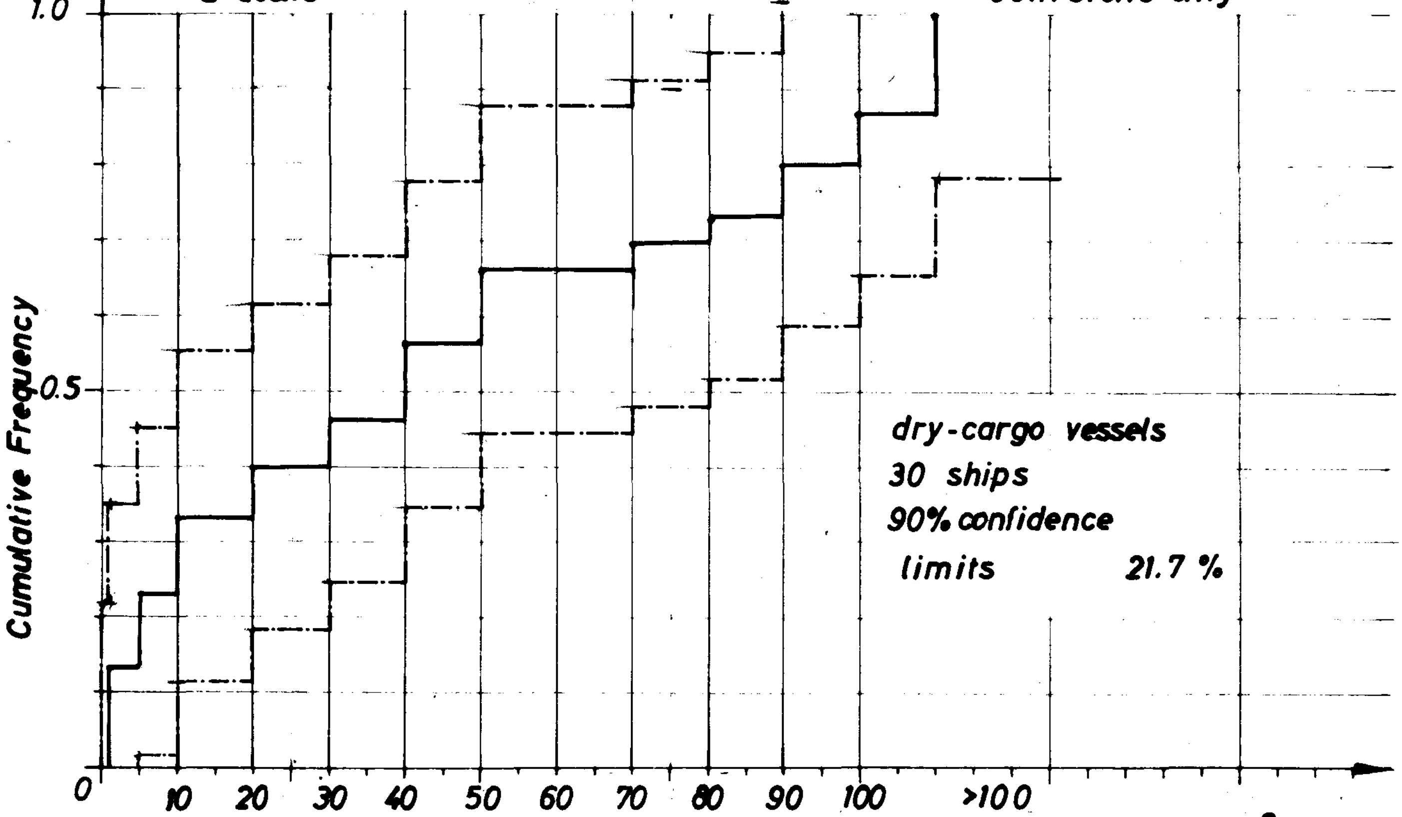

Relation between Damage Length
and Penetration of Damage
cargo vessels with 3 decks; Lpp more than 100 m
35 ships
collisions only
b = Penetration of Damage in m
l = Damage Length in m
line of constant l x b
1
5
10
20
30
40
50
60
70
80
90
100 m²
0
5.0
10.0
15.0
20.0
25.0

Fig. 6.0.11

Cumulative Frequency Polygon of Product $l \times b$

Dependence of damage extension on number of decks; Lpp more than 100 m

2 decks — *collisions only*



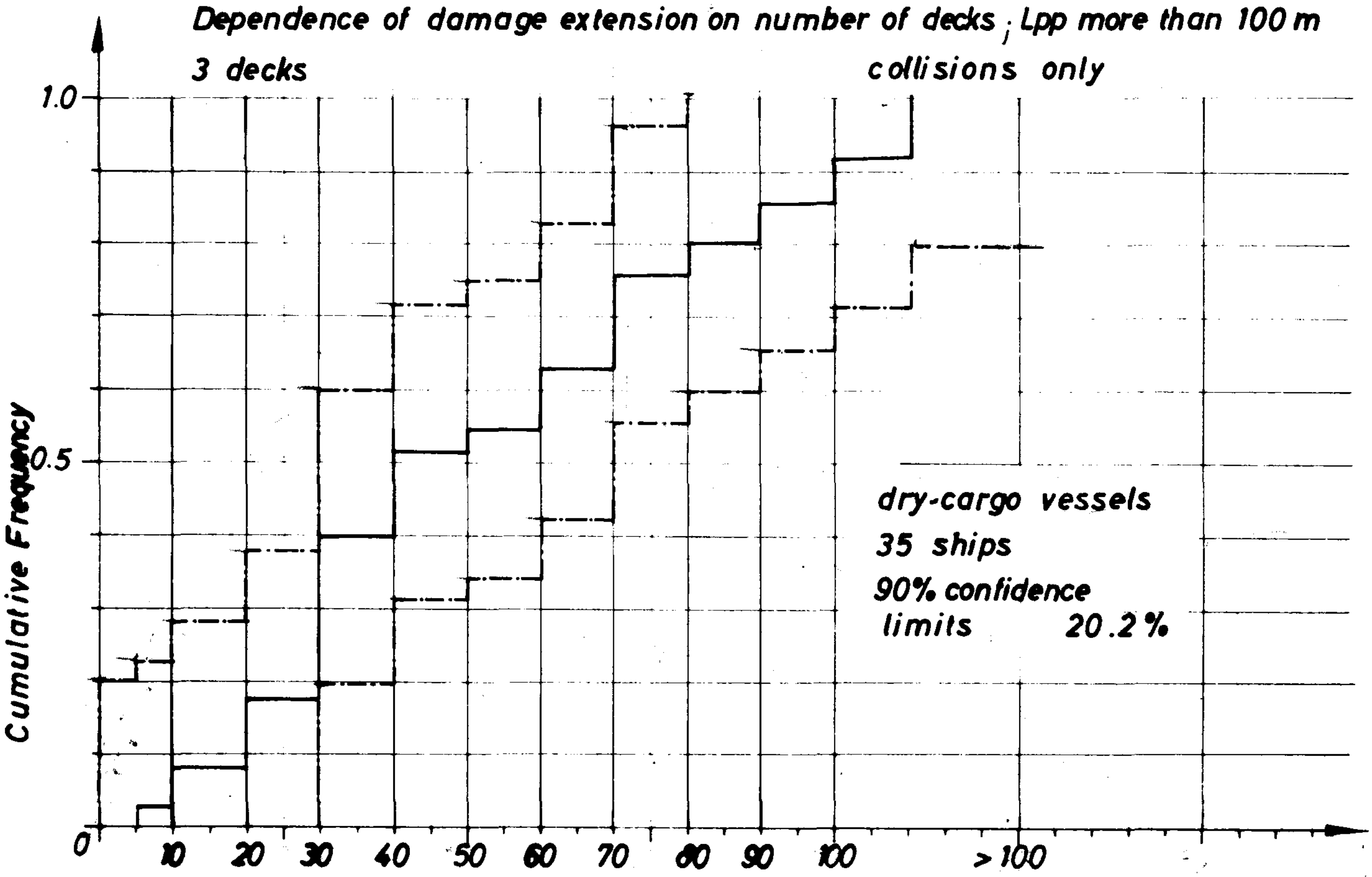
Product of Damage Length and Penetration in m^2

Fig. 6.0.12

Cumulative Frequency Polygon of Product $l \times b$

Dependence of damage extension on number of decks; Lpp more than 100 m

3 decks — *collisions only*



Product of Damage Length and Penetration in m^2

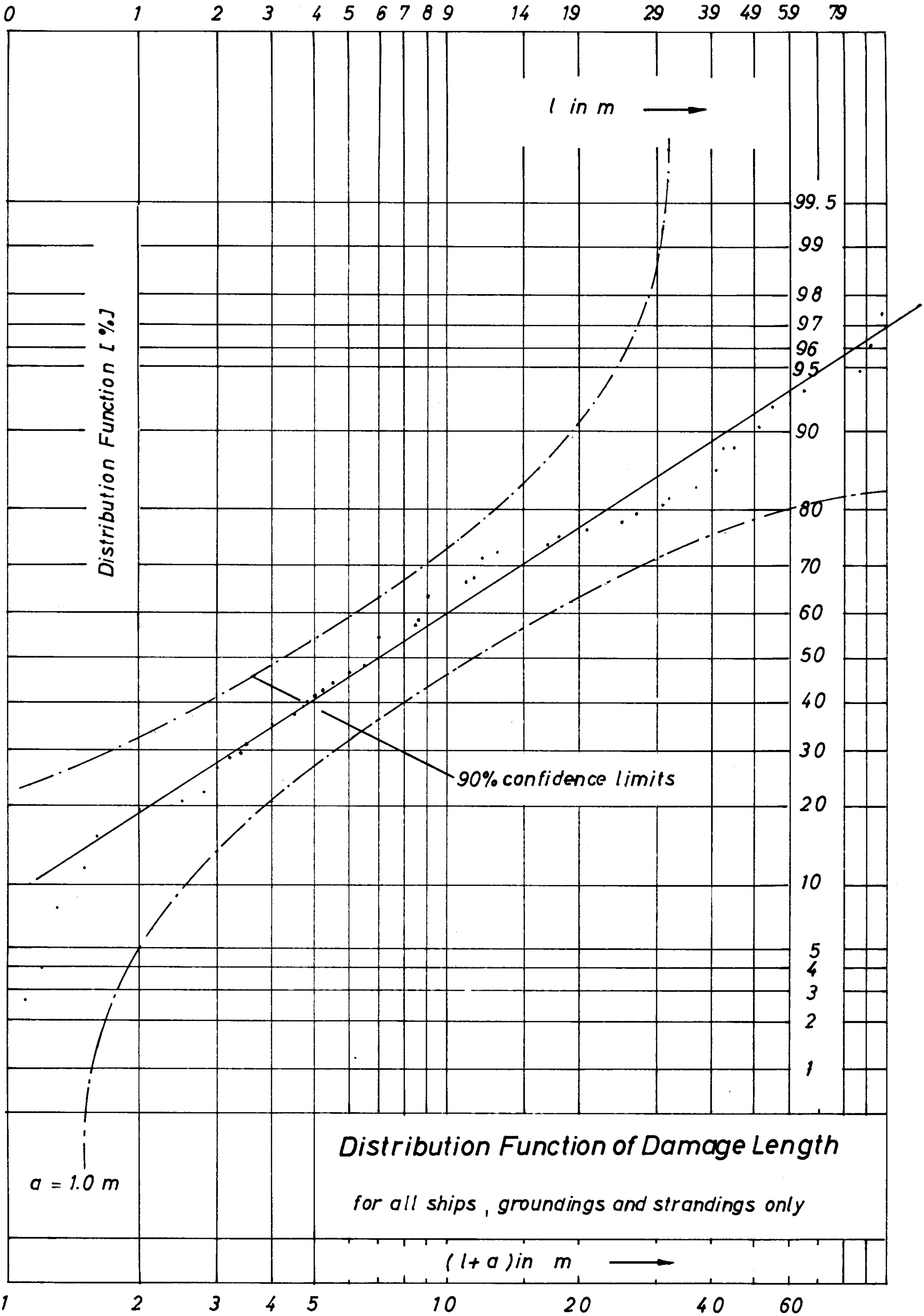

0 1 2 3 4 5 6 7 8 9 14 19 29 39 49 59 79
l in m
99.5 99 98 97 96 95 90 80 70 60 50 40 30 20 10 5 4 3 2 1
Distribution Function [%]
90% confidence limits
a = 1.0 m
Distribution Function of Damage Length
for all ships, groundings and strandings only
(l+ a)in m
1 2 3 4 5 10 20 40 60

Fig. 14. 02

Distribution Function of Damage Length

for ships with Lpp less than 100 m

strandings and groundings only

25 ships 90% confidence limits = 23.7 %

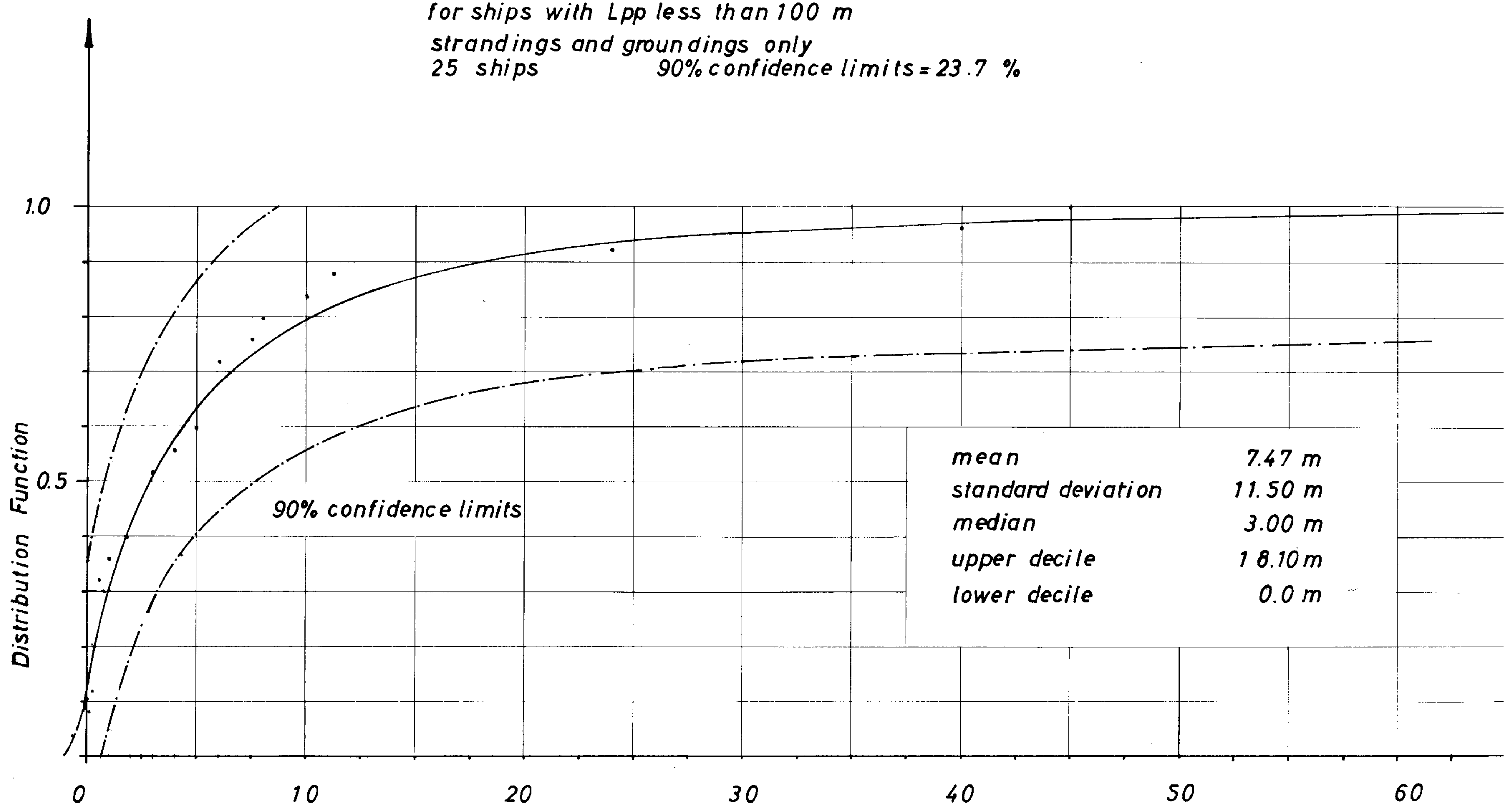
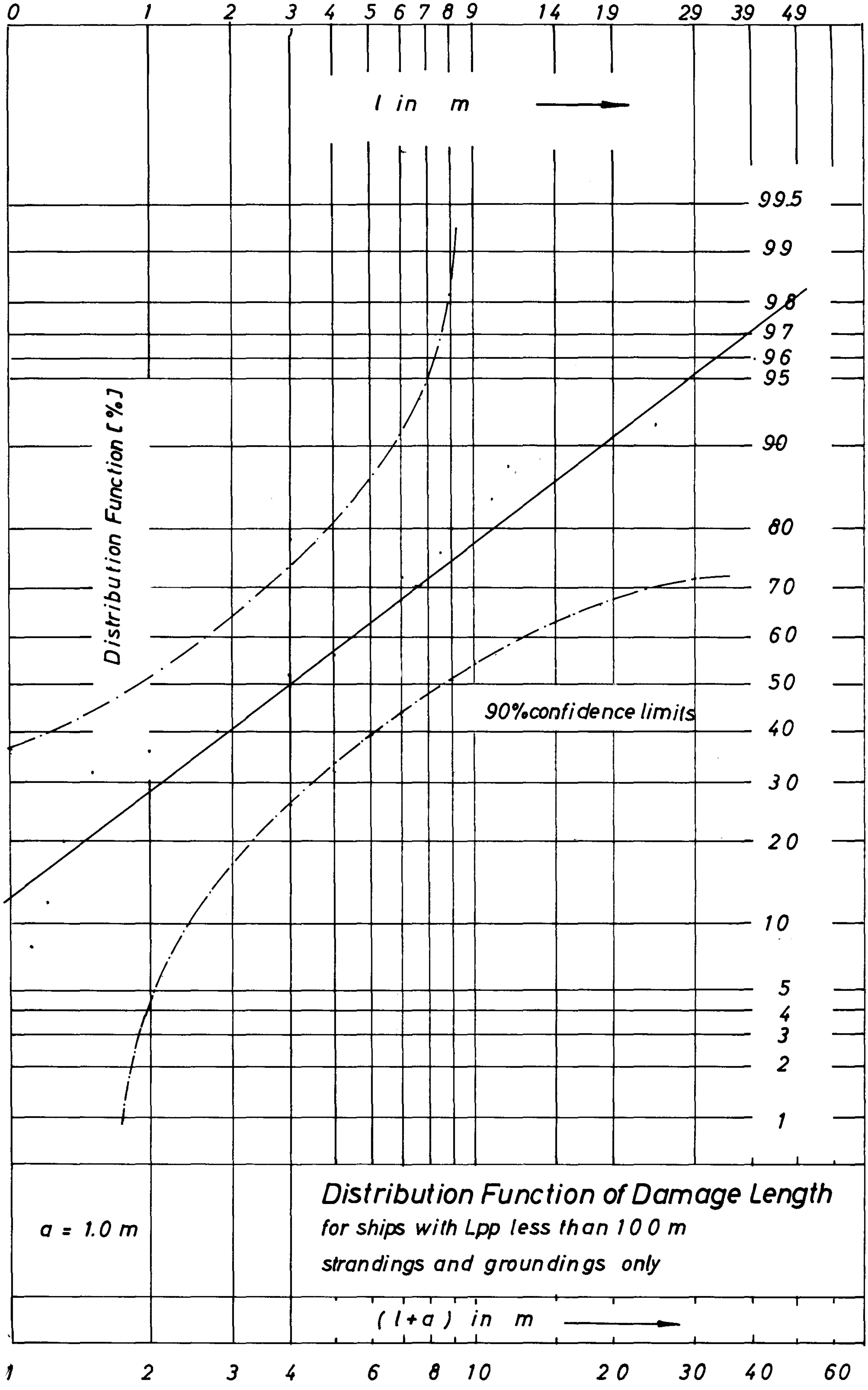


Fig. 1.4.03



0 1 2 3 4 5 6 7 8 9 14 19 29 39 49
l in m
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
Distribution Function [%]
90% confidence limits
Distribution Function of Damage Length
for ships with Lpp less than 100 m
strandings and groundings only
a = 1.0 m
(l+a) in m
1 2 3 4 6 8 10 20 30 40 60

Fig. 14.04

Distribution Function of Damage Length

for ships with Lpp more than 100 m
strandings and groundings only
52 ships 90% confidence limits = 16.6 %

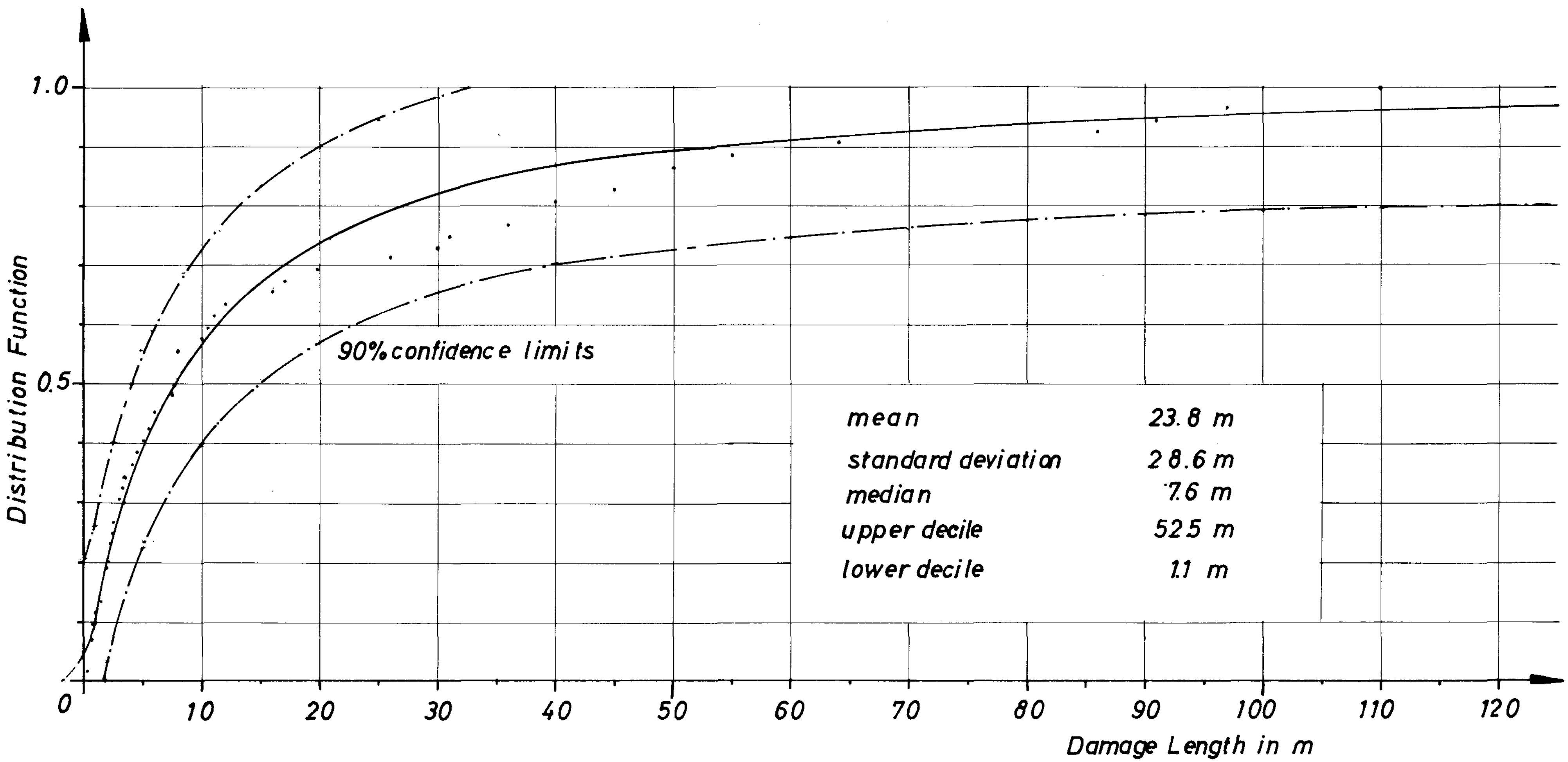


Fig. 1.4.05

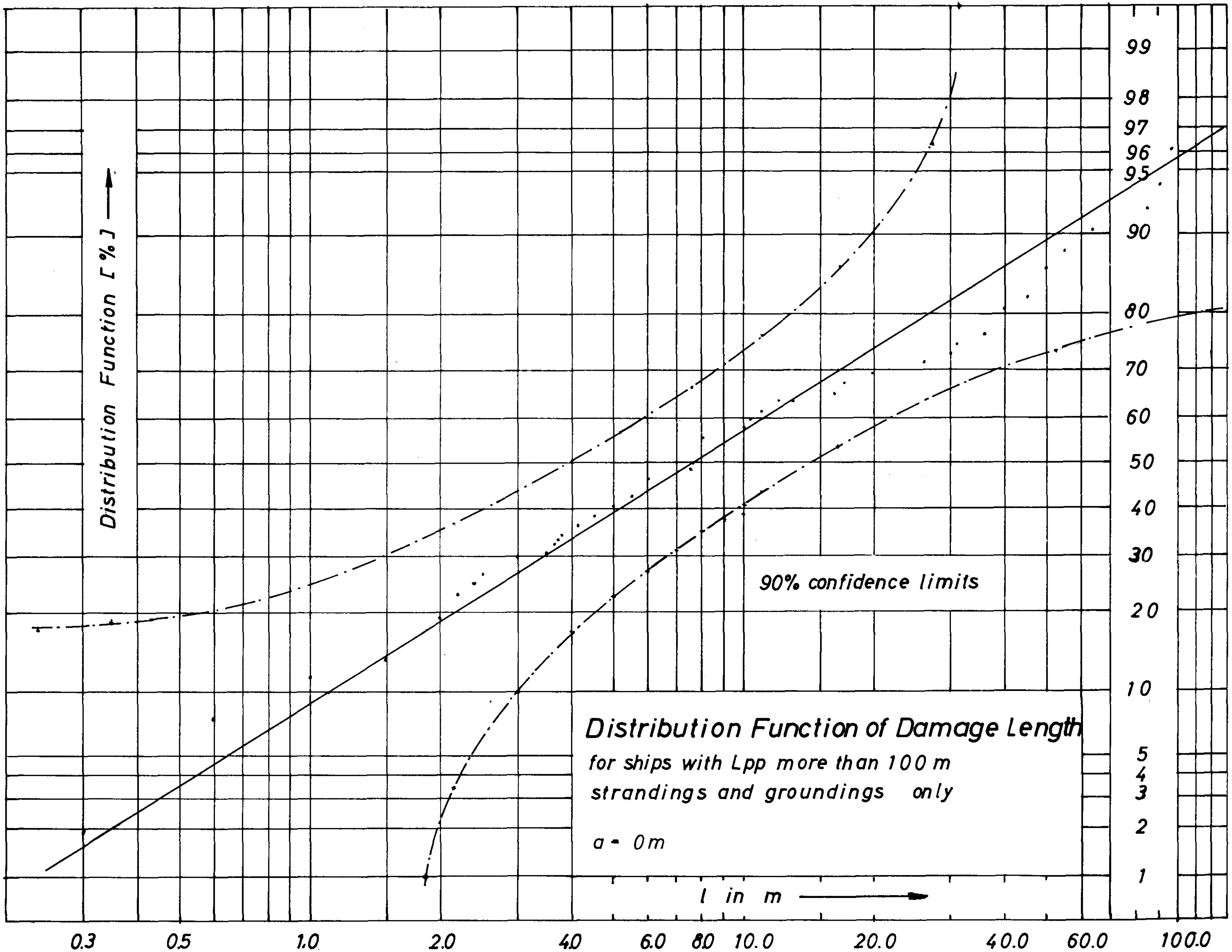
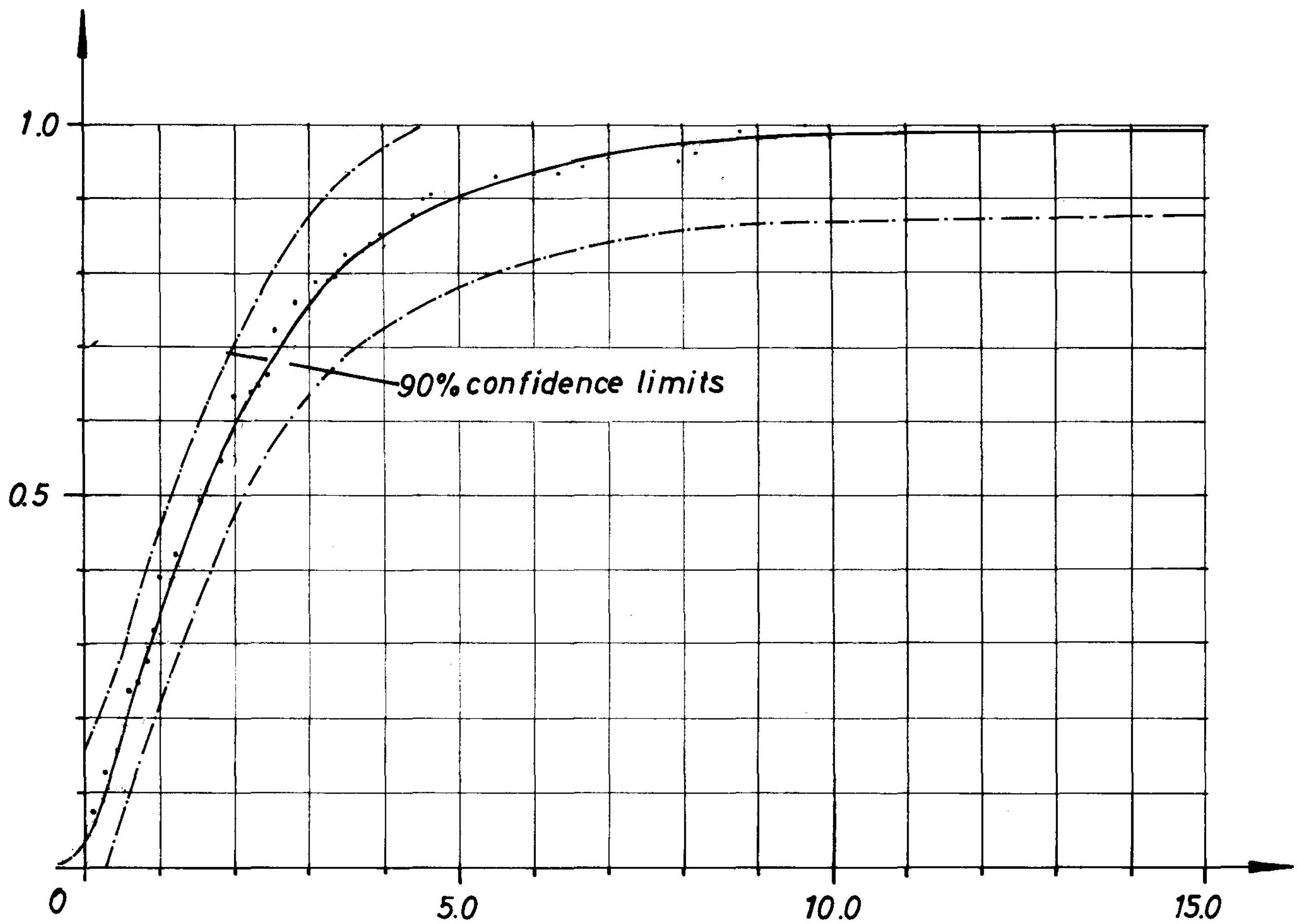

Distribution Function [%]
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
90% confidence limits
Distribution Function of Damage Length
for ships with Lpp more than 100 m
strandings and groundings only
a = 0m
l in m
0.3
0.5
1.0
2.0
4.0
6.0
8.0
10.0
20.0
40.0
60.0
100.0

Fig. 1.4.06

Distribution Function of Penetration of Damage

for ships with Lpp less than 100 m   collisions only

104 ships   90% confidence limits = 11.95%



mean	2.2 m
standard deviation	2.2 m
median	1.6 m
upper decile	4.9 m
lower decile	0.2 m

Fig. 2.0.01

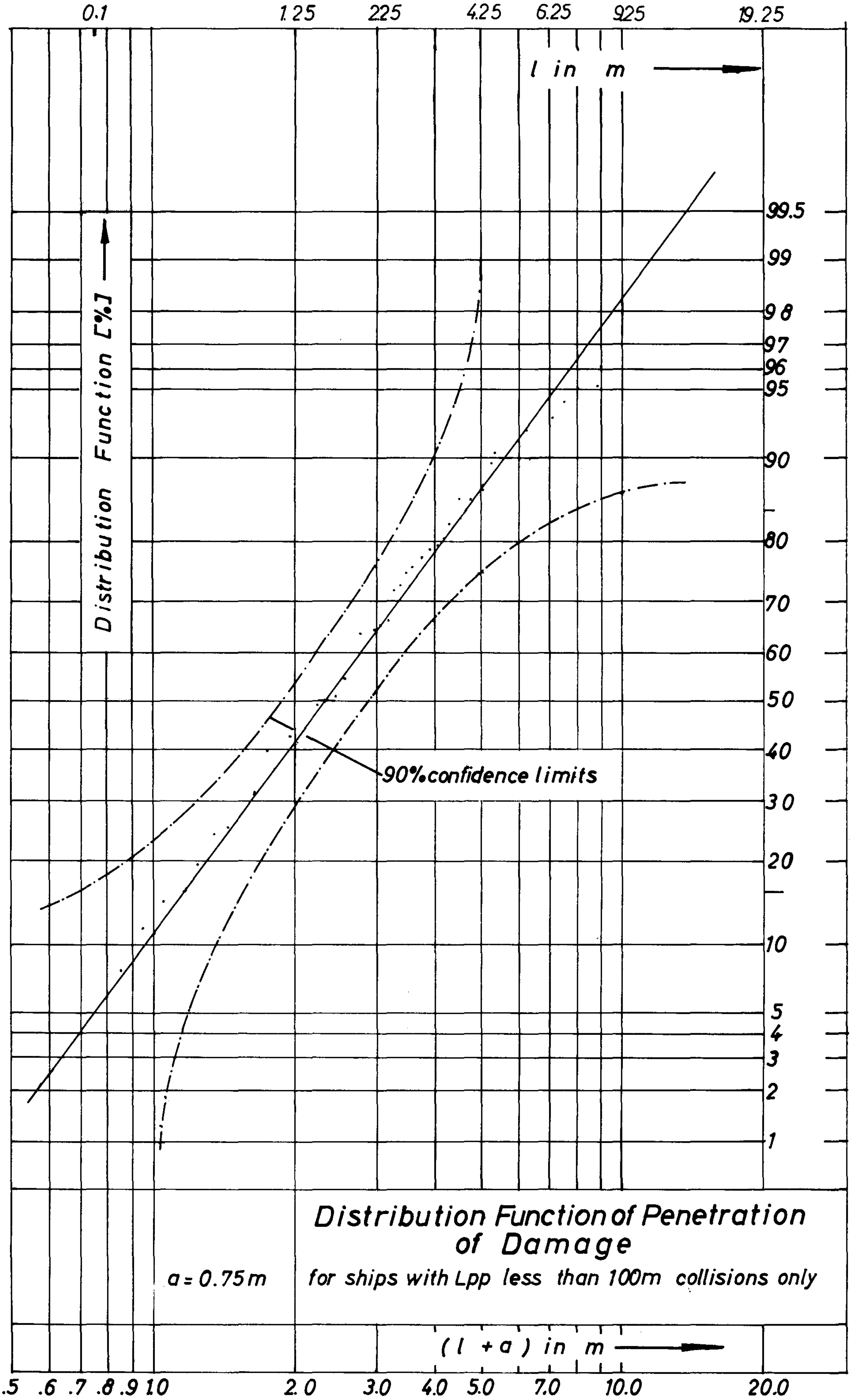

0.1
1.25
2.25
4.25
6.25
9.25
19.25
l in m
Distribution Function [%]
99.5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
90% confidence limits
Distribution Function of Penetration of Damage
a = 0.75 m
for ships with Lpp less than 100m collisions only
(l + a) in m
.5
.6
.7
.8
.9
1.0
2.0
3.0
4.0
5.0
7.0
10.0
20.0

Fig. 2.0.02

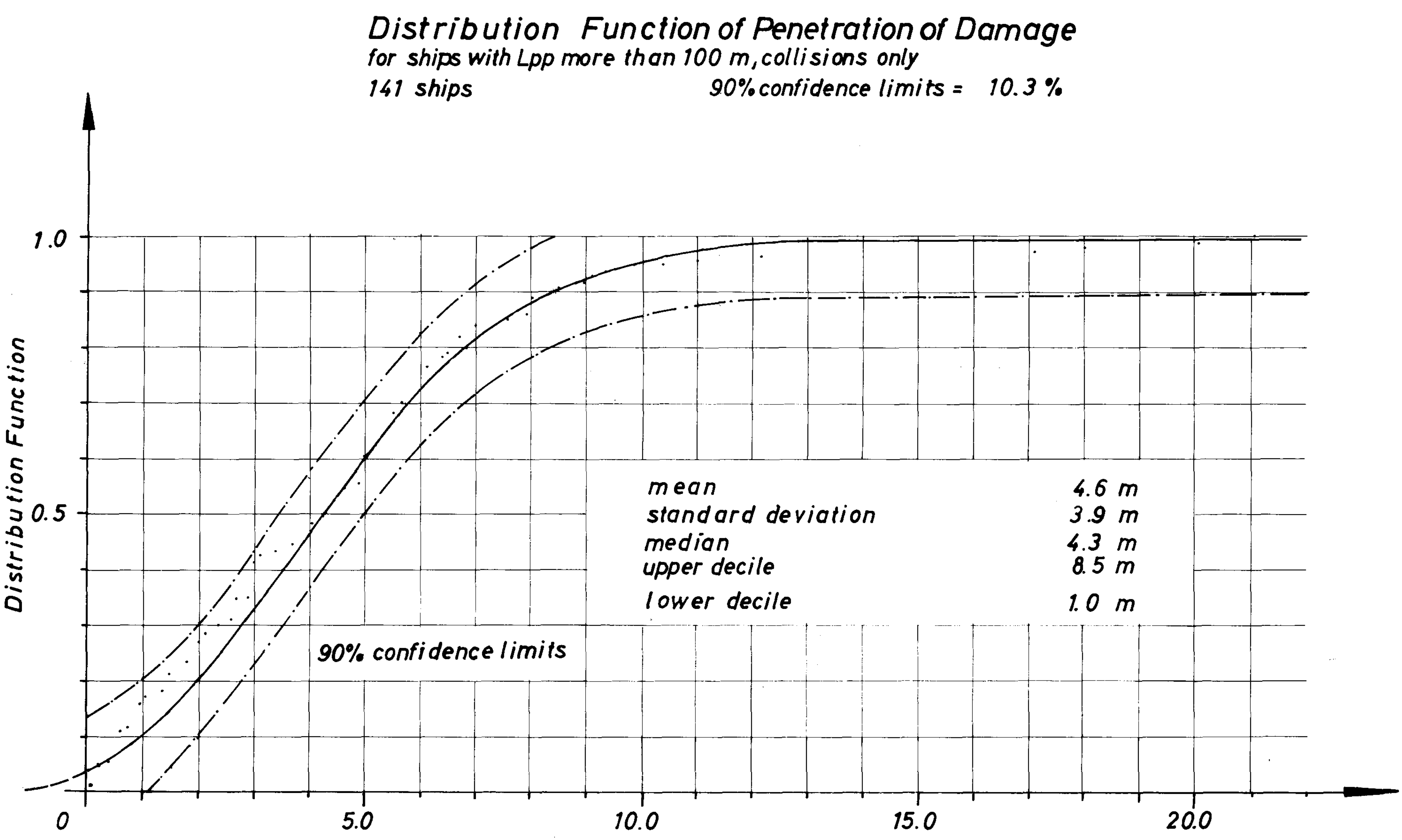

Distribution Function of Penetration of Damage
for ships with Lpp more than 100 m, collisions only
141 ships
90% confidence limits = 10.3 %
Distribution Function
1.0
0.5
0
5.0
10.0
15.0
20.0
Penetration of Damage in m
90% confidence limits
mean 4.6 m
standard deviation 3.9 m
median 4.3 m
upper decile 8.5 m
lower decile 1.0 m

Fig. 2.0.03

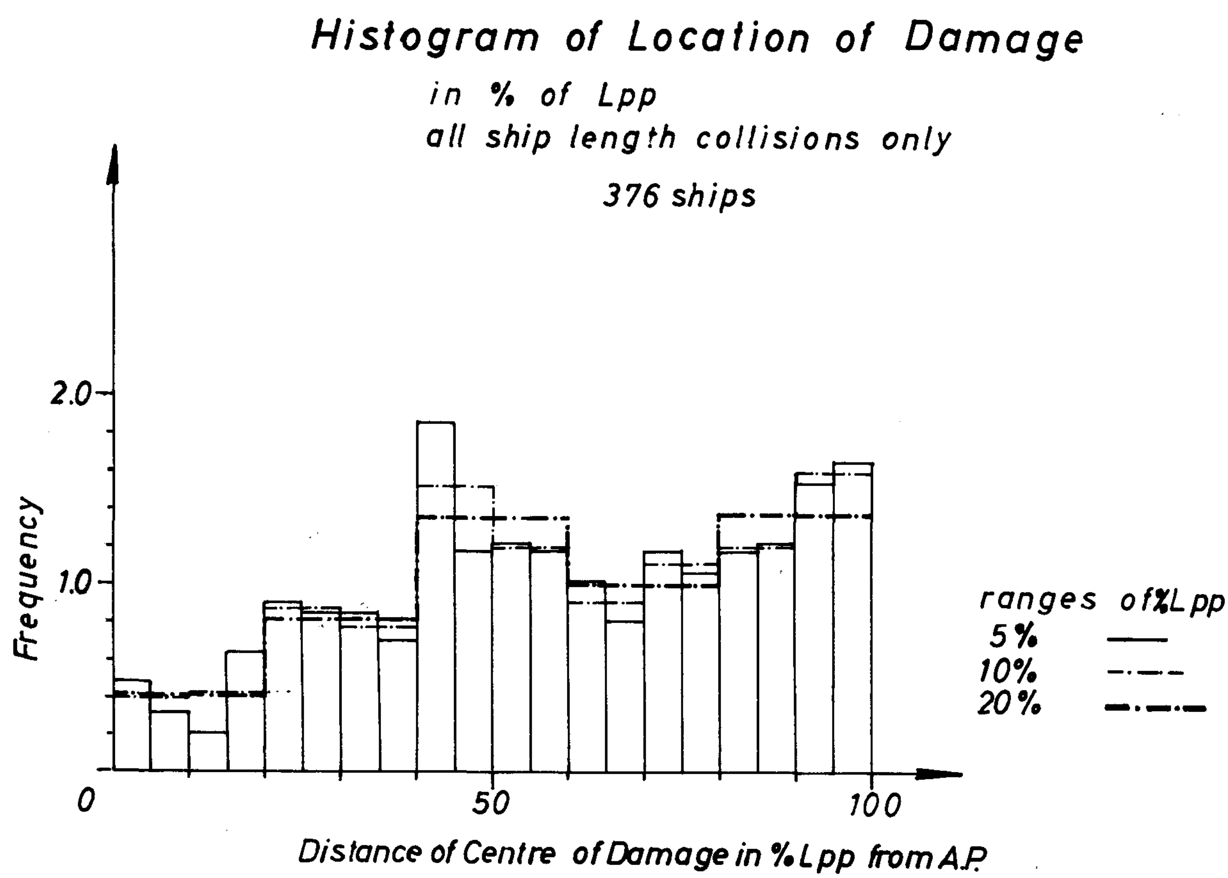
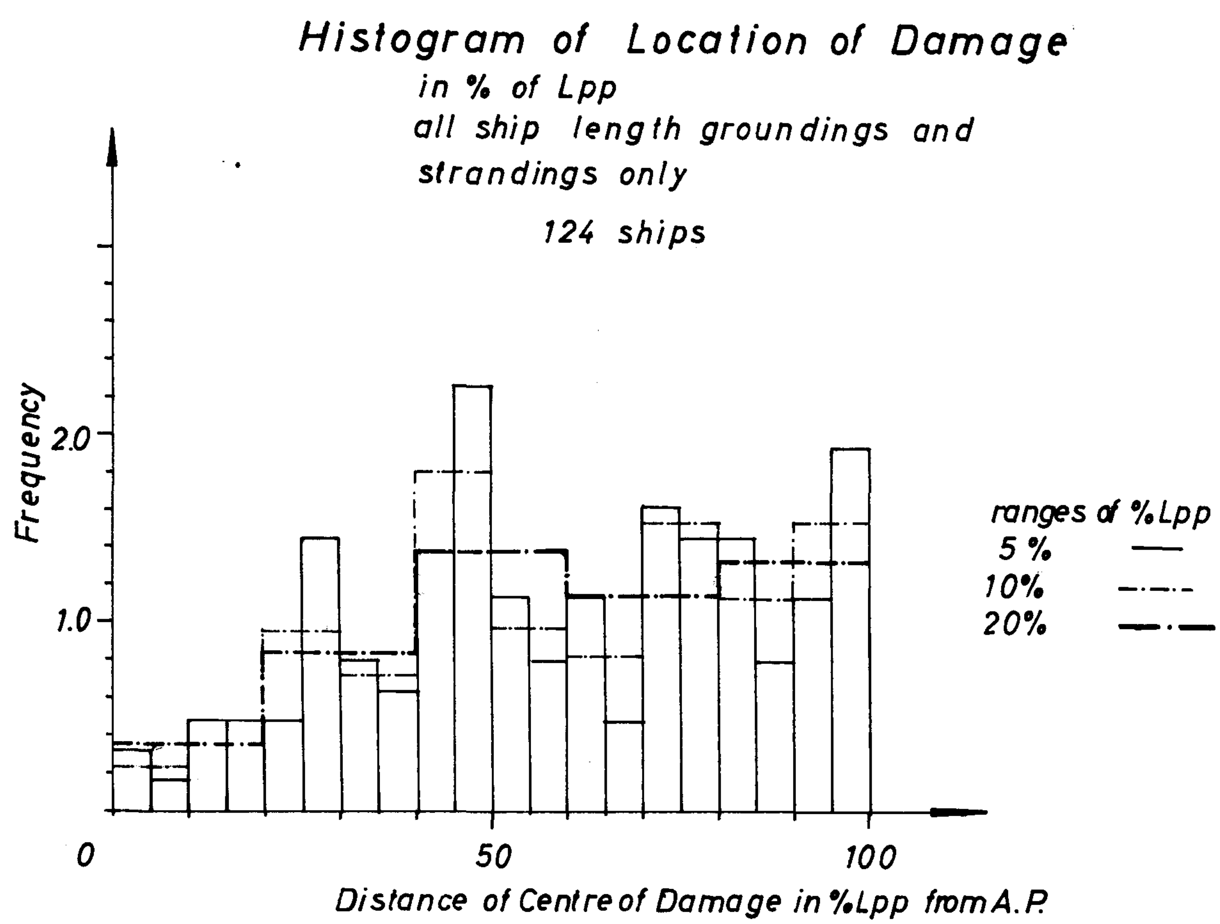

Histogram of Location of Damage
in % of Lpp
all ship length collisions only
376 ships
Frequency
2.0
1.0
0
50
100
Distance of Centre of Damage in % Lpp from A.P.
ranges of % Lpp
5 %
10%
20 %

Fig. 3.1. 01


Histogram of Location of Damage
in % of Lpp
all ship length groundings and
strandings only
124 ships
Frequency
2.0
1.0
0
50
100
Distance of Centre of Damage in % Lpp from A.P.
ranges of % Lpp
5 %
10%
20%

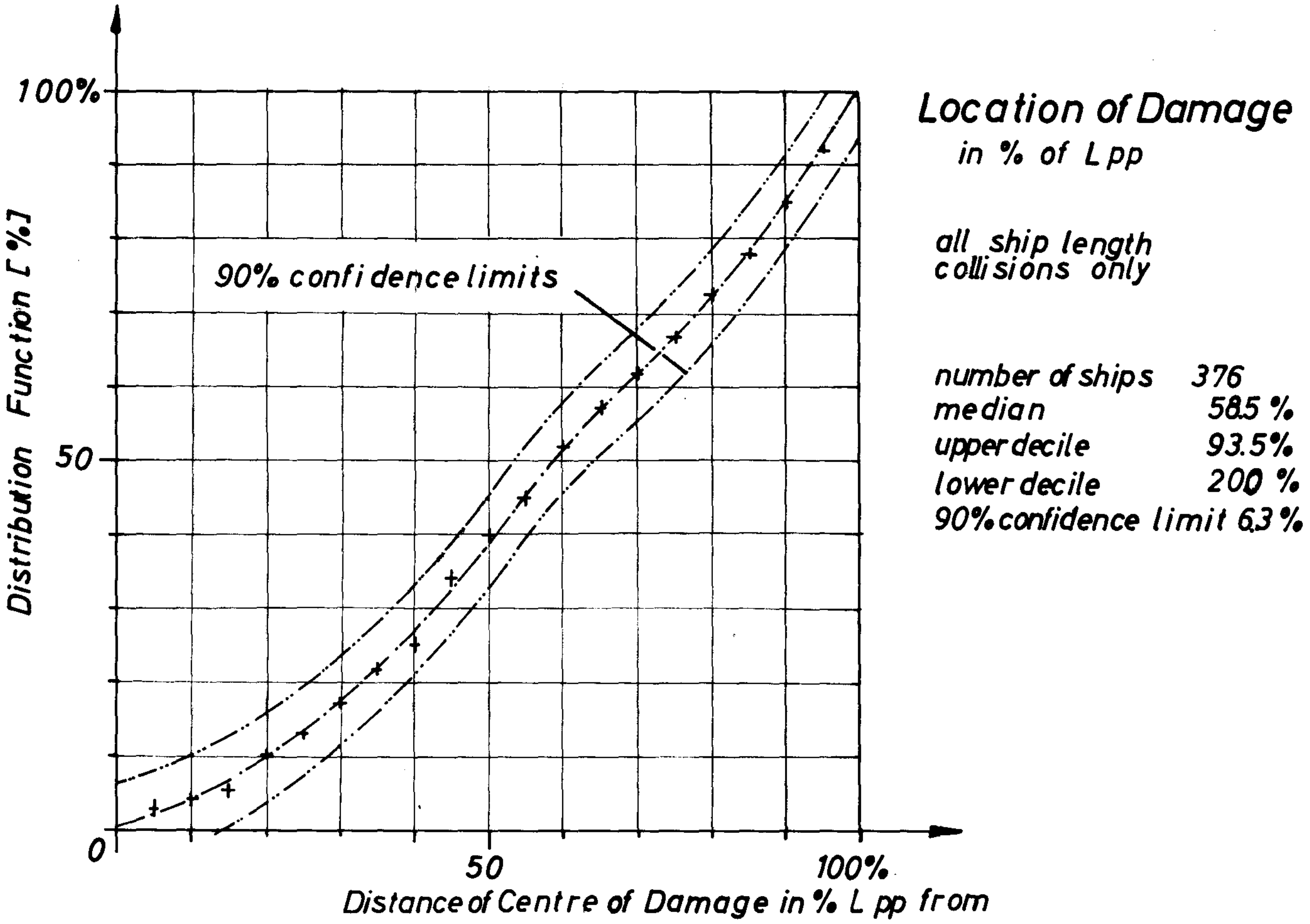


Fig. 3.1.02

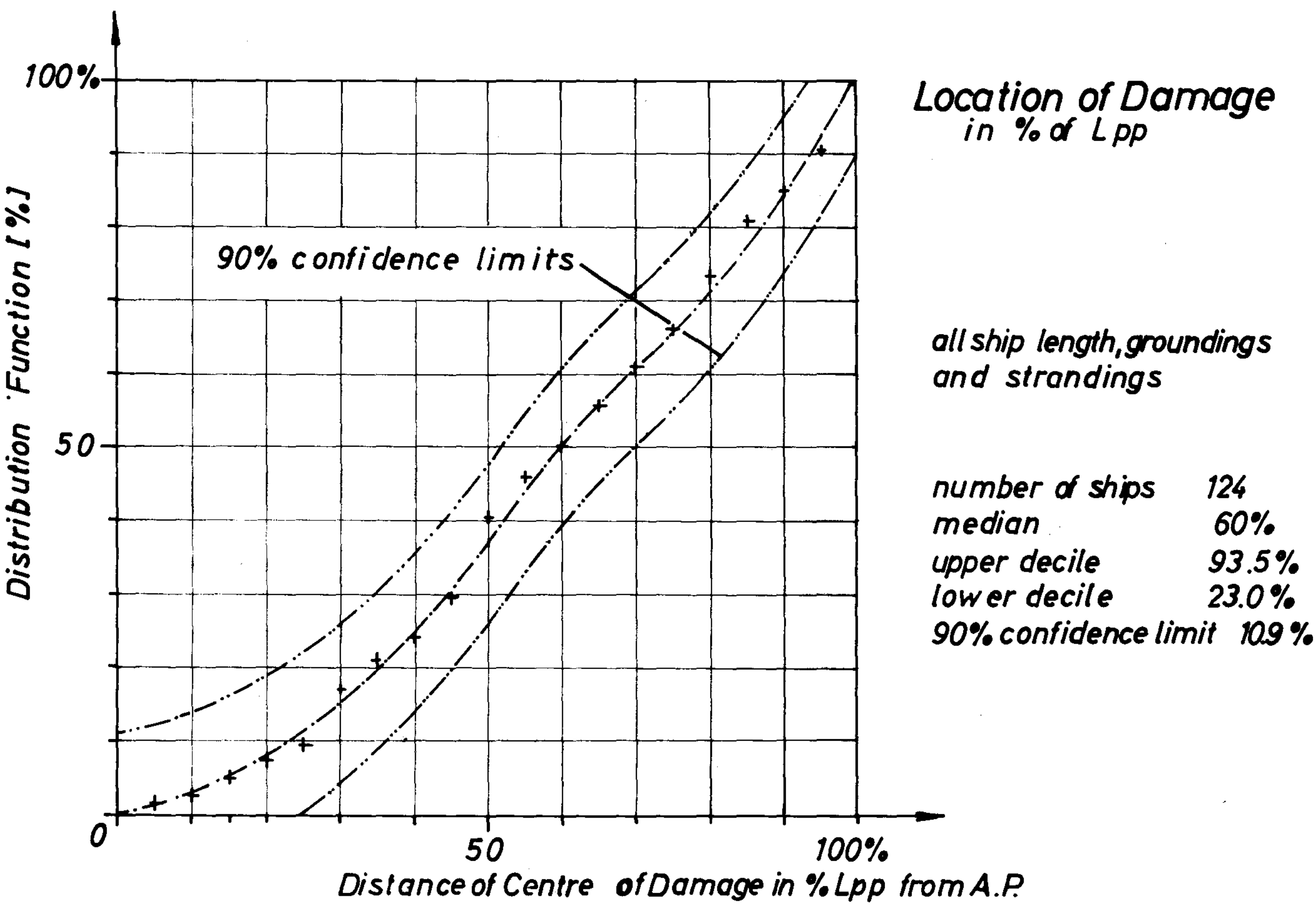


Fig. 3.1.04

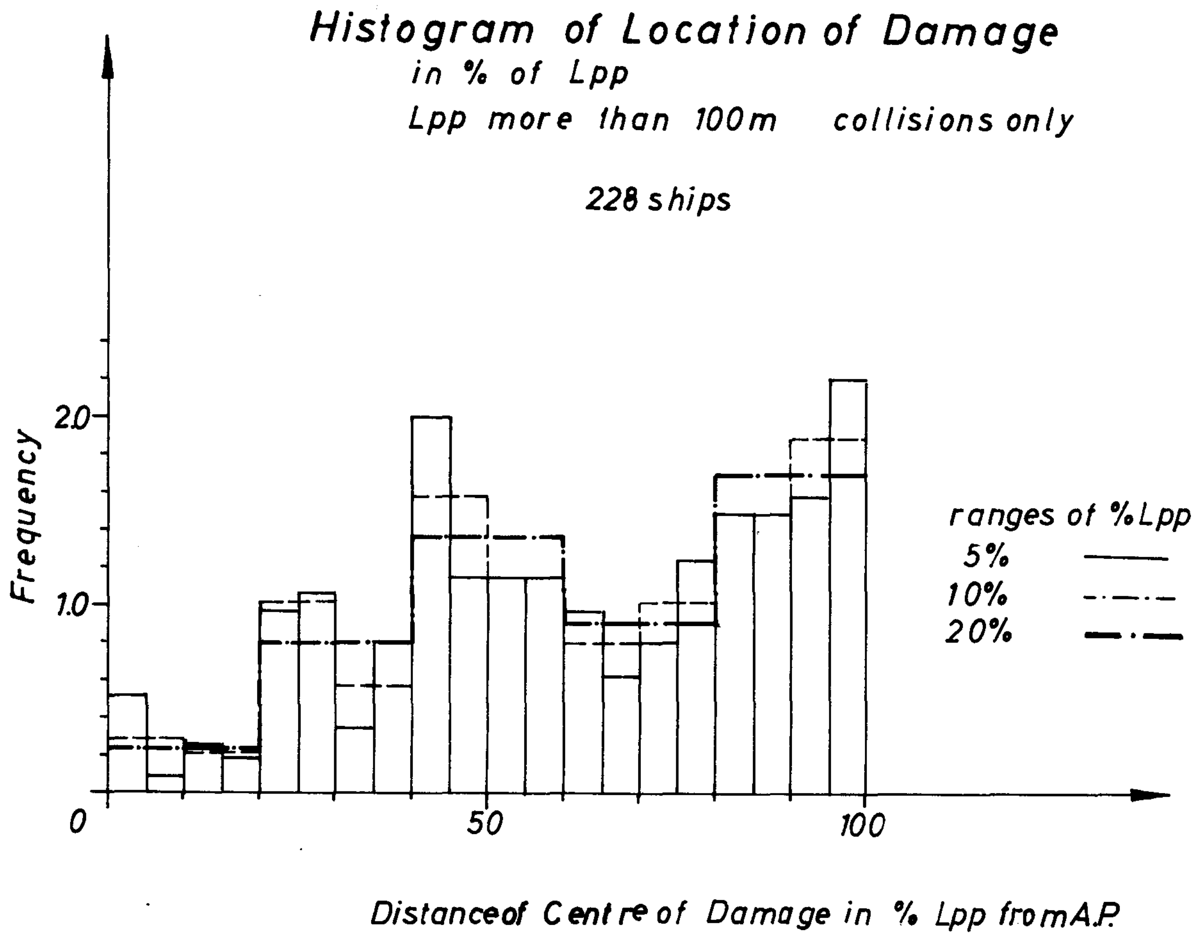
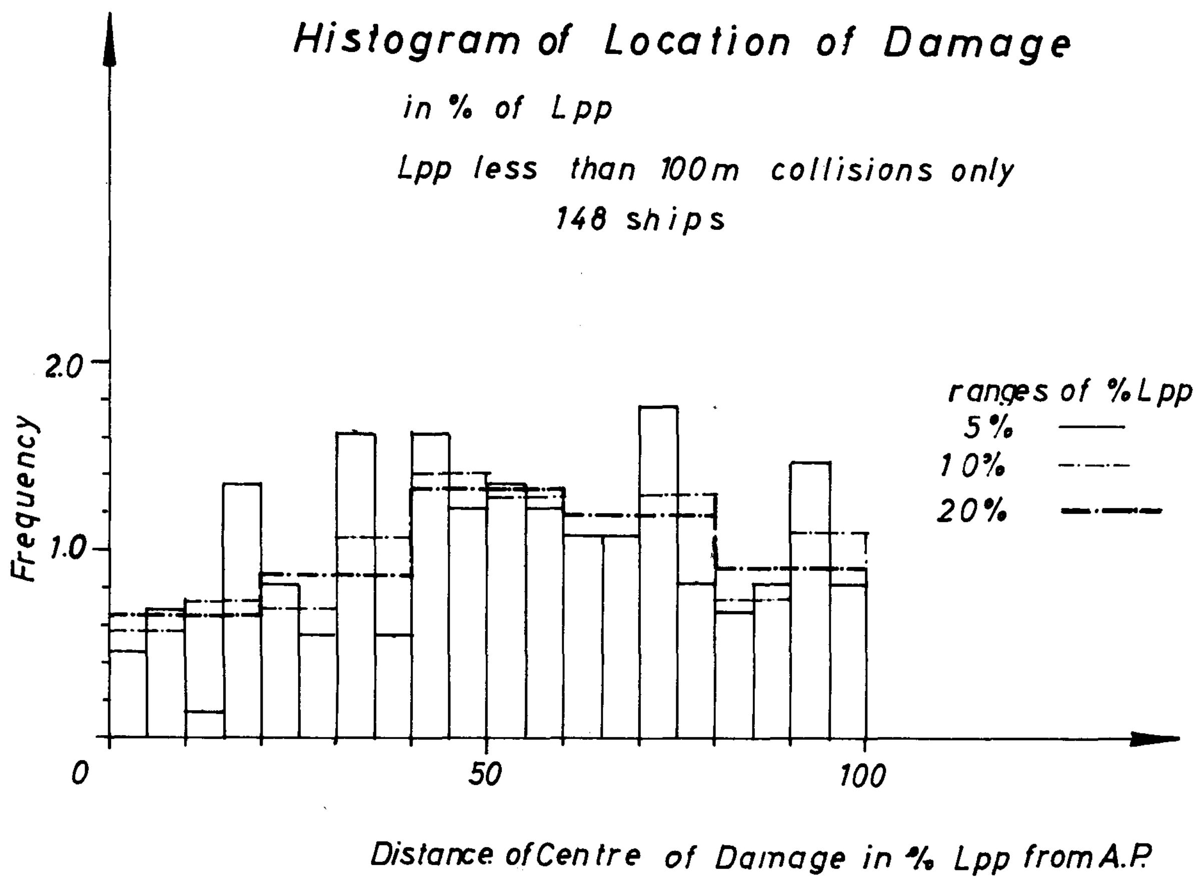

Histogram of Location of Damage
in % of Lpp
Lpp more than 100m collisions only
228 ships
Frequency
2.0
1.0
0
50
100
ranges of %Lpp
5%
10%
20%
Distance of Centre of Damage in % Lpp from A.P.

Fig. 3.1.05


Histogram of Location of Damage
in % of Lpp
Lpp less than 100m collisions only
148 ships
Frequency
2.0
1.0
0
50
100
ranges of %Lpp
5%
10%
20%
Distance of Centre of Damage in % Lpp from A.P.

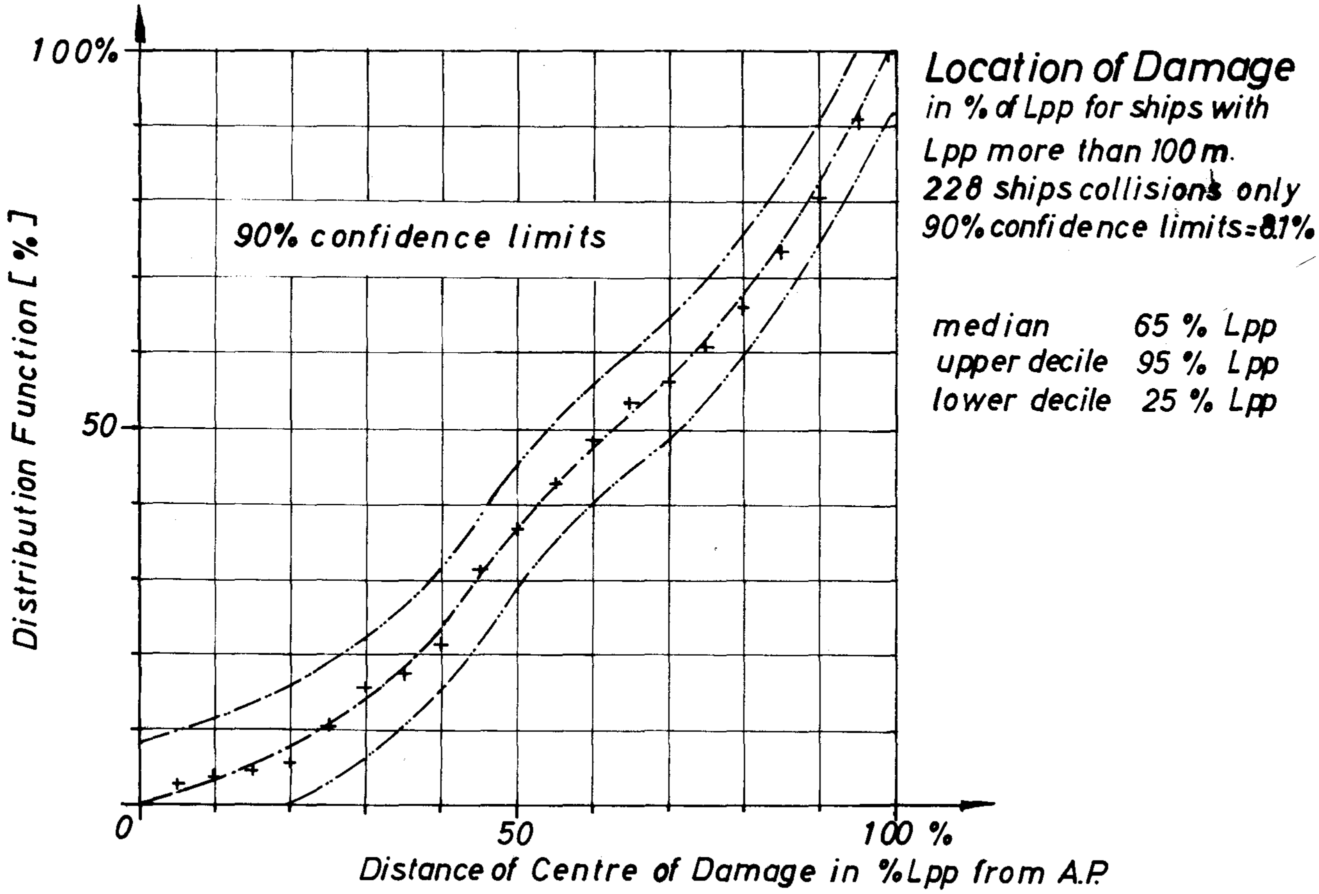


Fig. 3.1.06

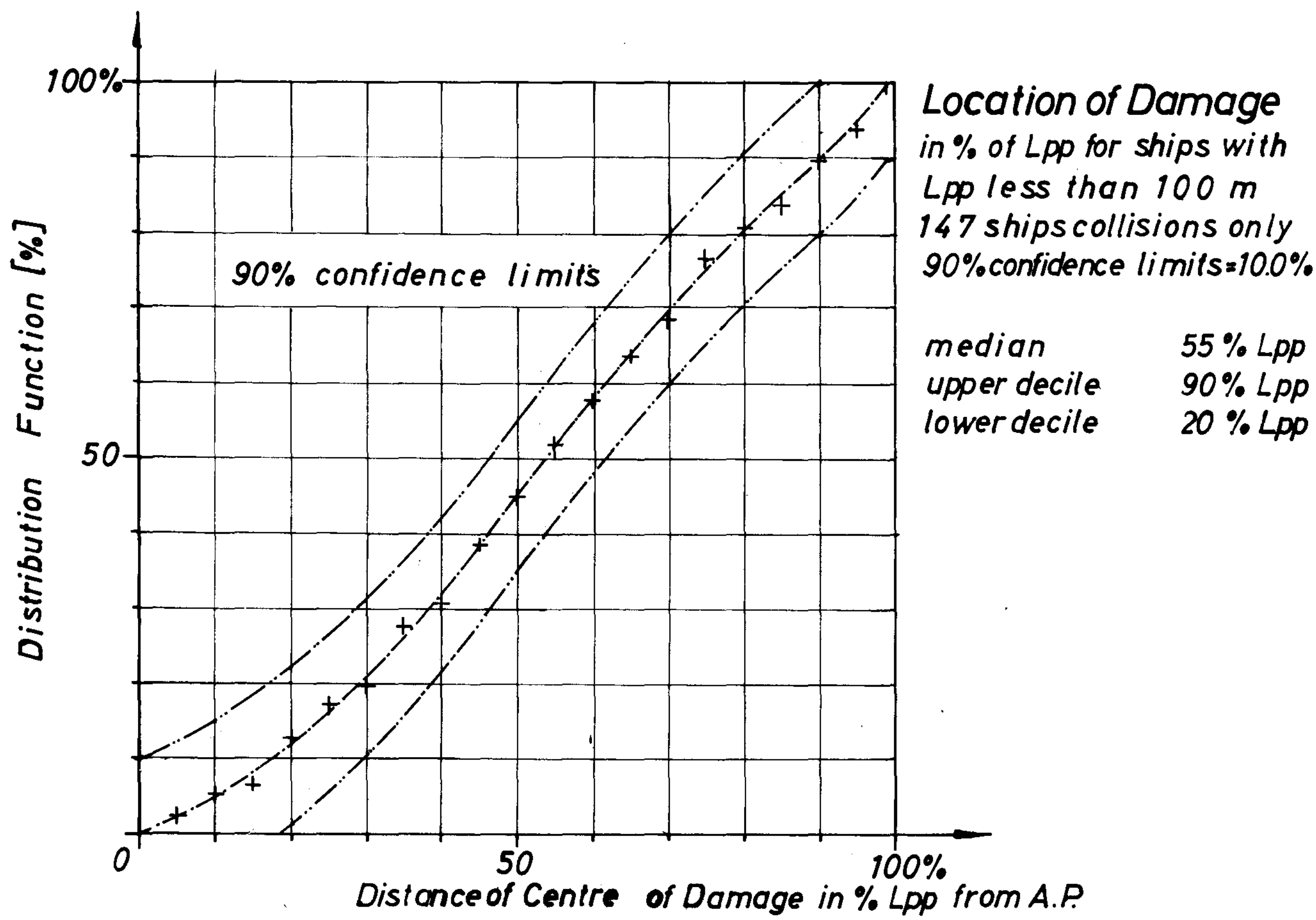


Fig. 3.1. 08

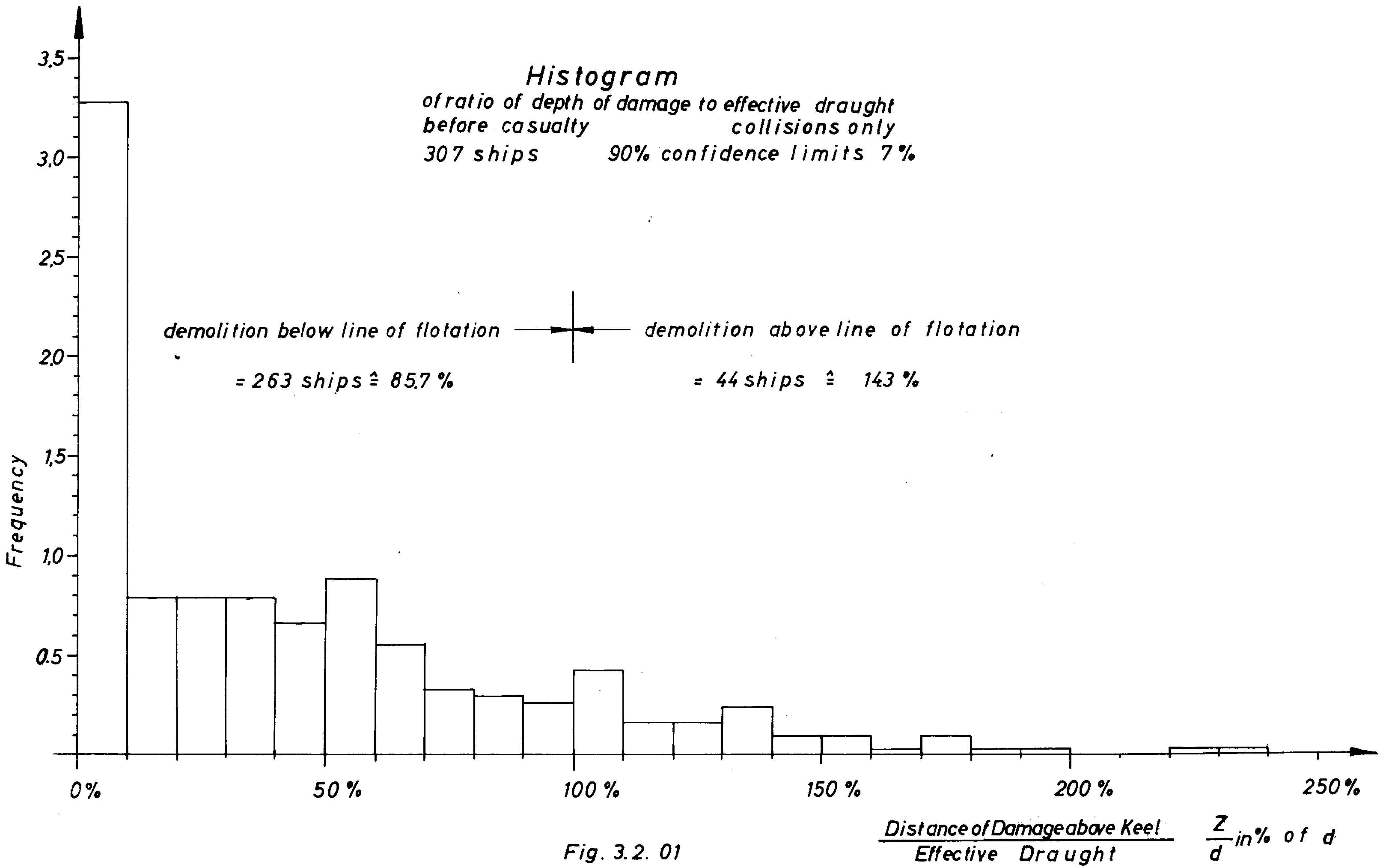
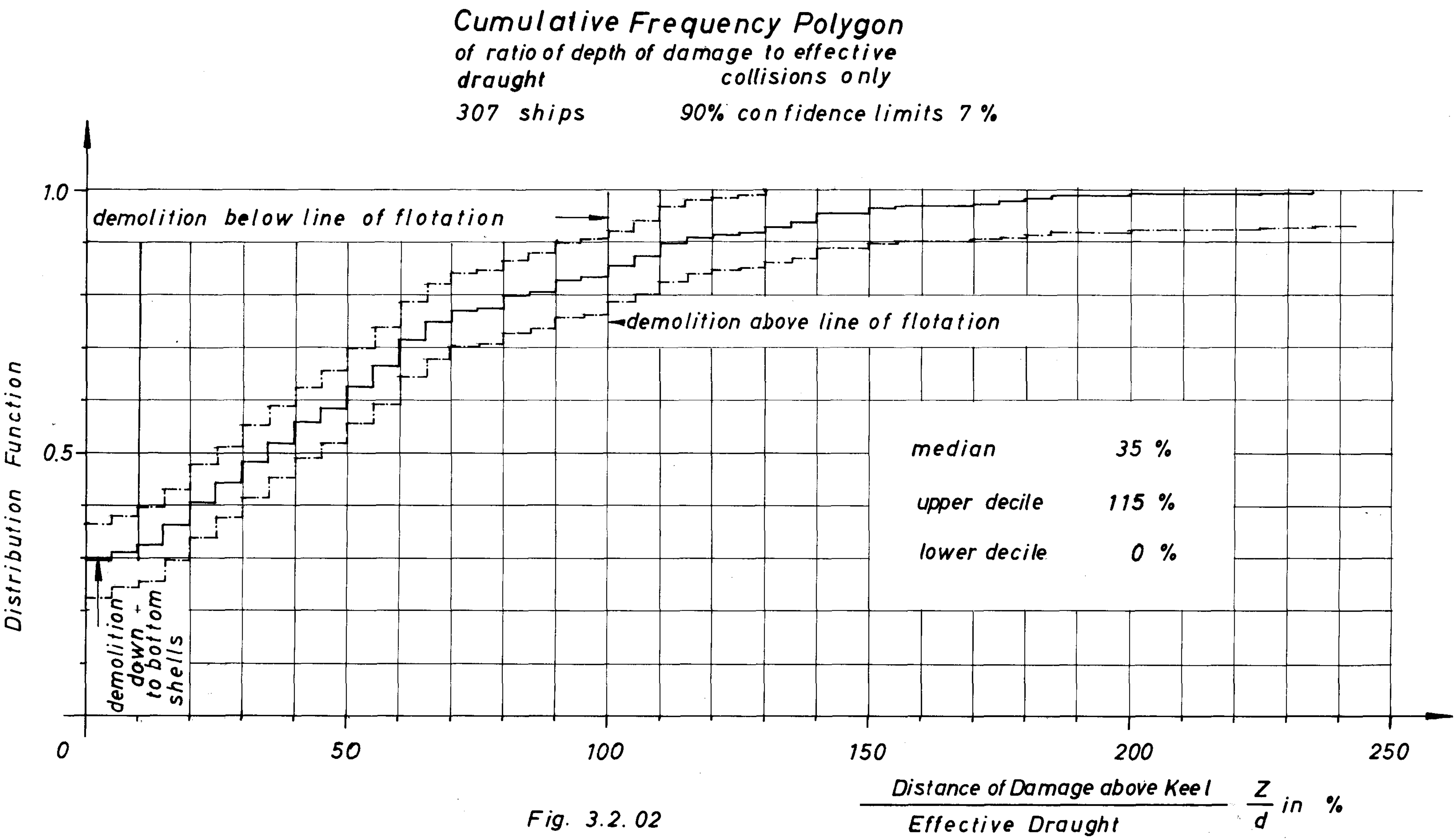

Histogram
of ratio of depth of damage to effective draught
before casualty
collisions only
307 ships
90% confidence limits 7%
demolition below line of flotation
= 263 ships ≙ 85.7 %
demolition above line of flotation
= 44 ships ≙ 14.3 %
Frequency
3,5
3,0
2,5
2,0
1,5
1,0
0.5
0%
50 %
100 %
150 %
200 %
250 %
Distance of Damage above Keel / Effective Draught
Z/d in % of d

Fig. 3.2. 01



Cumulative Frequency Polygon
of ratio of depth of damage to effective draught
collisions only
307 ships
90% confidence limits 7 %
Distribution Function
1.0
0.5
0
50
100
150
200
250
demolition below line of flotation
demolition above line of flotation
demolition down to bottom shells
median 35 %
upper decile 115 %
lower decile 0 %
Distance of Damage above Keel / Effective Draught Z/d in %

Fig. 3.2.02

Relation between Damage Length and Location of Damage

Lpp in a range of about 50 m

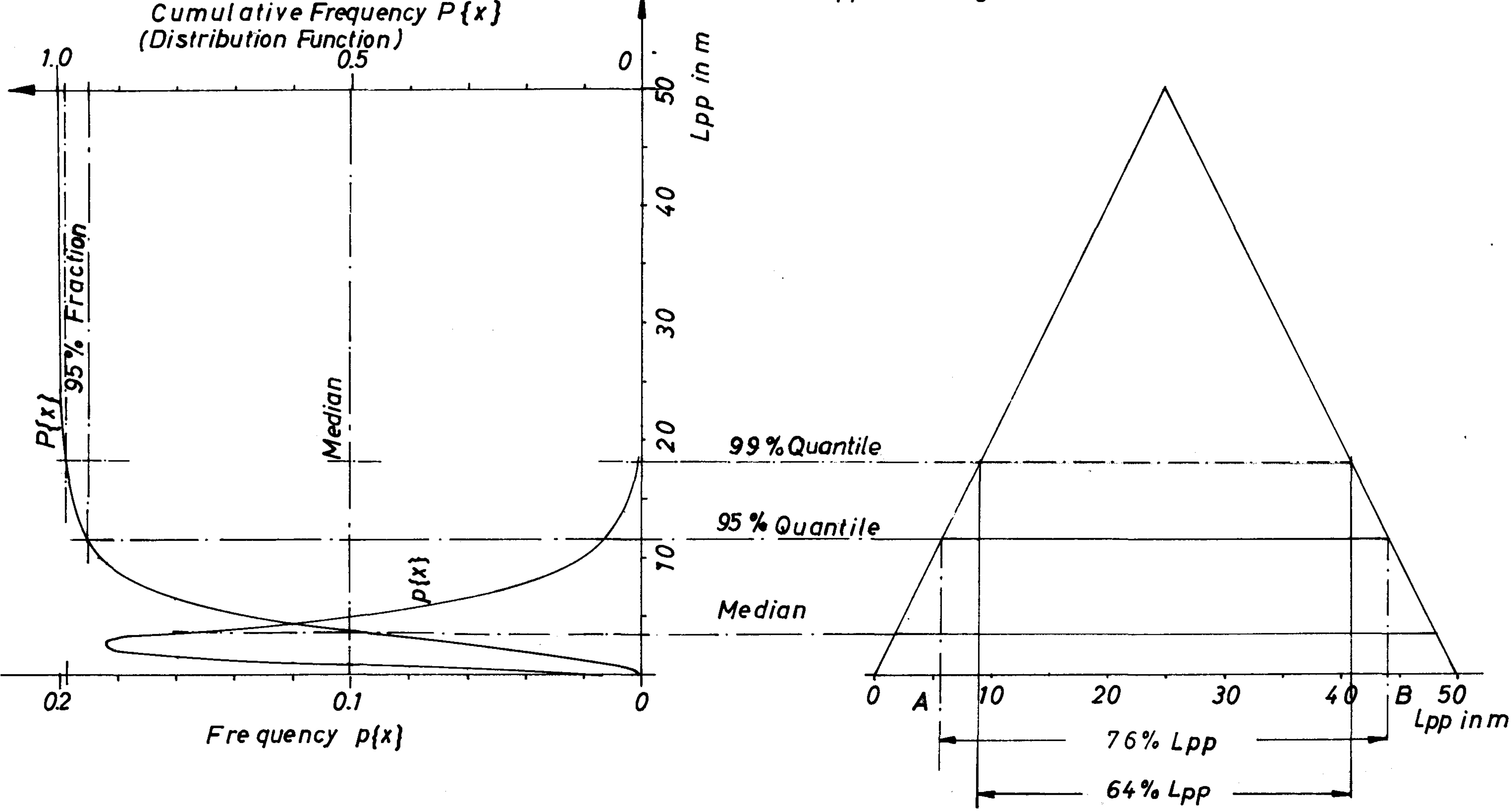


Fig. 4.0.01

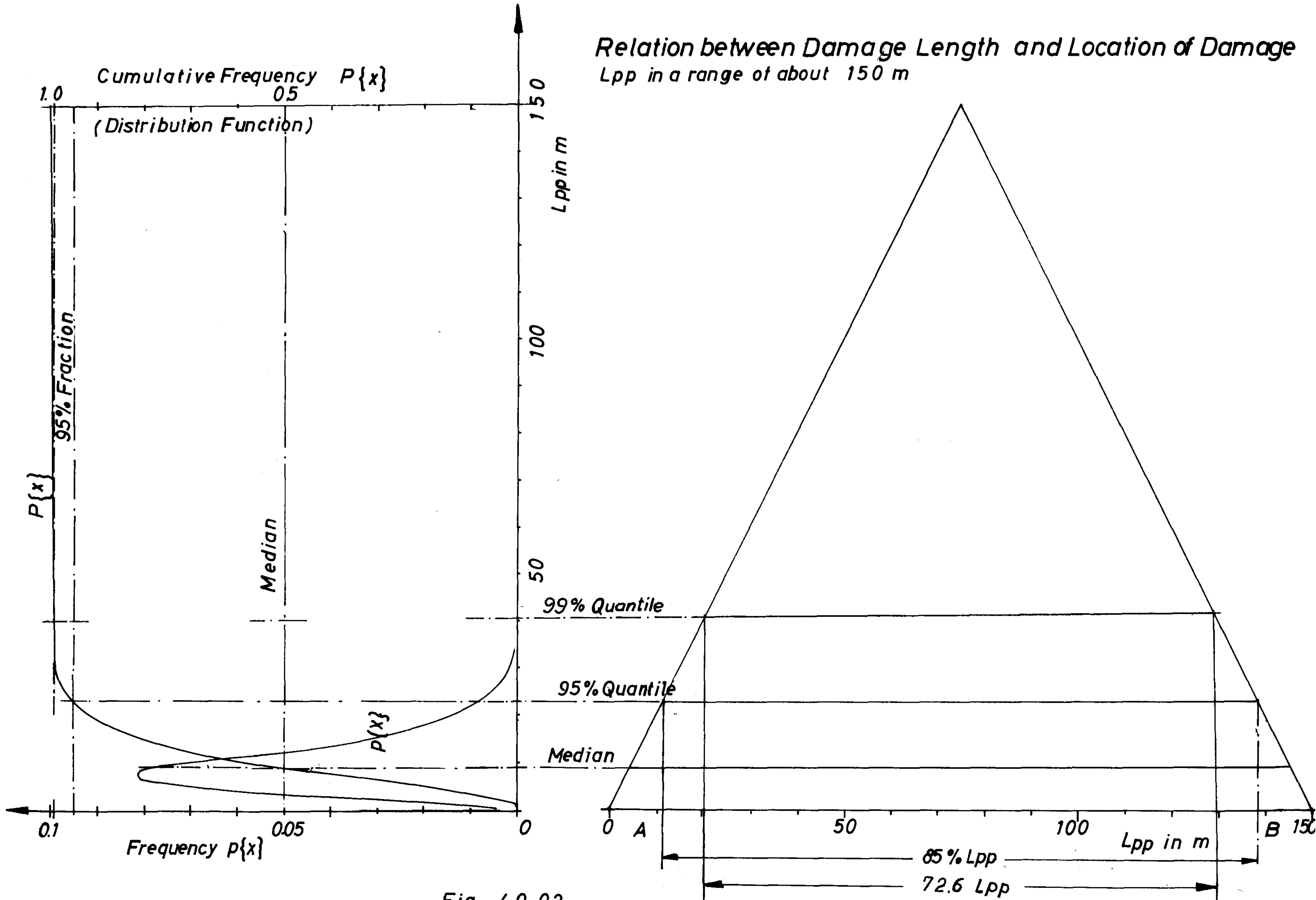

Relation between Damage Length and Location of Damage
Lpp in a range of about 150 m
Cumulative Frequency P{x}
(Distribution Function)
1.0
0.5
P{x}
95% Fraction
Median
p{x}
Frequency p{x}
0.1
0.05
0
50
100
150
Lpp in m
99% Quantile
95% Quantile
Median
A
B
85% Lpp
72.6 Lpp

Fig. 4.0.02

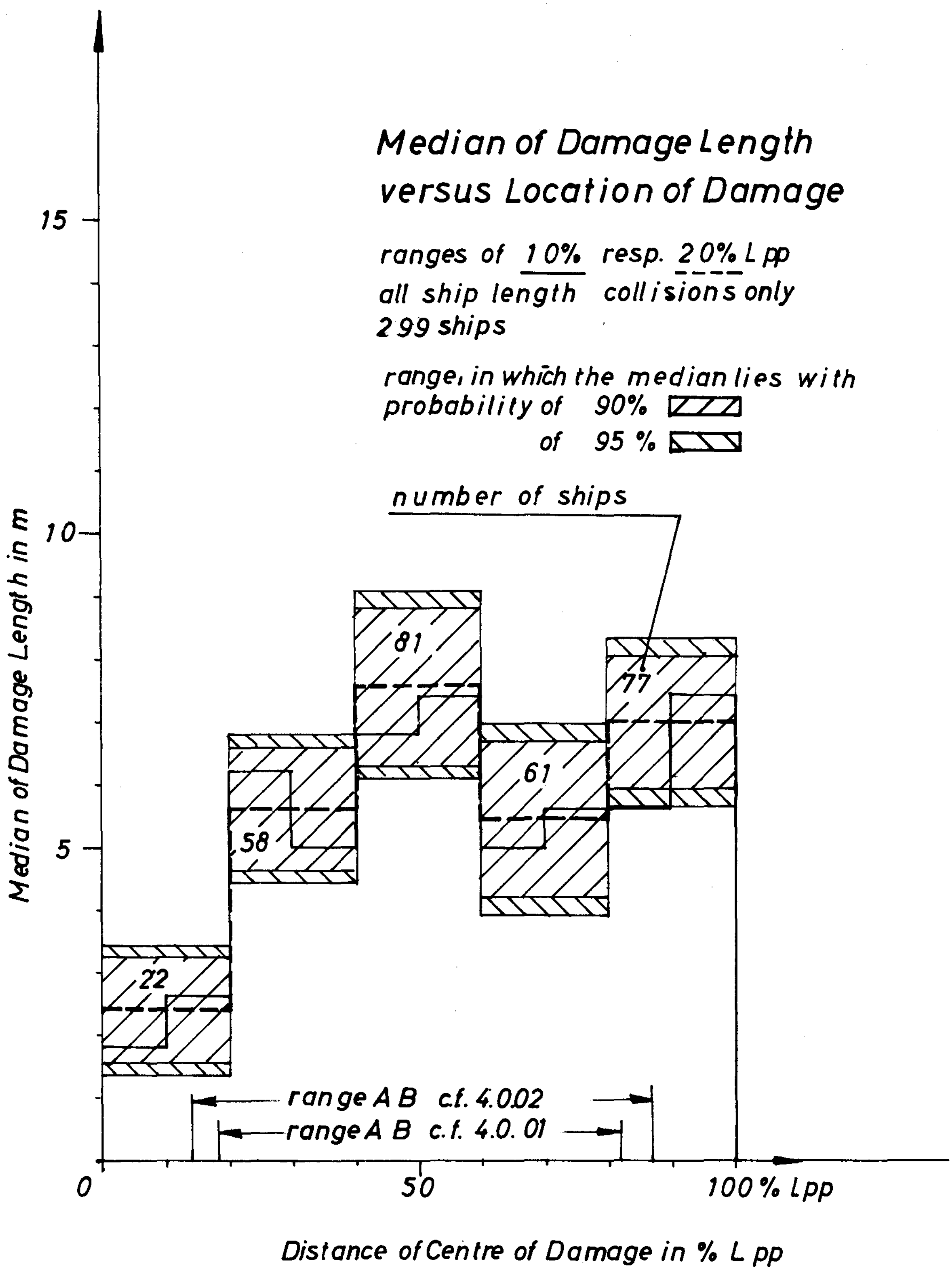

Median of Damage Length
versus Location of Damage
ranges of 10% resp. 20% L pp
all ship length collisions only
299 ships
range, in which the median lies with
probability of 90%
of 95 %
number of ships
22
58
81
61
77
range A B c.f. 4.0.02
range A B c.f. 4.0.01
Median of Damage Length in m
15
10
5
0
50
100 % Lpp
Distance of Centre of Damage in % L pp

Fig. 4.0.03

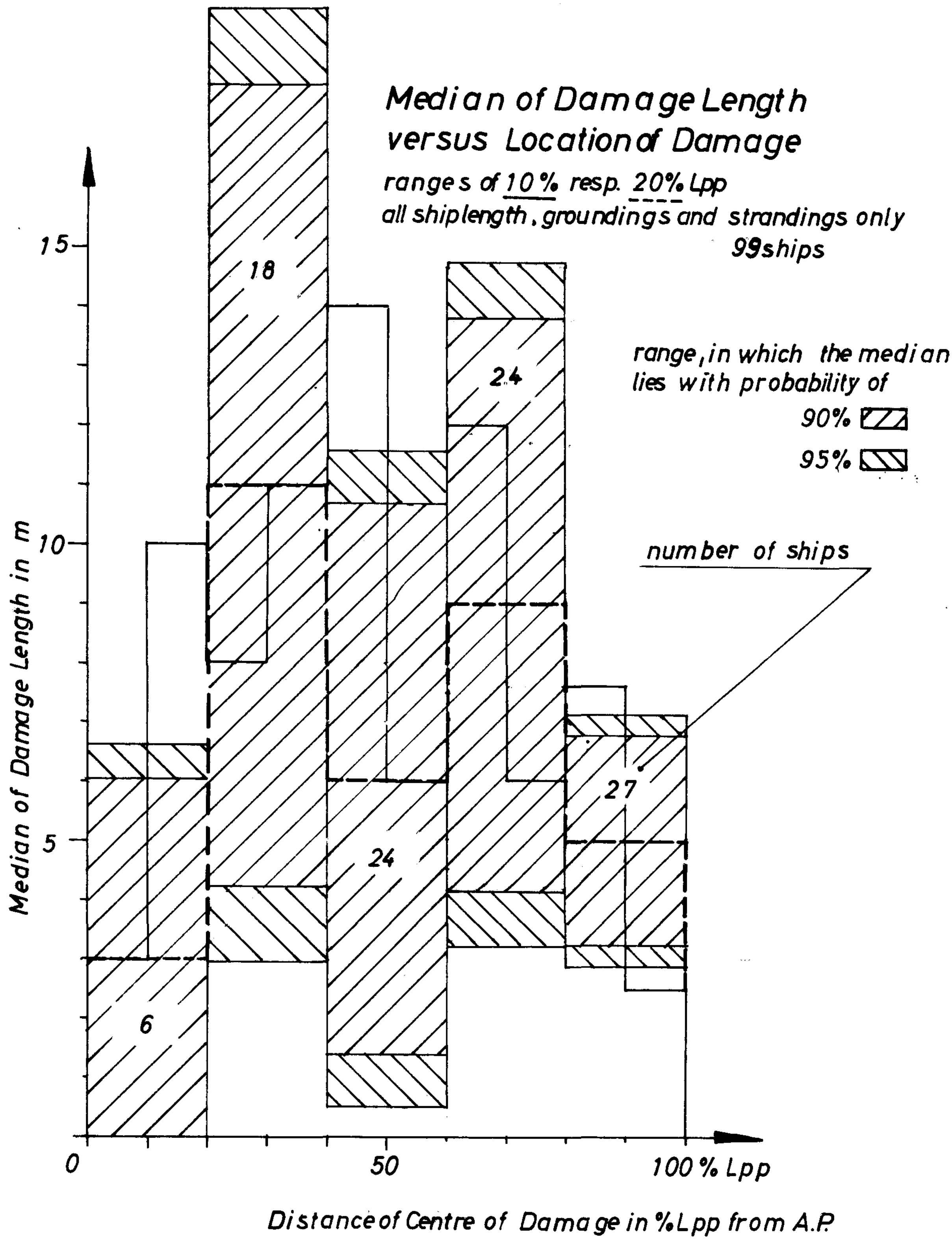

Median of Damage Length
versus Location of Damage
ranges of 10% resp. 20% Lpp
all shiplength, groundings and strandings only
99ships
range, in which the median
lies with probability of
90%
95%
number of ships
18
24
24
6
27
15
10
5
0
50
100% Lpp
Median of Damage Length in m
Distance of Centre of Damage in % Lpp from A.P.

Fig. 4. 0.04

Forces of wind and sea
according to Beaufort's scale