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Lloyd's Register

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FINAL DRAFT REPORT

STUDY INTO THE STRENGTH RELIABILITY OF OFFSHORE STRUCTURES

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Part 2 Revision 1

STUDY INTO THE STRENGTH RELIABILITY OF OFFSHORE STRUCTURES

Part 2 PROBABILISTIC COLLAPSE STRENGTH

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SUMMARY of STOCHASTIC RESULTS

The collapse mode of the first two platforms analysed (ie the lifted platform in shallow water and barge launched in deep water) is caused by the failure of the diagonal bracing members joining the main legs. Once these bracing members become ineffective the main legs will fail soon after in bending. The statistical strength of these structures has been based on the strength of the diagonal bracing members only.
Hovever, the analysis of the four leg lifted platform in deep water shows that the bracing members remain effective and the collapse is caused by the failure of the legs at the critical height.

The following is a summary of the resulting stochastic strengths. The deterministic strengths are also tabulated for comparison purposes.

LIFTED PLATFORM in SHALLOW WATER see Section 3 of Report No of LEGS = 6 : WATER DEPTH = 36.6m	
Stochastic Strength	Deterministic Strength
55.4MN Standard Deviation of 1.63	49.3MN

BARGE LAUNCHED PLATFORM in DEEP WATER see Section 4 of Report No of LEGS = 8 : WATER DEPTH = 138.0m	
Stochastic Strength	Deterministic Strength
190MN Standard Deviation of 4.64	168MN

LIFTED PLATFORM in DEEP WATER see Section 5 of Report No of LEGS = 4 : WATER DEPTH = 141.3m	
Stochastic Strength	Deterministic Strength
88.6MN Standard Deviation of 4.31	80.3MN

1) STOCHASTIC COLLAPSE STRENGTH of a REDUNDANT MULTI-MEMBER STRUCTURE

i) Basis of the Method

All statistical calculations are undertaken using Lloyd's Register Offshore Division's Level III Risk Analysis Program. This program is an entirely in-house development.

The forces applied to the platform are transmitted through the members to the piled foundations. At any section through the structure (see Figure 1 section A-A) a number of loadpaths are available to transfer the load on the upper structure to the members below. Collapse of the platform through this section will only occur when all of these loadpaths are fully utilised.

The theoretical strength of any loadpath depends on the component strengths of the members and joints comprising this route. The theoretical strengths used in the deterministic collapse analyses undertaken are based on the strength formulae for joints and members in the API and AISC codes. Documented comparisons between these theoretical strengths and achieved test strength failures allow a stochastic strength of the joints and members to be estimated.

LR's Level III Risk Analysis Program offers several facilities. Two facilities, namely the '-OR-' and the '-PLUS-', are particularily relevant to this type of analysis. Selection of the '-OR-' facility produces the failure strength of a system having a number of components in series, whilst the '-PLUS-' facility sums the statistical strengths of a number of components in parallel. Thus, using the '-OR-' facility, the statistical strength of each loadpath may be obtained by processing its component joint and member strengths. The '-PLUS-' facility enables the determination of the collapse strength of the platform through a section by summing the statistical strengths of the available loadpaths.

The final stochastic collapse strength of the overall structure is obtained by undertaking similar calculations at other critical sections and then finally processing these sectional statistical strengths using the '-OR-' facility.

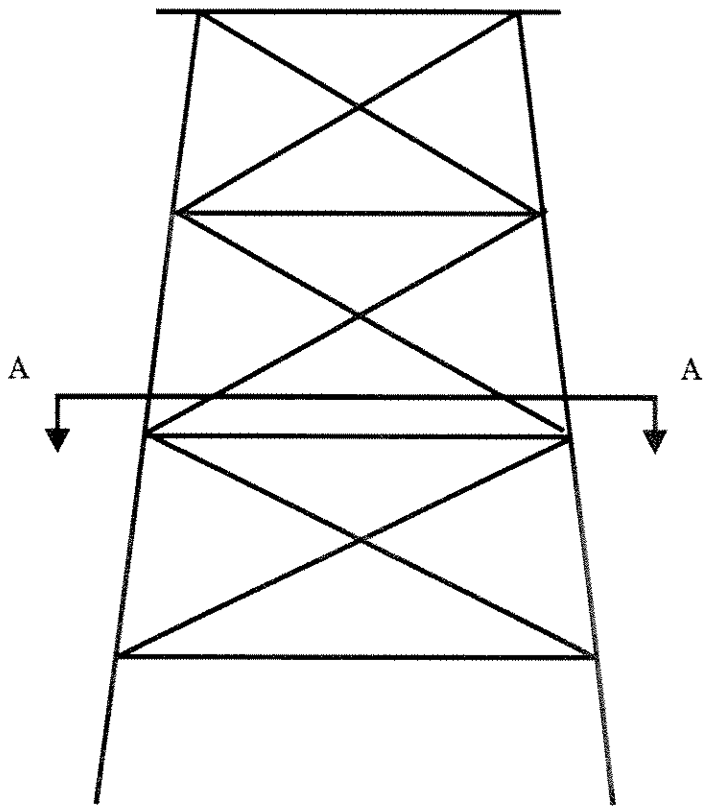


Figure 1

1) STOCHASTIC COLLAPSE STRENGTH of a REDUNDANT MULTI-MEMBER STRUCTURE

i) Basis of the Method (cont)

The basic statistical process is demonstrated by the solution of a simple example shown in Appendix A and discussed in the following section. Statistical distributions of member strength used are typical but have assumed values.

ii) Simple Example Demonstrating the Statistical Process

An idealised pin-jointed framework is analysed and illustrated in Appendix A.

The structure is shown in Figure A.1 and the member loads for the two independent loadpaths are given on Figure A.2.

Table A.1 gives the utilisation ratios at the end of the deterministic collapse analysis.

The deterministic collapse load $Pc = P1 + P2 = 35$ kips.

Table A.2 gives the safety ratio (mean theoretical strength/test strength) and the coefficient of variation between the theoretical and observed test results for the different member types. These values have been assumed and Normal distributions are taken to apply.

Table A.3 gives the load path strengths based on failure of the different component members. These values are obtained by a proportional adjustment of the load in the appropriate loadpath to give a utilisation ratio of unity on the member. The safety factor is then removed to obtain the mean strength. Finally, the standard deviation is determined by multiplying the mean strength by the appropriate coefficient of variation.

Plots A.1 to A.5 show the basic load path strengths based on failure of each of the component members.

The combined probabilities for the two loadpaths based on any member failing are given in Plots A.6 to A.8. These results are obtained using the '-OR-' facility in the Level III Program.

1) STOCHASTIC COLLAPSE STRENGTH of a REDUNDANT MULTI-MEMBER STRUCTURE

ii) Simple Example Demonstrating the Statistical Process (cont)

Plot A.9 gives the stochastic collapse strength of the structure corresponding to both load paths failing. This result makes use of the '-PLUS-' facility in the Level III Program.

The complete risk calculation is illustrated by a statistical distribution of loading given in Plot A.10. The associated risk is shown on Plot A.11. The conservative part of the risk is due to truncation of the upper and lower tails of the distributions. Should this component part prove significant, extension of the tails would be required.

The stochastic collapse strength shown in Plot 9 has been normalised and the resulting distribution is shown in Plot 12. The derived mean and standard deviation are quoted.

iii) Discussion of Results for Pin-jointed Frame Example

Comparing the deterministic collapse strength of 35 kips with the mean and standard deviation derived for the stochastic collapse distribution (Plot A.12) gives a safety ratio of 0.875 and a coefficient of variation of 0.04 . Hence, the coefficient of variation for the strength of the total structure is less than the coefficients of variation of the component members whilst the the safety factor associated with the final strength is intermediate to that for the component members.

1) STOCHASTIC COLLAPSE STRENGTH of a REDUNDANT MULTI-MEMBER STRUCTURE

iv) Generalising the Method

Initially, the horizontal force applied to a fixed steel platform is predominantly carried by tension and compression in the diagonal bracing members. If the main legs are battered then a proportion of the horizontal force will be balanced by the endload in the main legs and piles. As yielding of the diagonal bracing members occurs a significant proportion of any further applied horizontal loading is transmitted as shear and bending of the piles and main legs which will eventually yield in bending.

In order to recognise the relative importance of the various loadpaths as the collapse progresses, a special program (Loadpath Weighting Program) has been written to calculate the proportion of the horizontal force being carried by the various members crossing a given height level on the structure. The use of this program will be demonstrated using the results obtained previously for the collapse analyses of a 2D braced test frame.

v) Example in the use of Loadpath Weighting Program

The overall test structure is shown in Figure B.1 of Appendix B. The critical section under consideration is given by the line A-A. Table B.1 gives the distribution of internal forces prior to yielding. In this linear elastic condition, the diagonal braces are carrying 98.4% of the horizontal applied force almost exclusively as member endload.

In Table B.2 both the diagonal brace loadpaths have yielded. Brace 20 is limited by a joint failure at node 14 whilst brace 21 is yielding in tension. Both legs are still behaving linear elastically but are now carrying some 20.6% of the horizontal applied loading as shear forces in the members.

Tables B.3 and B.4 show the main legs increasing the proportion of horizontal force they carry with both approaching yielding, where failure of the structure at this section would occur. The progress is traced in Figure B.2.

1) STOCHASTIC COLLAPSE STRENGTH of a REDUNDANT MULTI-MEMBER STRUCTURE

vi) Method of Calculation of Stochastic Collapse Strength of Test Frame

Calculation of the collapse strength of the frame would be similar to the calculation for the pin-jointed frame shown in Appendix A.
Four loadpaths would be included in the calculations:

1. member 20 -OR- joint 14 -OR- joint 12
2. member 21 -OR- joint 13
3. member 22
4. member 23

The joints given are the brace end joints at the chord/brace interface, and the -OR- denotes the use of the '-OR-' facility in LR's Level III Program which combines statistical distributions of paths in series. The level of load in each loadpath would be taken from the horizontal forces HF on Table B.4. Statistical distributions for each type of failure would be taken from comparisons between test and theory.
The stochastic collapse strength through this section P(A-A) is calculated as:

P(A-A) = path 1 -PLUS- path 2 -PLUS- path 3 -PLUS- path 4

where -PLUS- denotes combining the individual path strengths evaluated above using the LR's Level III Program '-PLUS-' facility for parallel events.

The overall stochastic collapse strength of the frame would be obtained by repeating the calculations across other critical sections and then using the '-OR-' facility to process the collapse strengths at the chosen critical sections thus resulting in the determination of the overall stochastic collapse strength of the structure.

2) GENERAL METHOD used for EVALUATING the STOCHASTIC COLLAPSE STRENGTHS of the SELECTED PLATFORMS

The loadpath weighting program (section 1. iv) has been used to give the contribution of the component members to the total horizontal force transferred through a selected critical horizontal level in the finally achieved collapse state of each platform.

The subsequent statistical analysis has been simplified by ignoring any further strength remaining across a level once all the main diagonal bracing member loadpaths in either the X or Y direction have yielded. A member loadpath will fail when either the member or a joint at its ends yields.

Table 2.0 gives the safety factors and coefficients of variation assumed for joint and member failures for all the analyses undertaken. These values have been estimated for the different components and loadings and may be easily replaced if more accurate estimates become available.

Type	Safety factor	Coeff. of variation
COMPRESSION	0.8	0.1
TENSION	0.9	0.05
JOINT FAILURE	0.85	0.08

Table 2.0 Approximate Safety Factors and Coefficients of Variation used in estimations of Probabilistic Collapse Strength of Platforms in sections 3,4 and 5

3) STOCHASTIC COLLAPSE ANALYSIS for the LIFTED PLATFORM in SHALLOW WATER

i) Member Forces through the selected Critical Platform Bay

The selected critical bay lies between elevations -22.0m (z=14.6m) and -8.0m (z=28.6m) and a diagrammatic view of this structure is shown on Figure 3.1. The direction of the chosen storm wave is shown on the diagram.

Table 3.1 gives the horizontal components of member forces at a cutting height of 21.6 m. From the table column of HX/HX totals it is seen that the X direction shear is predominately carried by endload in the four X-wise bracing members, there being no leg batter in the XZ plane. The HY/HY total shows that 72% of the Y direction shear is carried by the three Y-wise bracing members with the remainder being mainly resisted by axial force in the battered legs and piles.

The interaction ratios in the piles and legs are still reasonably low through this section and will be capable of withstanding any further required increase with the statistical variation of brace forces. As the braces yield then further force transfer through this section will be achieved by bending of the legs and piles. The amount of force that may be transferred by this method is relatively small and is ignored.

3) STOCHASTIC COLLAPSE ANALYSIS for the LIFTED PLATFORM in SHALLOW WATER

ii) Statistical distributions for critical members and joints

Tables 3.2 and 3.3 give the mean strengths and standard deviations for the critical members and joints in the selected collapse zone.

Table 3.4 documents the probability distributions required in the calculation of the probabilistic collapse strength of the platform through this critical zone. The ranges used for numerical integration are also given.

Figures 3.2 to 3.8 show sample distributions at various stages of the analysis, whilst figure 3.9 gives the estimated probabilistic collapse strength through this section.

iii) Discussion of results

The finally achieved probabilistic collapse strength through the chosen critical section has a mean strength of 56.3 MN and a standard deviation of 1.91 MN. This compares with the deterministic collapse strength of 49.3 MN, calculated with safety factors included.
To gauge the effect of other critical zones on the overall probabilistic strength of the platform a second zone having the same probabilistic strength as that calculated above is assumed to exist. This reduced the mean strength to 55.4 MN with a standard deviation of 1.63 MN.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : UM2PS1_13

Combined Name : T88$D

Units : Force = kN

Members cutting Height : 21.60m ie Height for member forces listed

Safety Factor Retained

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 21.60m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

HYTotal : Horizontal force in Y direction applied above height 21.60m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal kN	HXOverall kN	HYTotal kN	HYOverall kN
101	0.207E+05	0.292E+05	-.290E+05	-.397E+05

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC	
151	101	0.000E+00	12.4	12.4	0.596E-03	-.900E+04	16.8	-.899E+04	0.310	1.000	Y dirn
152	101	0.000E+00	-5.65	-5.65	-.273E-03	-.526E+04	8.78	-.525E+04	0.181	0.993	Y dirn
153	101	0.000E+00	-55.2	-55.2	-.266E-02	-.666E+04	18.4	-.664E+04	0.229	0.990	Y dirn
154	101	0.000E+00	-91.3	-91.3	-.441E-02	-.153E+04	204.	-.133E+04	0.458E-01	0.347	pile
155	101	0.000E+00	-258.	-258.	-.124E-01	-138.	-45.8	-183.	0.633E-02	0.254	leg
156	101	0.000E+00	-165.	-165.	-.798E-02	0.216E+04	-2.60	0.215E+04	-.744E-01	0.928	leg
157	101	0.000E+00	-1.56	-1.56	-.755E-04	-.271E+04	181.	-.252E+04	0.872E-01	0.531	pile
158	101	0.408E+04	-5.48	0.408E+04	0.197	-392.	-30.0	-421.	0.146E-01	0.995	X dirn
159	101	0.430E+04	-7.96	0.429E+04	0.207	413.	-6.31	407.	-.140E-01	1.000	X dirn
160	101	0.000E+00	378.	378.	0.183E-01	-.298E+04	-938.	-.392E+04	0.135	0.724	pile
161	101	0.000E+00	110.	110.	0.532E-02	0.112E+04	-678.	440.	-.152E-01	0.771	leg
162	101	0.000E+00	130.	130.	0.629E-02	697.	-97.9	600.	-.207E-01	0.452	leg
163	101	0.000E+00	311.	311.	0.150E-01	-633.	-327.	-960.	0.332E-01	0.284	pile
164	101	0.676E+04	-8.19	0.675E+04	0.326	649.	10.4	659.	-.228E-01	1.001	X dirn
165	101	0.560E+04	-13.5	0.559E+04	0.270	-537.	-38.3	-576.	0.199E-01	0.890	X dirn
166	101	0.000E+00	-19.4	-19.4	-.938E-03	-.259E+04	91.5	-.250E+04	0.863E-01	0.396	pile
167	101	0.000E+00	-21.3	-21.3	-.103E-02	-952.	-114.	-.107E+04	0.368E-01	0.282	leg
168	101	0.000E+00	-173.	-173.	-.835E-02	0.160E+04	-109.	0.149E+04	-.514E-01	0.508	leg
169	101	0.000E+00	-133.	-133.	-.642E-02	-302.	-60.4	-363.	0.125E-01	0.143	pile

Table 3.1

Critical Members

Direction	Member Id	Compression/ Tension	Mean Failure MN	Standard Deviation
Y	151	Tension	23.58	1.18
Y	152	Compression	15.60	1.56
Y	153	Tension	17.60	0.88
X	158	Compression	12.20	1.22
X	159	Compression	12.76	1.28
X	164	Tension	17.84	0.89
X	165	Tension	16.62	0.83

Table 3.2

Critical Joints

Joint Id	Brace Id	Interaction Ratio	Mean Failure MN	Standard Deviation
64	151	0.739	33.80	2.70
89	159	0.719	16.70	1.34
146	164	0.817	23.14	1.85
89	165	0.841	18.62	1.49

Table 3.3

Input Distributions

Description	Title	Lower Bounds	Upper Bounds	Figure No.
1. Failure of member 151 (Y-Z)	Strength MN M151	18.0	27.8	
2. Failure of member 152 (Y-Z)	Strength MN M152	9.0	21.0	
3. Failure of joint at end of member 151	Strength MN J64	22.0	43.0	
4. Failure of member 157 or joint at member end	Strength MN 151 M/J	19.0	27.8	3.2
5. Failure of member 151 and 152	Not Used	21.0	33.0	
6. Failure of member 153 (Y-Z)	Strength MN M153	14.0	21.0	
7. Not Used	Not Used			
8. Failure due to member 158 (X-Z)	Strength MN M158	7.5	16.5	
9. Failure due to member 159 (X-Z)	Strength MN M159	8.0	17.5	
10. Failure of member 164 (X-Z)	Strength MN M164	14.0	21.0	
11. Failure of member 165 (X-Z)	Strength MN M165	13.0	19.5	
12. Failure of joint at end of 165	Strength MN J89	16.0	30.0	
13. Not Used	Not Used			
14. Failure due to member 152 and 151 or joint at end of 151	Strength 152 & 151 M/J	32.0	47.2	3.3
15. Crossing Z=21.6m in Y direction	Fail Strength MN (Y)	48.0	65.0	3.4
16. Loading at Z=21.6m (Y)	Not Used			
17. Failure of member 165 or joint at member end	Strength MN 165 M/J	13.2	20.0	3.5
18. Failure of member 158 and 164	Strength MN 158 & 164	24.0	36.0	3.7
19. Failure of member 159 and 165 or joint at member end	Strength MN 159 & 165 M/J	23.0	36.0	3.6
20. Strength of members crossing Z=21.6m in the X direction	Fail Strength MN (X)	50.0	68.0	3.8
21. Horizontal base shear to fail structure through section at Z=21.6m	Fail Strength MN	48.0	64.0	3.9
22. As above. Normal fit	Normal Fit Strength	48.0	64.0	
23. Horizontal base shear to failure - two equally critical zones	Fail Strength MN	48.0	64.0	
24. Horizontal base shear to failure - two equally critical zones	Normal Fit	48.0	64.0	

Table 3.4

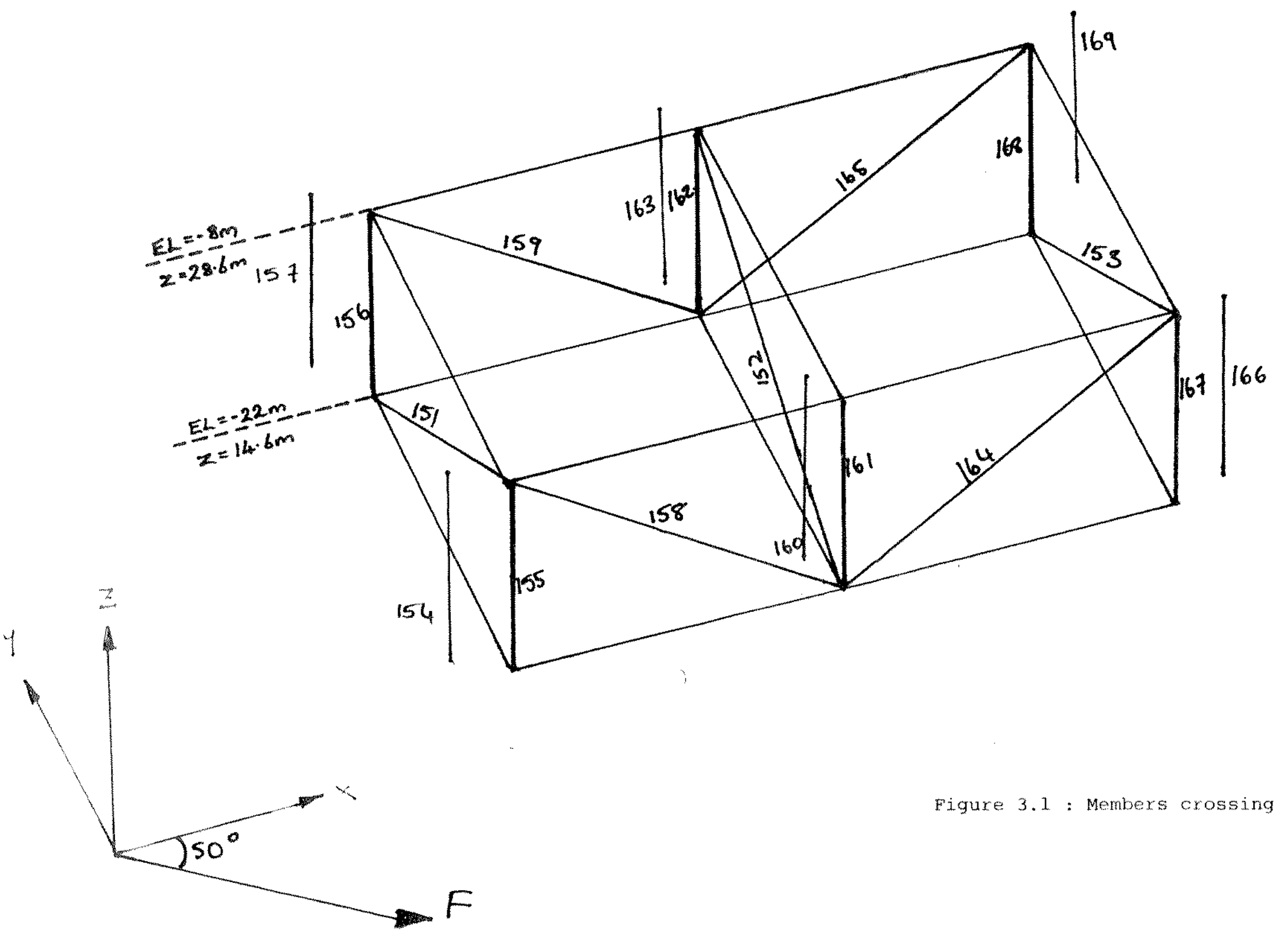
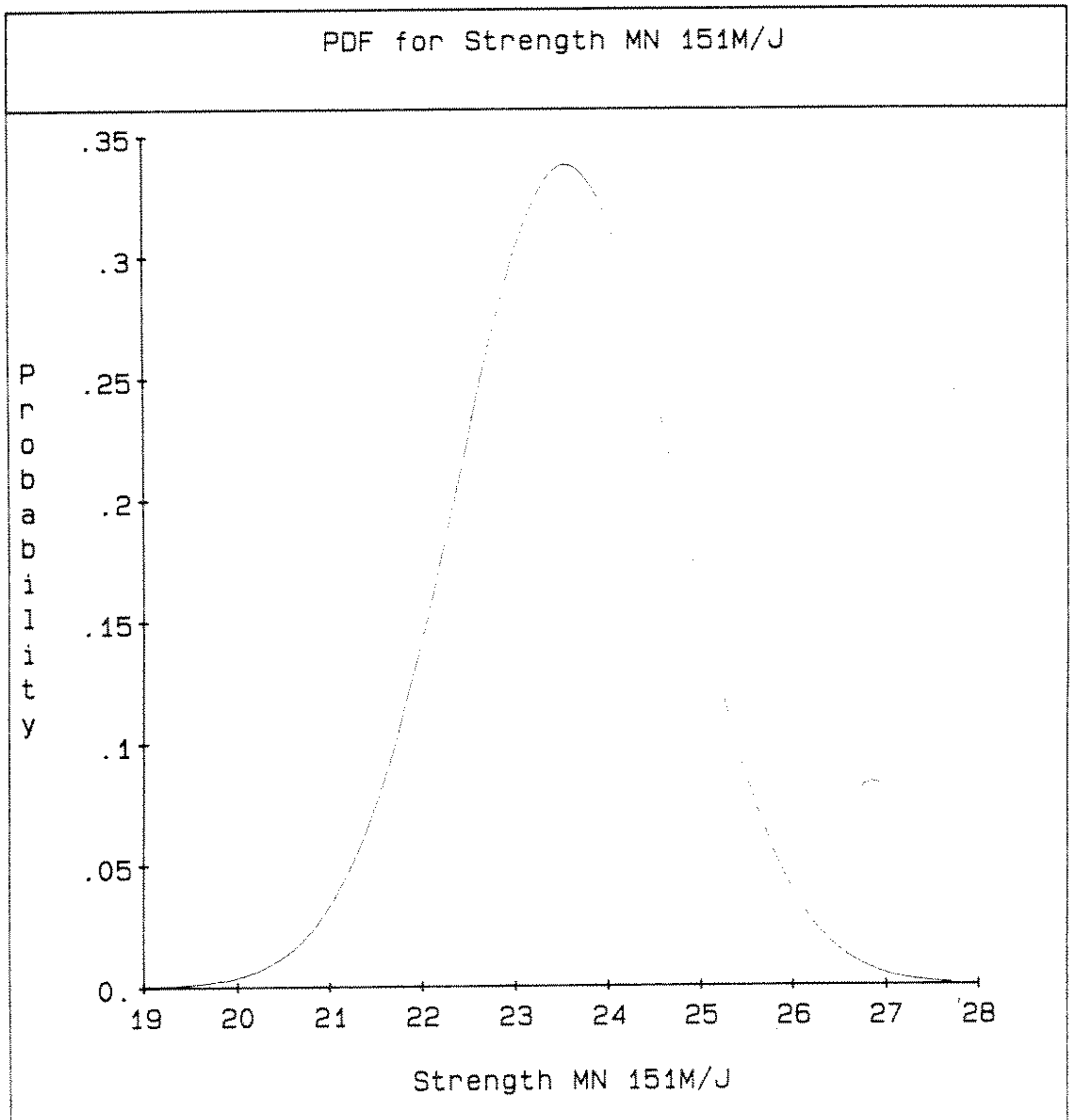


Figure 3.1 : Members crossing z = 21.6m



Overall Strength based on Failure of the diagonal member 151 or the joint at the member end which lie in the Y-Z Plane
Elevation Plane

Figure 3.2

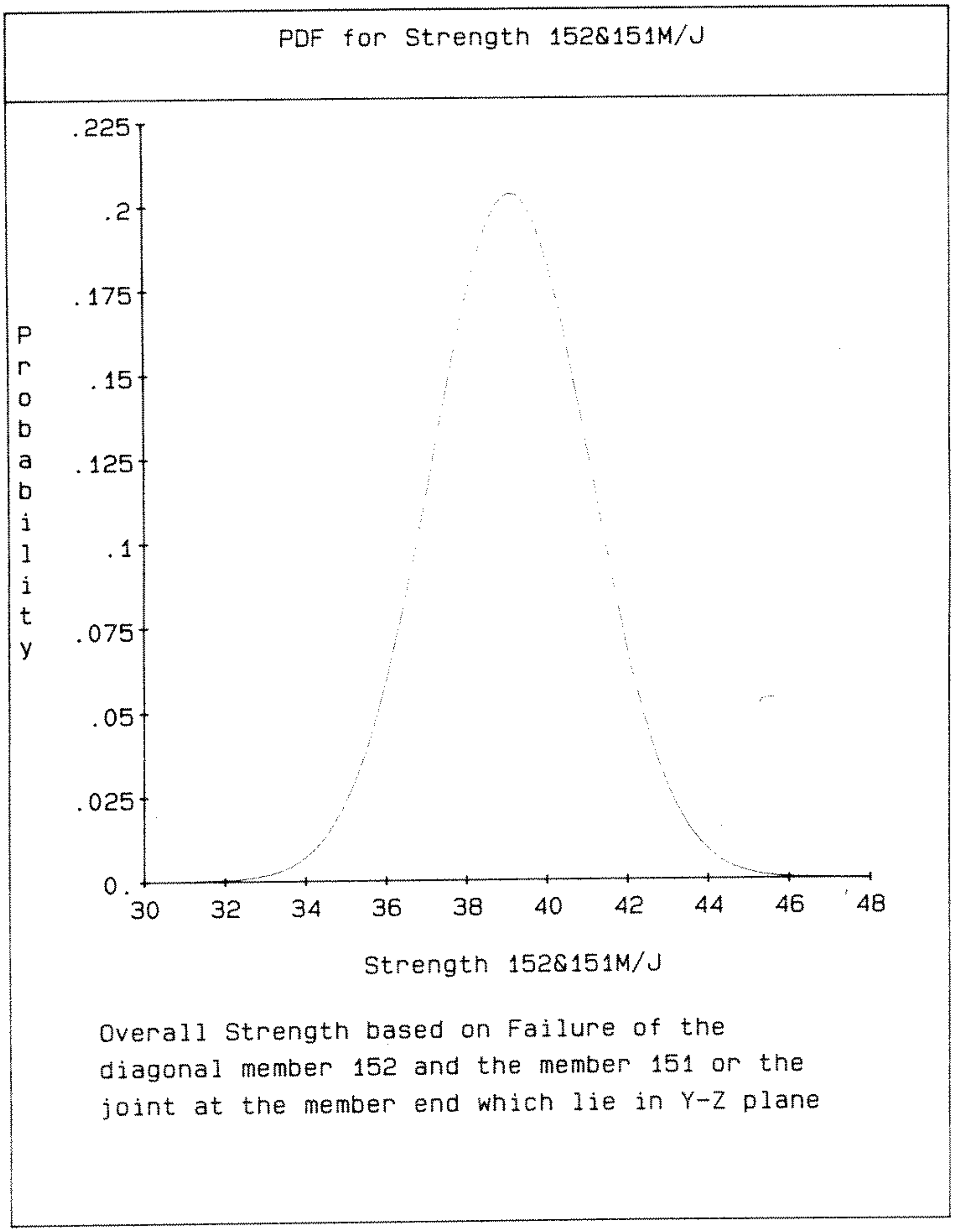
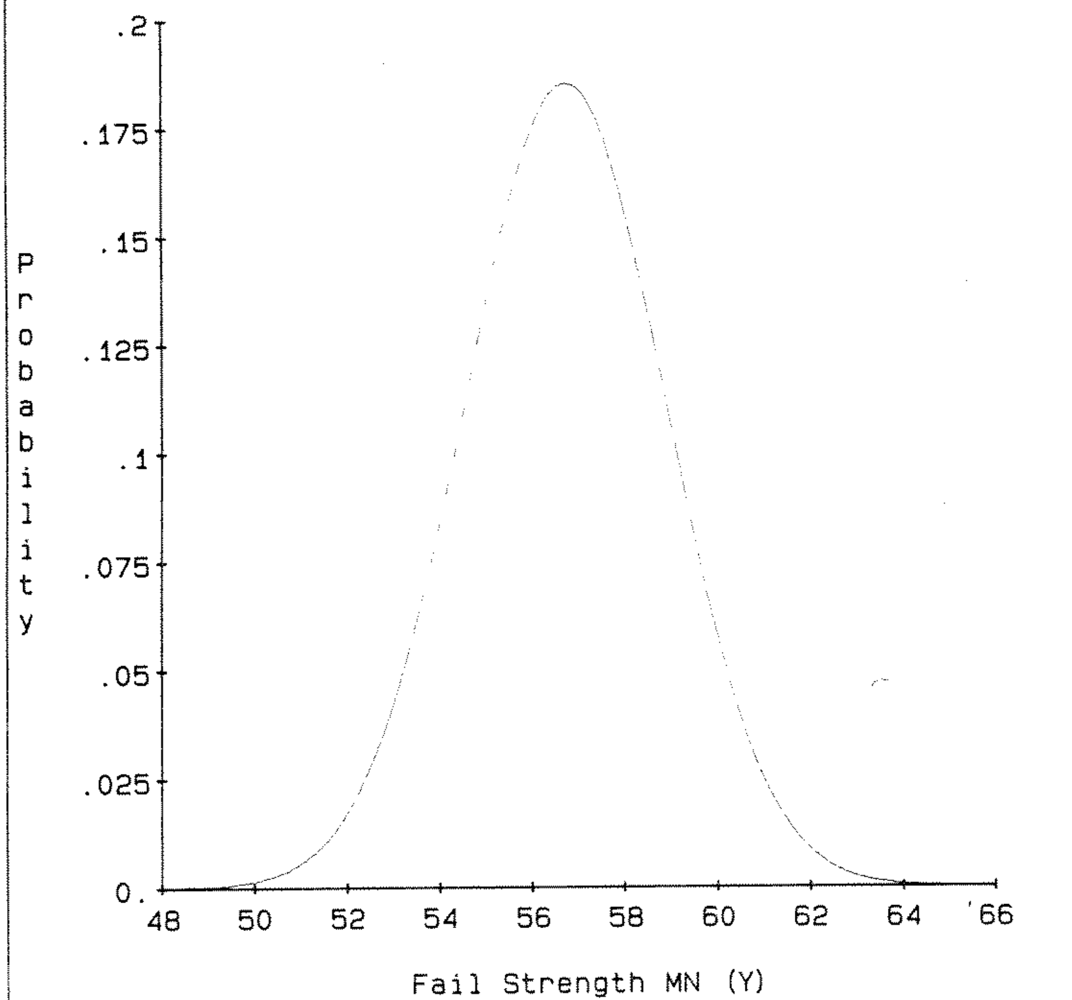

PDF for Strength 152&151M/J
.225
.2
.175
.15
.125
.1
.075
.05
.025
0.
Probability
30
32
34
36
38
40
42
44
46
48
Strength 152&151M/J
Overall Strength based on Failure of the
diagonal member 152 and the member 151 or the
joint at the member end which lie in Y-Z plane

Figure 3.3

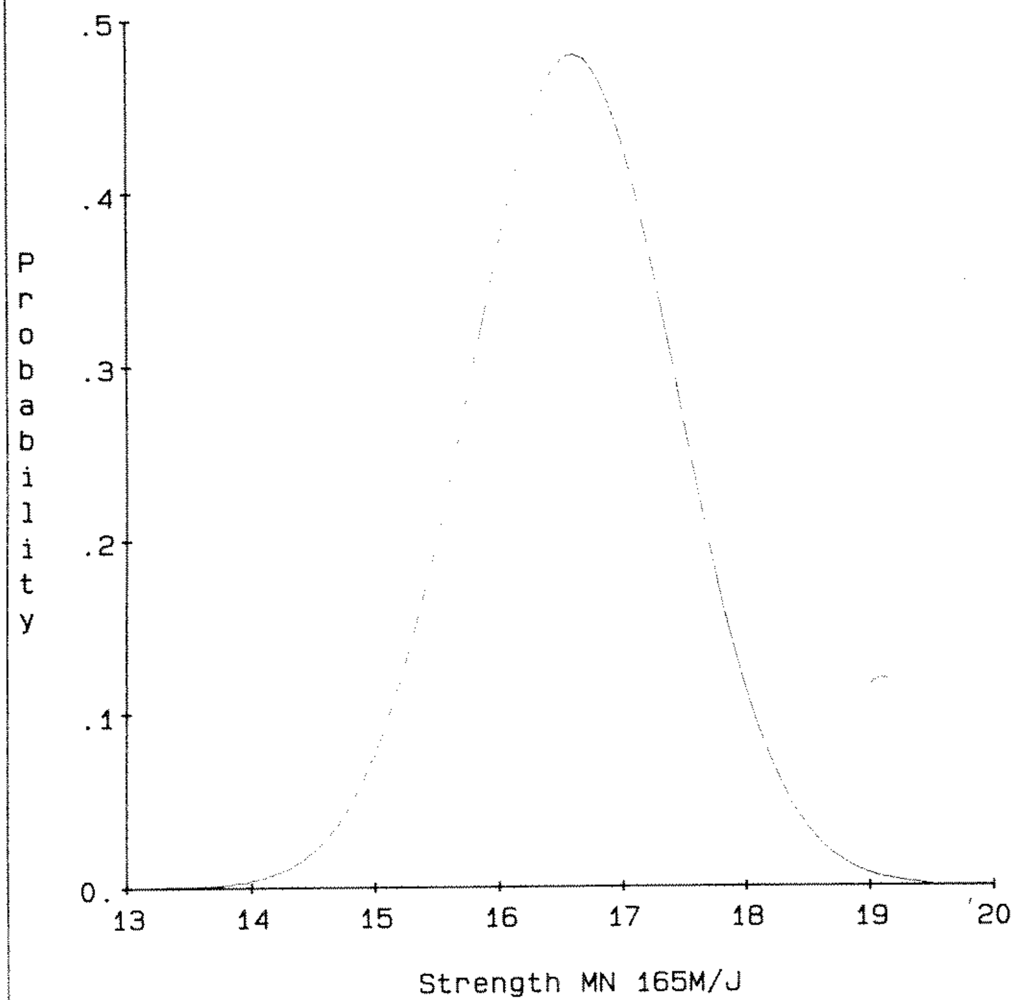
PDF for Fail Strength MN (Y)



Strength of Structural Members lying in the
Y-Z plane which cross the height Z=21.6m

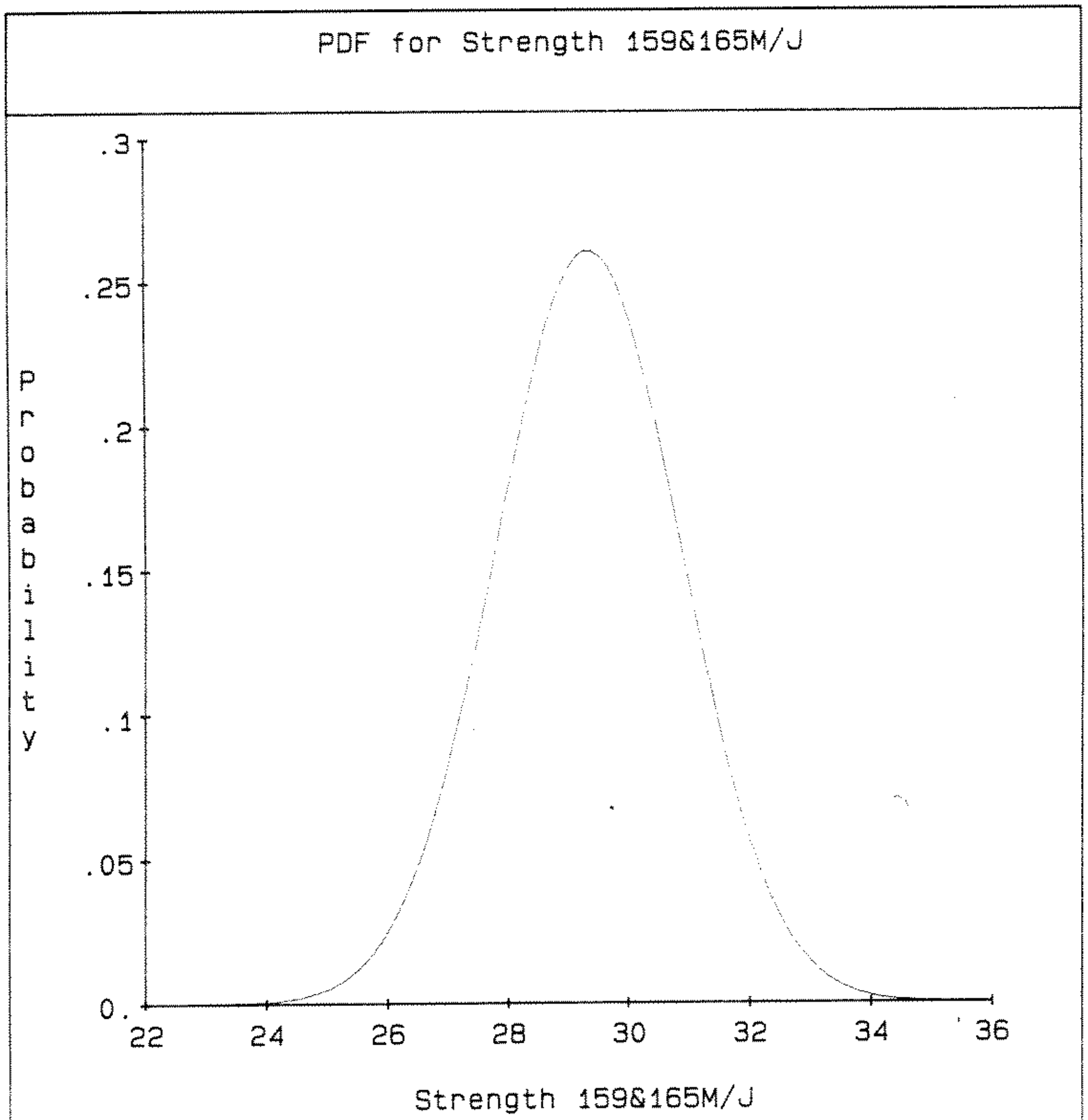
Figure 3.4

PDF for Strength MN 165M/J



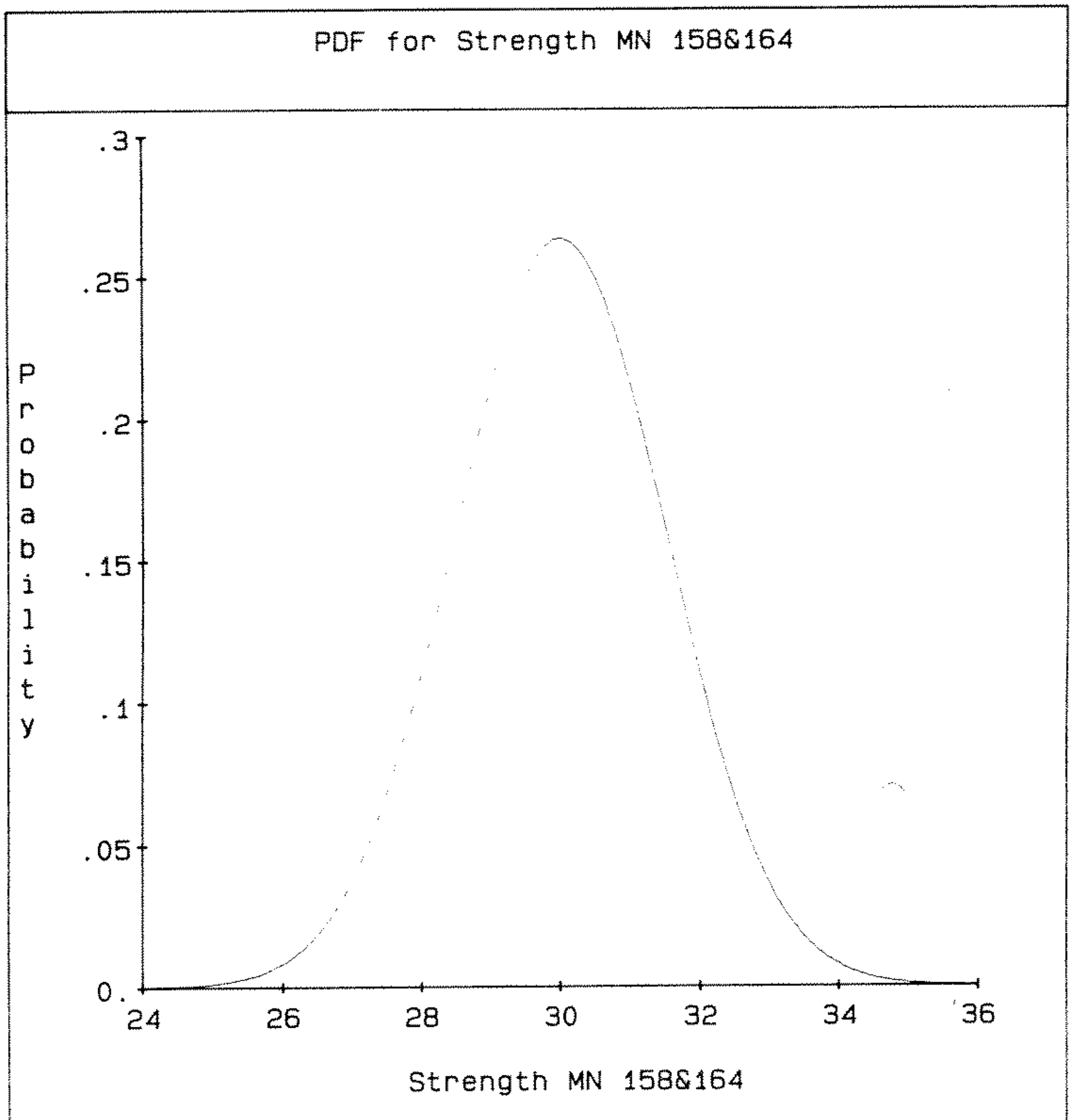
Overall Strength based on Failure of the diagonal member 165 or the joint at the member end lying in the X-Z plane

Figure 3.5



Overall Strength based on Failure of the diagonal member 159 and the member 165 or the joint at the member end which lie in the X-Z plane

Figure 3.6



Overall Strength based on Failure of the diagonal members 158 and 164 which lie in the X-Z plane

Figure 3.7

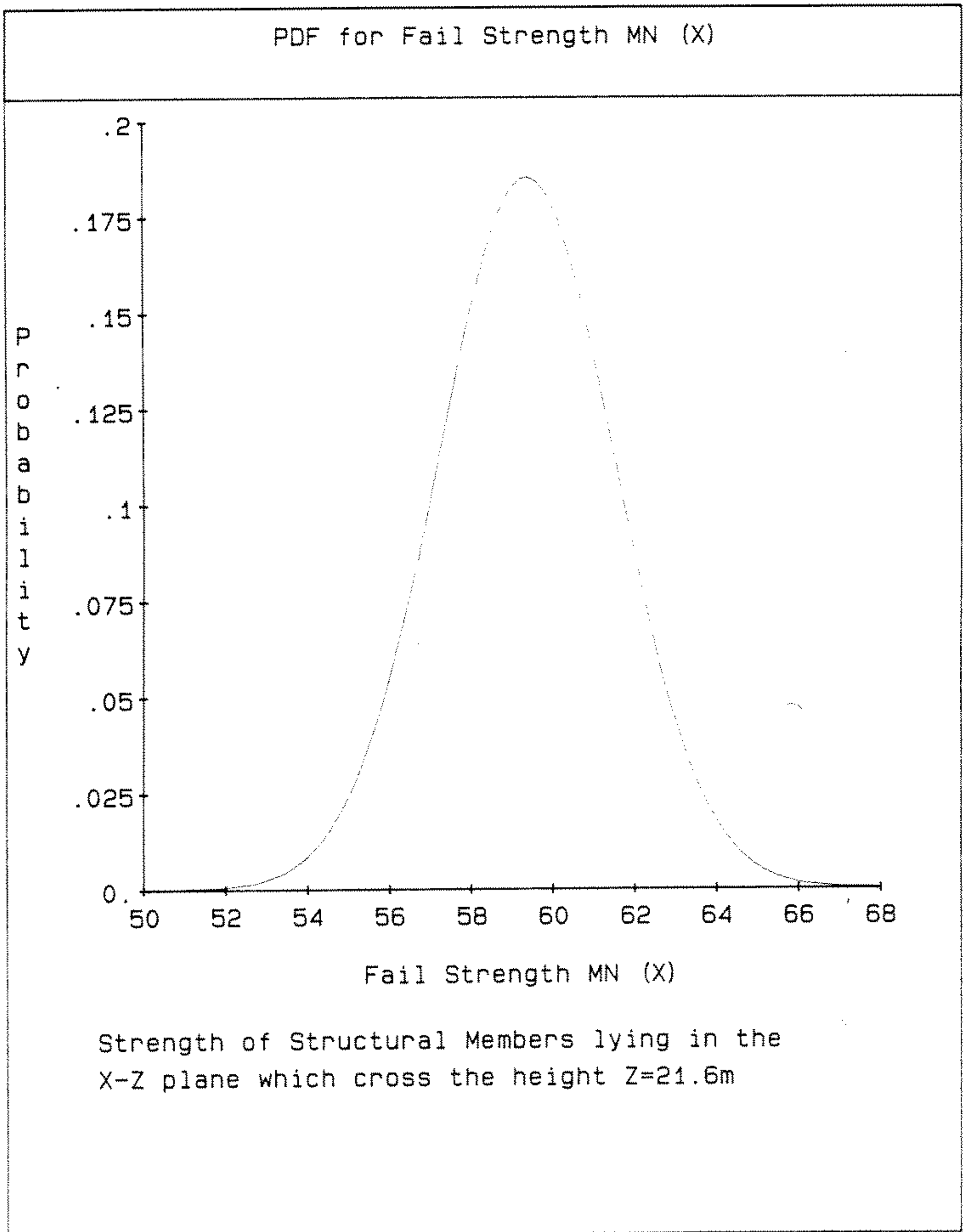
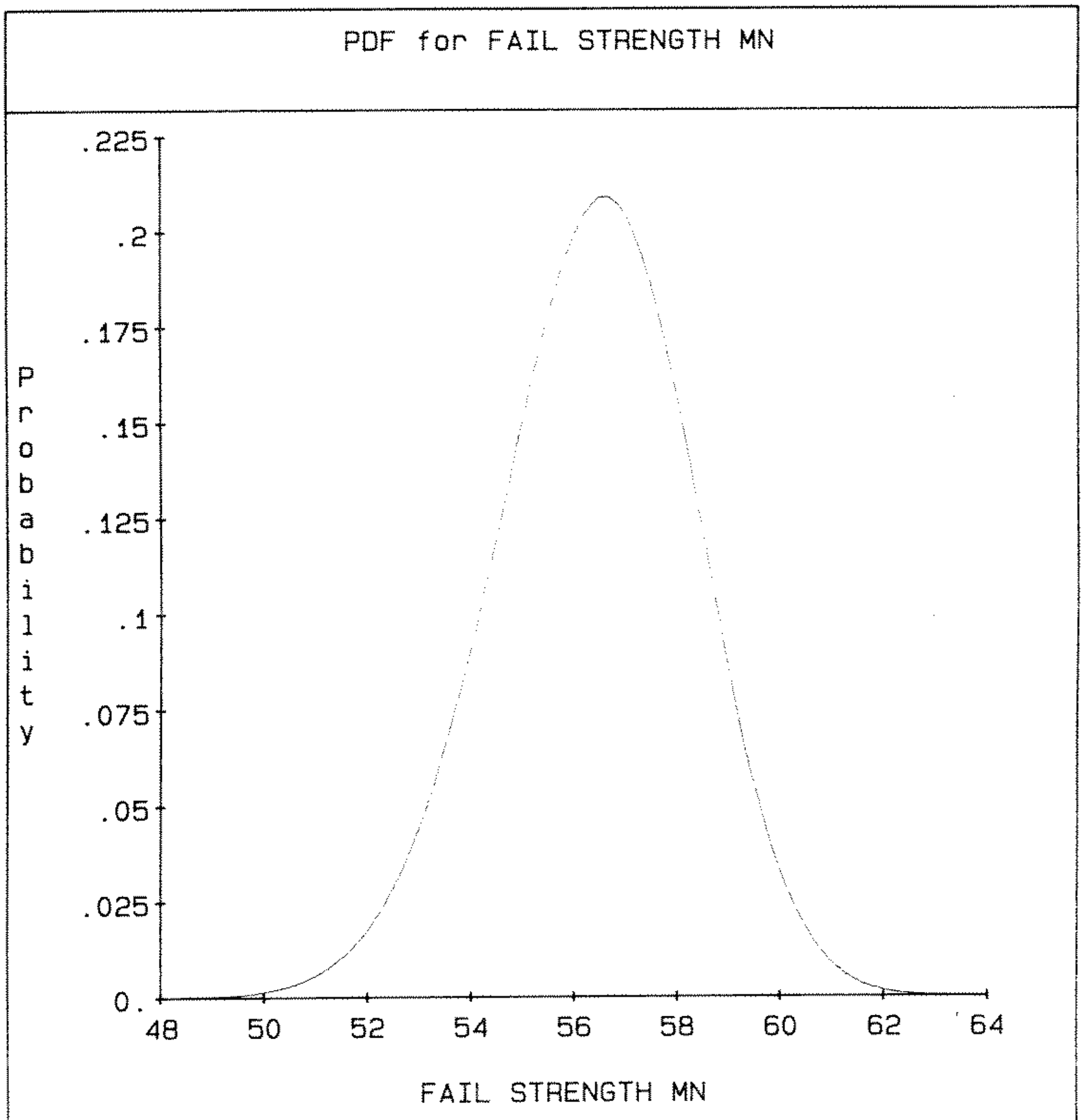

PDF for Fail Strength MN (X)
Probability
.2
.175
.15
.125
.1
.075
.05
.025
0.
50
52
54
56
58
60
62
64
66
68
Fail Strength MN (X)
Strength of Structural Members lying in the
X-Z plane which cross the height Z=21.6m

Figure 3.8



Horizontal base shear to fail structure through section at z=21.6m

Figure 3.9

4) STOCHASTIC COLLAPSE ANALYSIS for the BARGE LAUNCHED PLATFORM in DEEP WATER

i) Member Forces through the selected Critical Platform Bay

The probabilistic collapse strength is calculated with the wave in the global X direction.
The selected critical bay lies between elevations -72m (z=66.0m) and -42m (z=96.0m) and a diagrammatic view of this structure is shown on Figure 4.1. The direction of the chosen storm wave is shown on the diagram.

Table 4.1 gives the horizontal components of member forces at a cutting height of 90m. The HX/HX total shows that 73% of the X direction shear is carried by the six X-wise bracing members with the remainder being mainly resisted by axial force in the battered leg members.

The interaction ratios in the legs are still reasonably low through this section and will be capable of withstanding a further increase with the statistical variation of brace forces. As the braces yield then further force transfer through this section will be achieved by bending of the legs. The amount of force that may be transferred by this method is relatively small and is ignored.

ii) Statistical distributions for critical members and joints

Tables 4.2 and 4.3 give the mean failure strength and standard deviation for the critical members and joints in the selected collapse zone.

Table 4.4 documents the probability distributions required in the calculation of the probabilistic collapse strength of the platform through this critical zone. The ranges used for numerical integration are also given.

Figures 4.2 to 4.7 show sample distributions at various stages of the analysis, whilst figure 4.8 gives the estimated probabilistic collapse strength through this section. Figure 4.9 shows a normal distribution of this probabilistic collapse strength.

4) STOCHASTIC COLLAPSE ANALYSIS for the BARGE LAUNCHED PLATFORM in DEEP WATER

iii) Discussion of results

The finally achieved probabilistic collapse strength through the chosen critical section has a mean strength of 193MN and a standard deviation of 5.56MN. This compares with the deterministic collapse strength of 168MN, calculated with safety factors included.

To gauge the effect of other critical zones on the overall probabilistic strength of the platform a second zone having the same probabilistic strength as that calculated above is assumed to exist. This reduced the mean strength to 190MN with a standard deviation of 4.64MN.

5) STOCHASTIC COLLAPSE ANALYSIS for the LIFTED PLATFORM in DEEP WATER

i) Member Forces through the selected Critical Platform Bay

The selected critical bay lies between elevations -103m (z=38.3m) and -71m (z=70.3m) and a diagrammatic view of this structure is shown on Figure 5.1. The direction of the chosen storm wave is shown on the diagram.

The collapse of the first two platforms analysed (see Section 3 & 4) is caused by the failure of the diagonal bracing members joining the main legs. Once these bracing members become ineffective the main legs will fail soon after in bending. The statistical strength of these structures has been based on the strength of the diagonal bracing members only.

In the analysis of this four leg lifted platform in deep water however, the bracing members remain effective and the collapse is caused by the failure of the legs at the critical height.
The legs are initially all in compression due to gravity loading. Figure 5.2(a) shows the direction of the wave loading and the position of the neutral axis for the initial loading with all legs fully effective. At a load factor of 1.7 leg 2 will take no further compression and Figure 5.2(b) shows the new neutral axis position with further bending being resisted by compression in legs 3 and 4 and tension in leg 1. When leg 1 yields at a load factor of 2.6 further loading causes significant bending of legs 3 and 4 which fail soon after. The compression and tension in legs 1 and 2 throughout the loading process is given in Figure 5.3. The deterministic strengths used for legs 1 and 2 are F31 and F22 respectively. Assuming that the actual leg strengths are Fa1 and Fa2 the revised overall strength of the structure can be determined using the following procedure.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : ANPPS1_15

Combined Name : K33$D

Units : Force = kN

Members cutting Height : 90.00m ie Height for member forces listed

Safety Factor Retained

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 90.00m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

HYTotal : Horizontal force in Y direction applied above height 90.00m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal kN	HXOverall kN	HYTotal kN	HYOverall kN
101	0.116E+06	0.168E+06	-87.0	-99.3

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC	
427	101	-93.0	264.	171.	0.147E-02	724.	-4.94	719.	-8.26	0.799	Y dirn
428	101	-106.	286.	180.	0.156E-02	-824.	2.34	-822.	9.45	0.843	Y dirn
429	101	0.810E+04	-55.2	0.804E+04	0.693E-01	-.163E+04	-23.2	-.165E+04	19.0	0.987	X dirn
430	101	0.792E+04	-50.6	0.787E+04	0.679E-01	0.160E+04	27.6	0.162E+04	-18.7	0.975	X dirn
432	101	0.000E+00	197.	197.	0.170E-02	-48.8	1.79	-47.0	0.540	0.665	Y dirn
433	101	0.000E+00	0.186E+04	0.186E+04	0.160E-01	-.177E+04	32.0	-.174E+04	20.0	0.998	leg
434	101	0.256E+05	-45.1	0.256E+05	0.220	0.342E+04	23.1	0.344E+04	-39.6	1.000	X dirn
435	101	0.199E+05	-49.4	0.198E+05	0.171	0.266E+04	15.2	0.267E+04	-30.7	0.989	X dirn
437	101	0.000E+00	0.178E+04	0.178E+04	0.154E-01	0.183E+04	-77.0	0.176E+04	-20.2	0.999	leg
438	101	0.119E+05	-44.9	0.118E+05	0.102	0.215E+04	11.4	0.217E+04	-24.9	1.000	X dirn
439	101	0.117E+05	-37.3	0.116E+05	0.100	-.211E+04	-29.1	-.214E+04	24.6	1.000	X dirn
440	101	630.	278.	908.	0.783E-02	0.490E+04	-52.5	0.485E+04	-55.7	0.993	Y dirn
441	101	0.113E+04	99.8	0.123E+04	0.106E-01	-.880E+04	47.0	-.876E+04	101.	1.001	Y dirn
442	101	0.000E+00	4.40	4.40	0.380E-04	0.000E+00	0.934	0.934	-.107E-01	0.862	Vert
443	101	0.000E+00	12.8	12.8	0.110E-03	0.000E+00	-.608	-.608	0.699E-02	0.794	Vert
444	101	0.000E+00	192.	192.	0.165E-02	-.122E+04	10.1	-.121E+04	14.0	0.572	Y dirn
445	101	0.000E+00	0.236E+04	0.236E+04	0.204E-01	-469.	113.	-356.	4.09	0.775	leg
446	101	0.000E+00	223.	223.	0.192E-02	0.122E+04	14.4	0.123E+04	-14.2	0.401	Y dirn

Table 4.1 (page 1)

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC	
447	101	0.000E+00	0.171E+04	0.171E+04	0.147E-01	-.417E+04	-374.	-.454E+04	52.2	0.919	leg
448	101	0.000E+00	201.	201.	0.174E-02	0.277E+04	-53.0	0.271E+04	-31.2	0.494	Y dirn
449	101	-466.	0.278E+04	0.231E+04	0.199E-01	-710.	-86.9	-796.	9.15	0.220	leg
450	101	-449.	0.276E+04	0.231E+04	0.200E-01	684.	163.	847.	-9.73	0.220	leg
451	101	0.639E+04	0.132E+04	0.771E+04	0.665E-01	-.972E+04	-373.	-.101E+05	116.	0.605	leg
452	101	0.650E+04	0.131E+04	0.781E+04	0.674E-01	0.990E+04	158.	0.101E+05	-116.	0.607	leg

Table 4.1 (page 2)

Critical Members

Direction	Member Id	Compression/ Tension	Mean Failure MN	Standard Deviation
X	429	Compression	20.19	2.02
X	430	Compression	20.02	1.46
X	434	Tension	56.26	2.81
X	435	Compression	49.74	4.97
X	438	Tension	26.08	1.30
X	439	Tension	25.58	1.28

Table 4.2

Critical Joints

Joint Id	Brace Id	Interaction Ratio	Mean Failure MN	Standard Deviation
333	429	0.646	21.20	1.70
340	430	0.631	21.27	1.70
366	434	0.928	64.19	5.13
366	435	0.987	46.90	3.75
387	439	0.944	28.68	2.29

Table 4.3

Input Distributions

Description	Title	Lower Bounds	Upper Bounds	Figure No.
1.Failure of member 429 (X-Z)	Strength MN M429	12.0	27.0	
2.Failure of member 430 (X-Z)	Strength MN M430	12.0	27.0	
3.Failure of member 434 (X-Z)	Strength MN M434	40.0	67.0	
4.Failure of member 435 (X-Z)	Strength MN M435	30.0	67.0	
5.Failure of member 430 (X-Z)	Strength MN M438	20.0	31.0	
6.Failure of member 439 (X-Z)	Strength MN M439	20.0	30.0	
7.Not Used	Not Used			
8.Failure of joint at end of 434	Strength MN J366	44.0	82.0	
9.Failure of joint at end of 435	Strength MN J364	31.0	57.0	
10.Failure of joint at end of 439	Strength MN J387	20.0	37.0	
11.Failure of member 435 or joint at member end	Strength MN 435 M/J	31.0	57.0	4.3
12.Failure of member 439 or joint at member end	Strength MN 439 M/J	20.0	30.0	
13.Failure of member 434 or joint at member end	Strength MN 434 M/J	45.0	66.0	4.2
14.Failure of 429 and 434 or joint at member end	Strength 429 & 434 M/J	62.0	89.0	4.4
15.Failure of 429 and 438 and 434 or its joint	Strength 1 MN (X)	88.0	115.0	4.6
16.Failure of 430 and 435 or joint at member end	Strength 430 & 435 M/J	48.0	82.0	4.5
17.Failure of 430, (435 and 439) member or joint	Strength 2 MN (X)	74.0	107.0	4.7
18.Failure of 429, 430, 438 and (434, 435, 439) member or joint	Strength MN (X)	170.0	216.0	4.8
19.Not Used	Not Used			
20.Fit Normal Mean=193, SD=5.56		170.0	216.0	4.9
21.Horizontal base shear to failure - two equally critical zones	Fail Strength MN	170.0	216.0	
22.As 21, Normal Fit Mean=190, SD=4.64		170.0	216.0	

Table 4.4

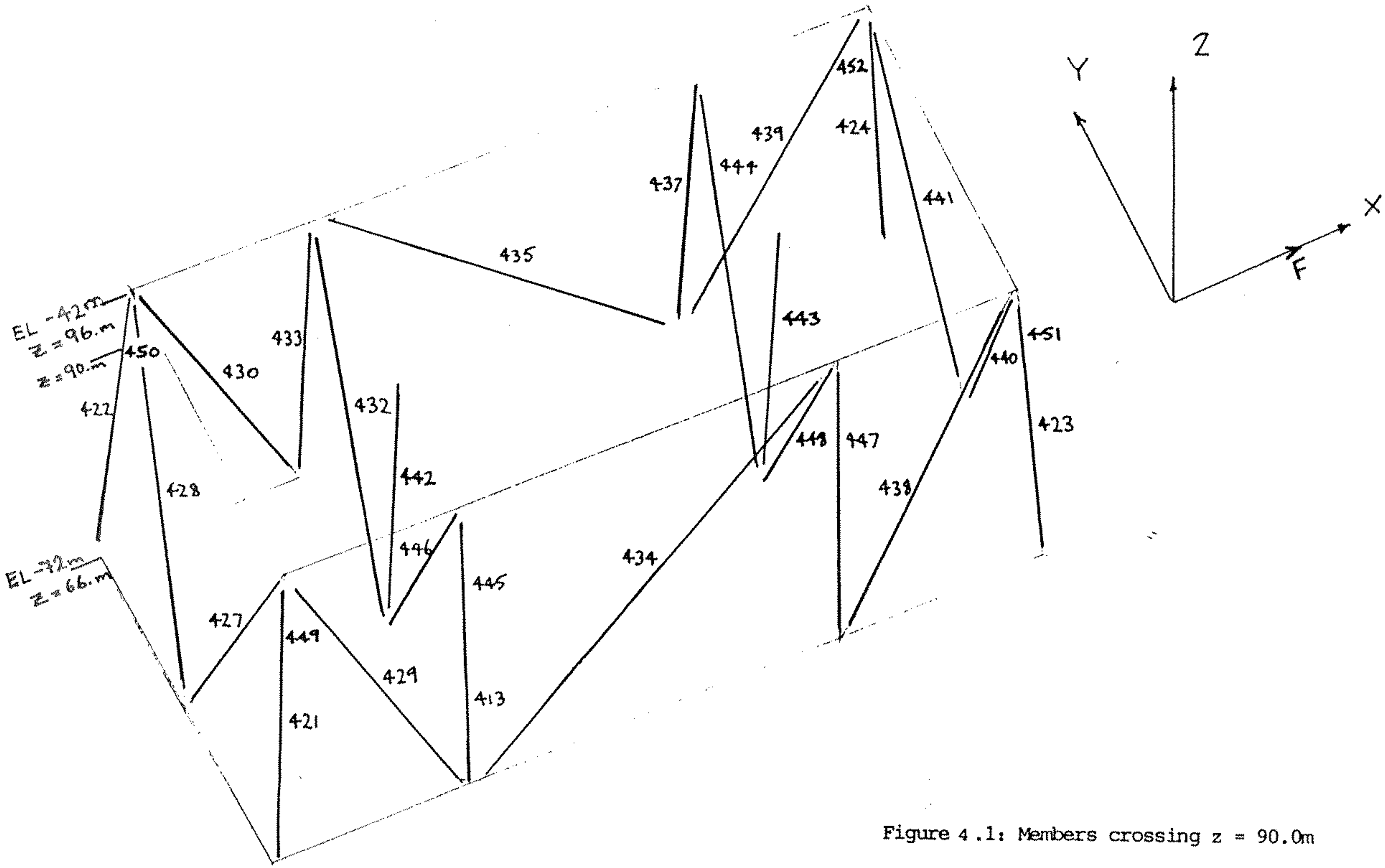
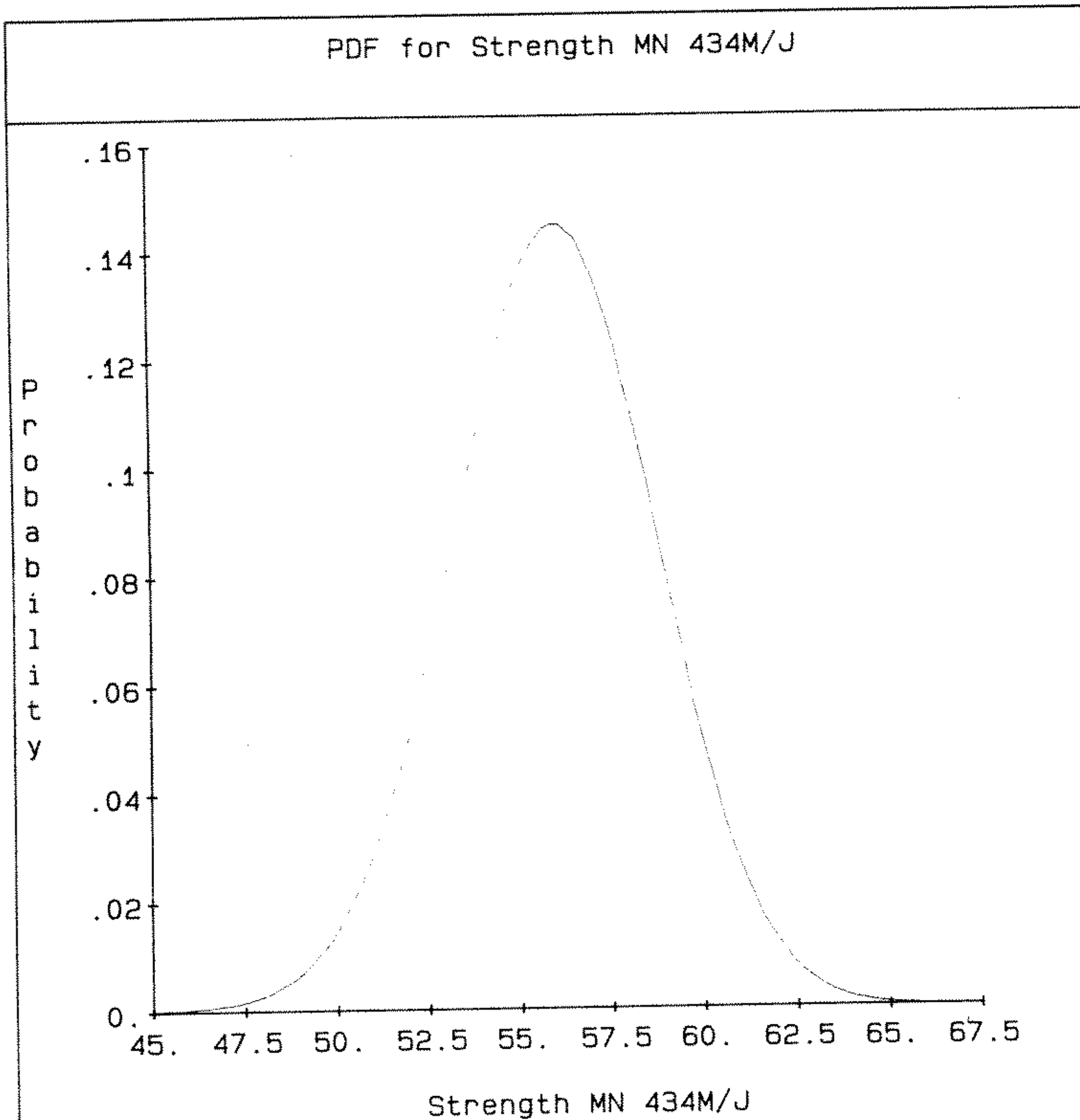
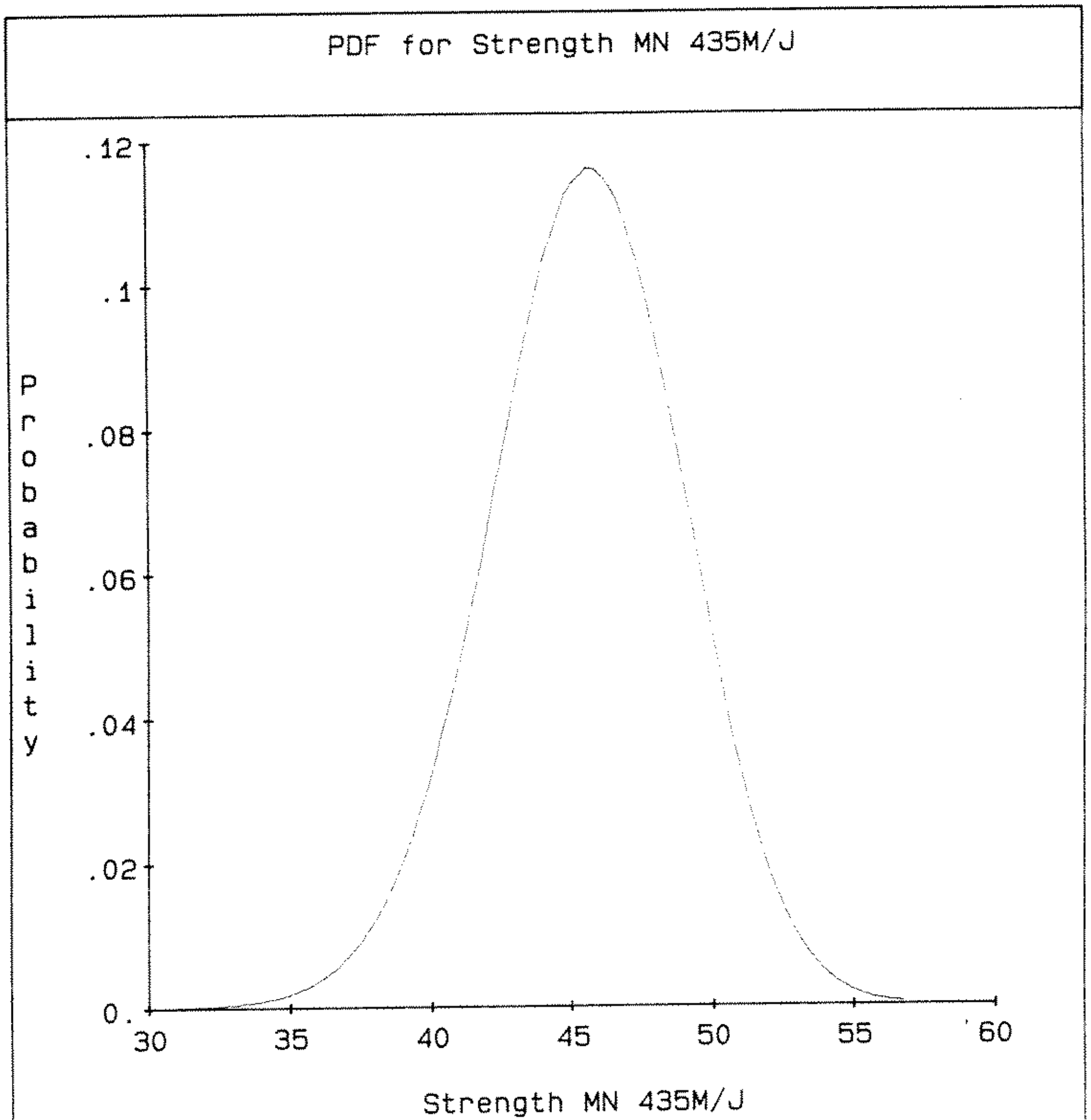


Figure 4 .1: Members crossing z = 90.0m



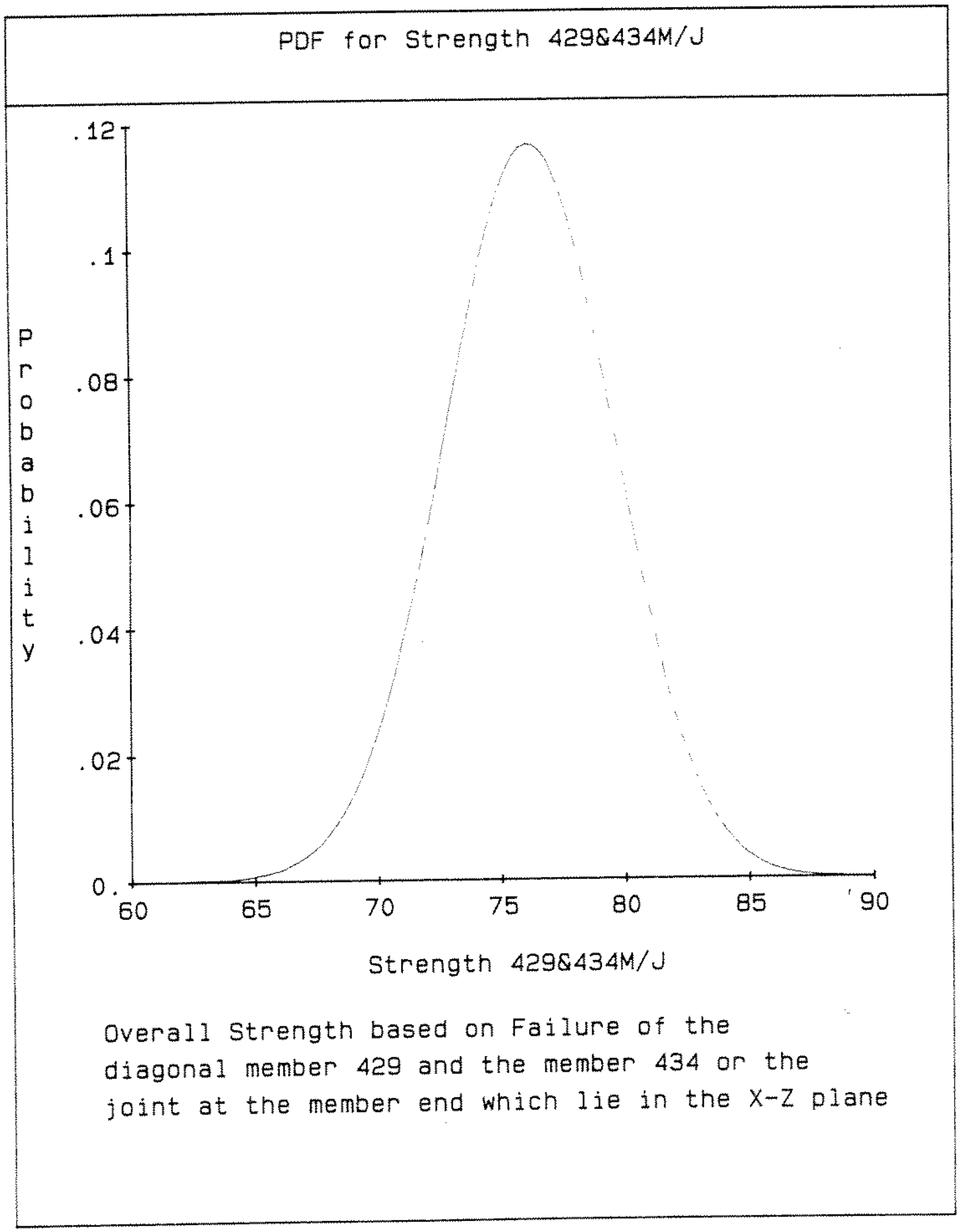
Overall Strength based on Failure of the diagonal member 434 or the joint at the member end which lie in the X-Z plane

Figure 4.2



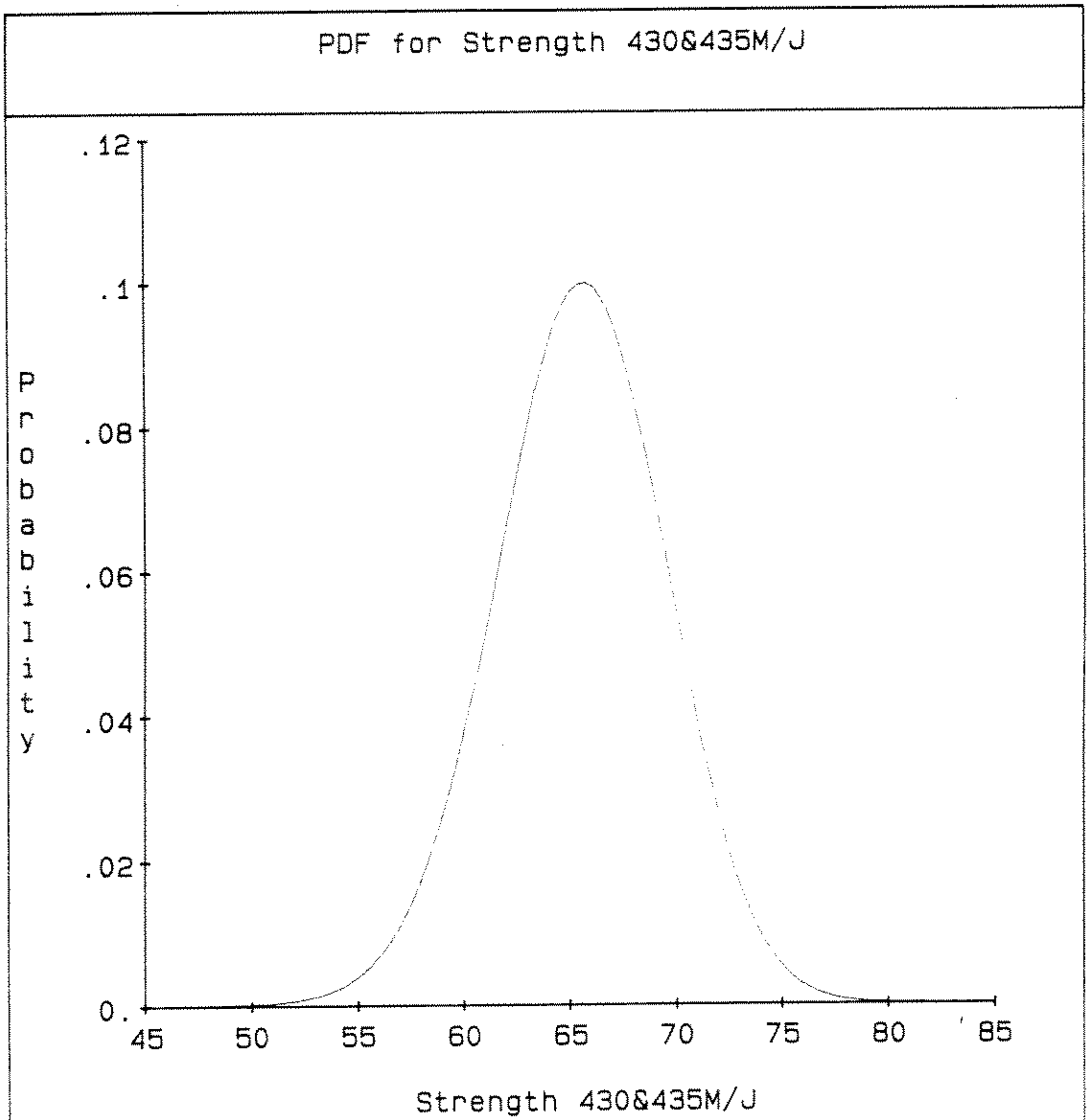
Overall Strength based on the Failure of the diagonal member 435 or the joint at the member which lie in the X-Z plane

Figure 4.3



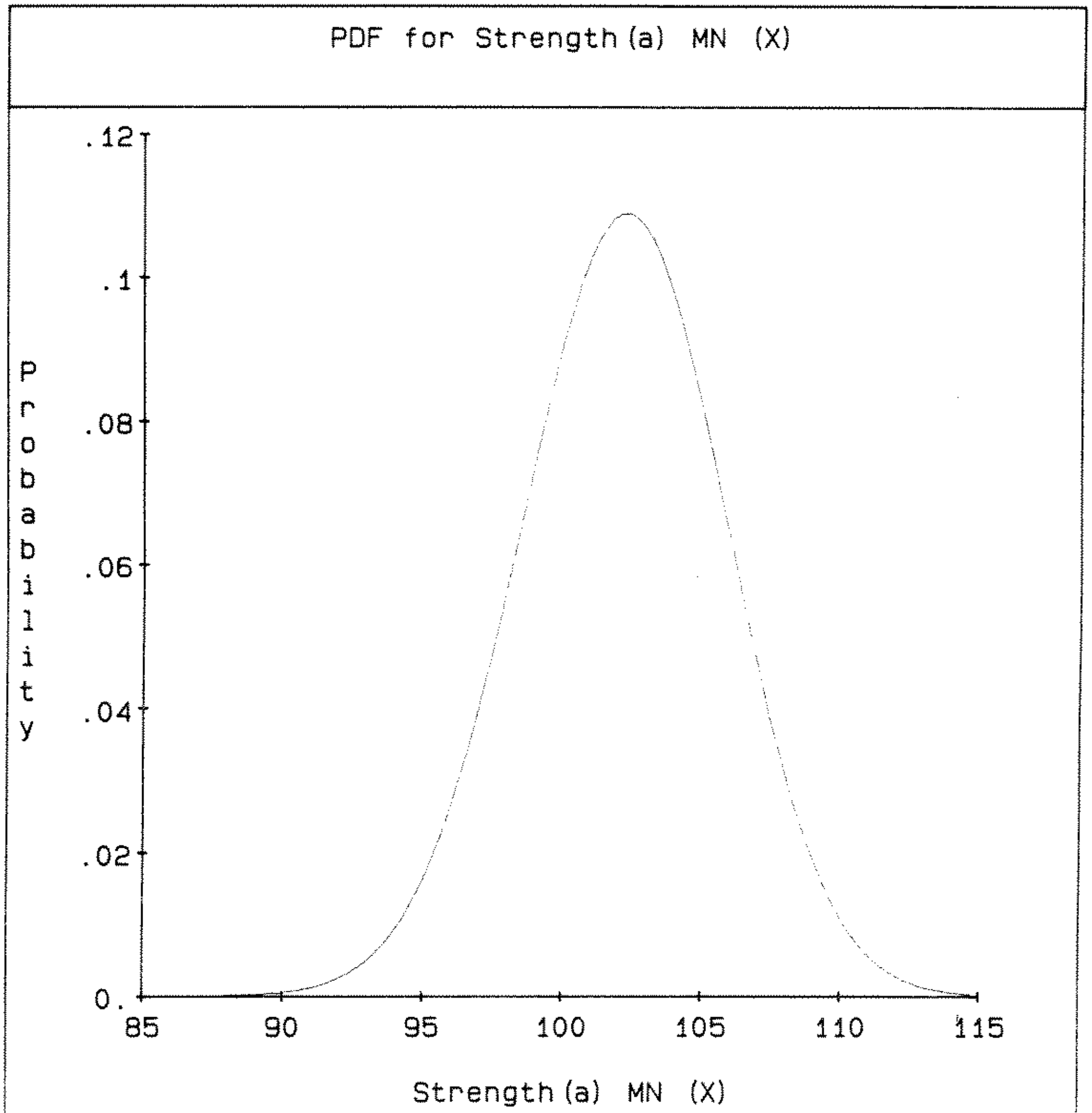
PDF for Strength 429&434M/J
.12
.1
.08
.06
.04
.02
0.
Probability
60
65
70
75
80
85
90
Strength 429&434M/J
Overall Strength based on Failure of the
diagonal member 429 and the member 434 or the
joint at the member end which lie in the X-Z plane

Figure 4.4



Overall Strength based on Failure of the diagonal member 430 and the member 435 or the joint at the member end which lie in the X-Z plane

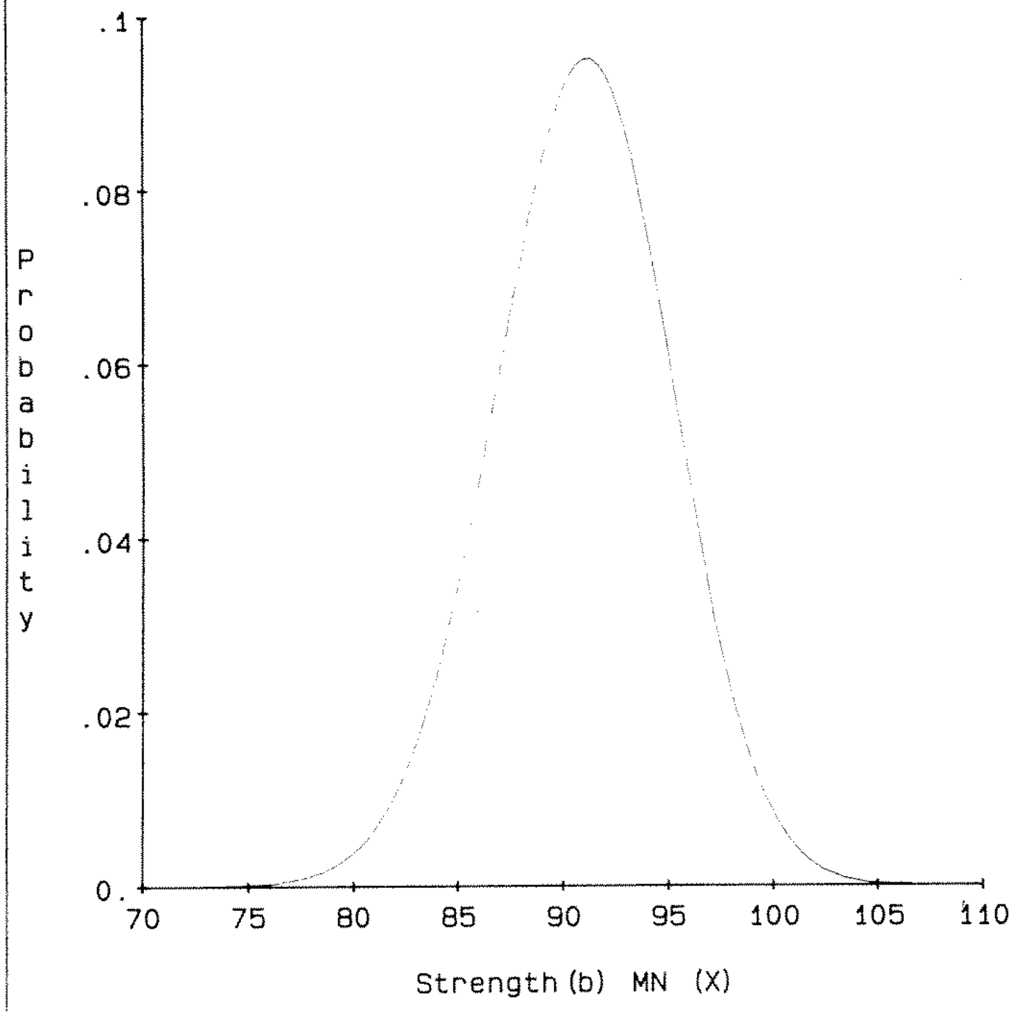
Figure 4.5



Overall Strength based on the Failure of the diagonal members 429 and 438 and the member 434 or the joint at the member end in the X-Y plane

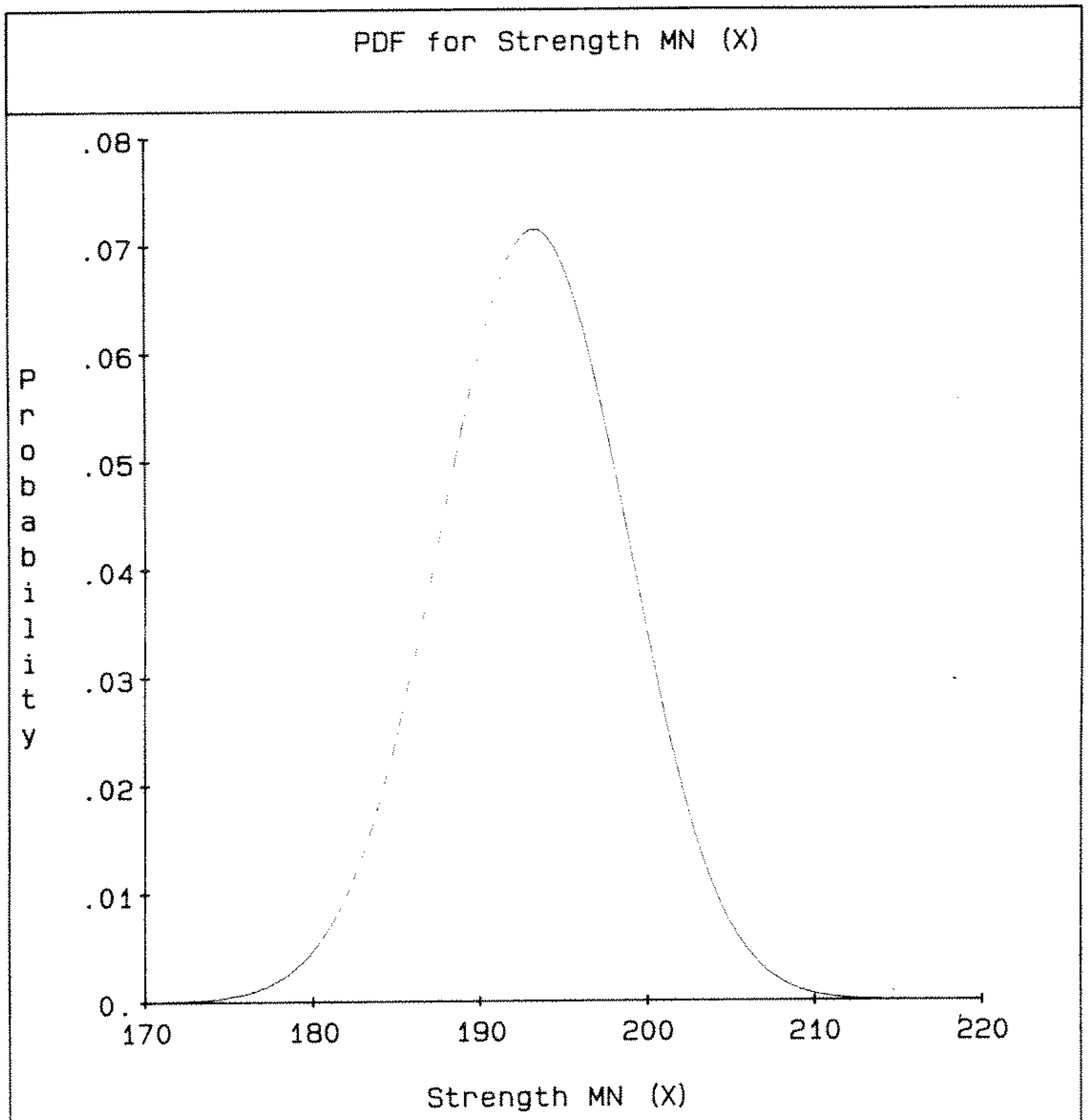
Figure 4.6

PDF for Strength (b) MN (X)



Overall Strength based on the Failure of the diagonal member 430 and the members or joints at the end of the members 435 and 439

Figure 4.7



Overall Strength based on Failure of the diagonal members 429, 430 and 438 and the members or the joints at the member end of 434, 435 and 439 which lie in the X-Z plane

Figure 4.8

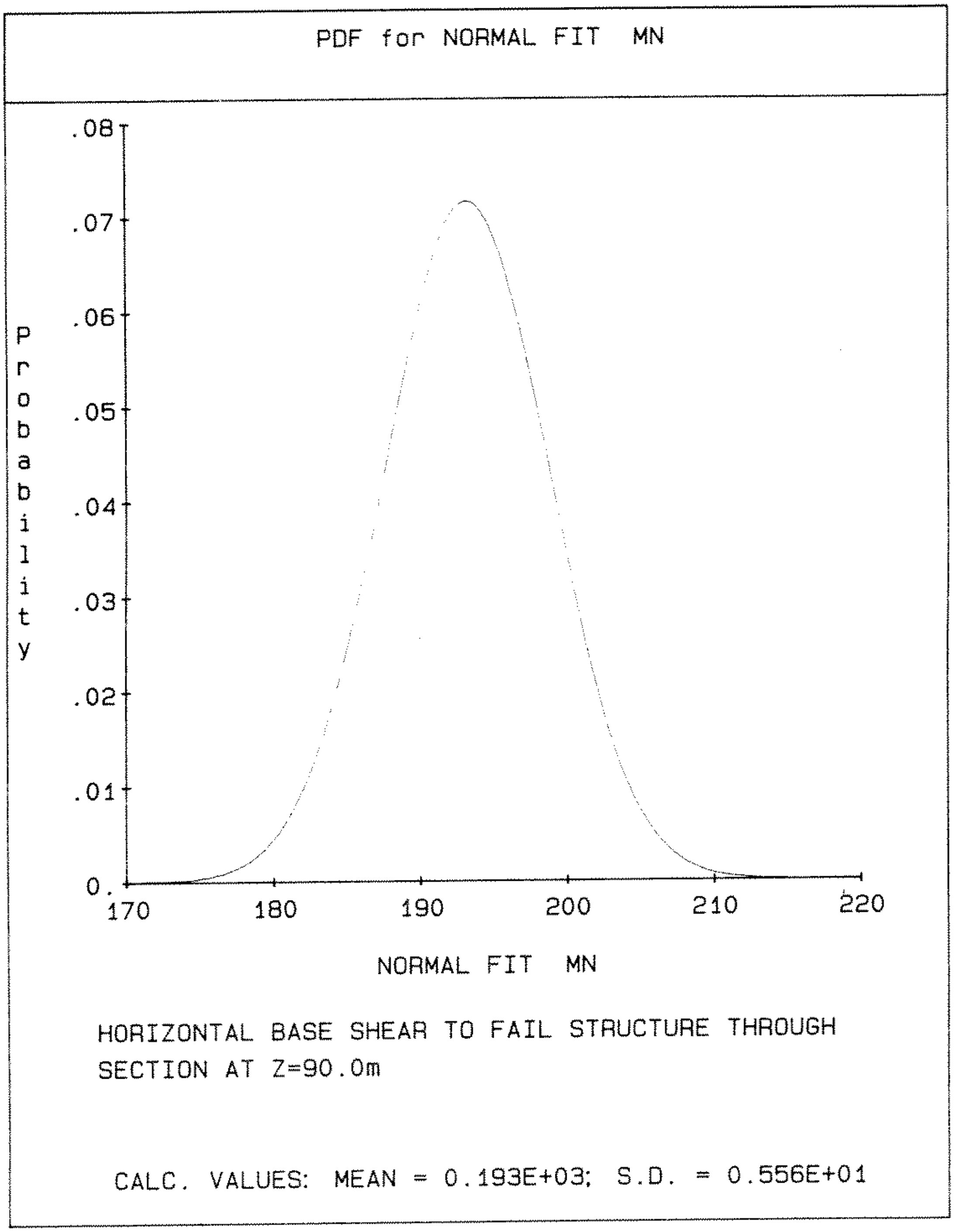

PDF for NORMAL FIT MN
.08
.07
.06
.05
.04
.03
.02
.01
0.
Probability
170
180
190
200
210
220
NORMAL FIT MN
HORIZONTAL BASE SHEAR TO FAIL STRUCTURE THROUGH
SECTION AT Z=90.0m
CALC. VALUES: MEAN = 0.193E+03; S.D. = 0.556E+01

Figure 4.9

5) STOCHASTIC COLLAPSE ANALYSIS for the LIFTED PLATFORM in DEEP WATER

i) Member Forces through the selected Critical Platform Bay (cont)

The load factor at yield of leg 2 ,LF2, would become

$$LF2 = 1.7*(Fa2-F12)/(F22-F12) \quad \text{--- (1)}$$

and at this load factor the endload in leg 1, Fn1 would be

$$Fn1 = F11 + LF2*(F21-F11)/1.7 \quad \text{--- (2)}$$

The load factor at the failure of leg 1, LF1 will be

$$LF1 = LF2 + (F21-Fn1)*(2.6-1.7)/(F31-F21) \quad \text{--- (3)}$$

Therefore, the load factor for the overall strength of the structure,

$$LS = LF1 + 0.3(\text{allowance for the bending strength of legs 3 \& 4}) \quad \text{--- (4)}$$

Substituting (1), (2) and (3) into (4) gives

$$LS = C1*Fa2 + C2*Fa1 + C3 \quad \text{--- (5)}$$

where C1, C2 and C3 are constants calculated from known values.

Thus, LS = C1 * statistical strength of leg 2 +
C2 * statistical strength of leg 1 + C3 ---(6)

Mean strengths for leg 1 and 2 are now determined by multiplying the load factor for failure by the base shear for the environmental load.

ii) Statistical distributions for critical members

Table 5.1 give the mean failure strength and the standard deviation for the critical leg members in the selected collapse zone.

Table 5.2 documents the probability distributions required in the calculation of the probabilistic collapse strength of the platform through this critical zone. The ranges used for numerical integration are also given.

Figures 5.4 and 5.6 show sample distributions at various stages of the analysis, whilst figure 5.7 gives the estimated probabilistic collapse strength through this section.

5) STOCHASTIC COLLAPSE ANALYSIS for the LIFTED PLATFORM in DEEP WATER

iii) Discussion of results

The finally achieved probabilistic collapse strength through the chosen critical section has a mean strength of 91.6MN and a standard deviation of 5.22MN. This compares with the deterministic collapse strength of 80.3MN, calculated with safety factors included. To gauge the effect of other critical zones on the overall probabilistic strength of the platform a second zone having the same probabilistic strength as that calculated above is assumed to exist. This reduced the mean strength to 88.6MN with a standard deviation of 4.31MN.

Critical Members

Member Id	Compression/ Tension	Mean Failure MN	Standard Deviation
443	Compression	47.20	4.72
446	Tension	44.38	2.22

Table 5.1

Note: The failure of leg members 444 and 445 have been included in the Mean Failure values quoted.

Input Distributions

Description	Title	Lower Bounds	Upper Bounds	Figure No.
1.Failure of leg member 443 + part adjustment for 444 & 445	Strength MN L443	25.0	65.0	5.4
2.Failure of leg member 446 + part adjustment for 444 & 445	Strength MN L446	35.0	55.0	5.5
3.Horizontal base shear to fail structure through section z=50.0m	Fail Strength	70.0	115.0	5.6
4.as above Normal fit	Normal fit MN	70.0	115.0	5.7
5.Horizontal base shear to failure - two equally critical zones	Fail Strength MN	70.0	115.0	
6.as above Normal fit	Normal fit MN	70.0	115.0	

Table 5.2

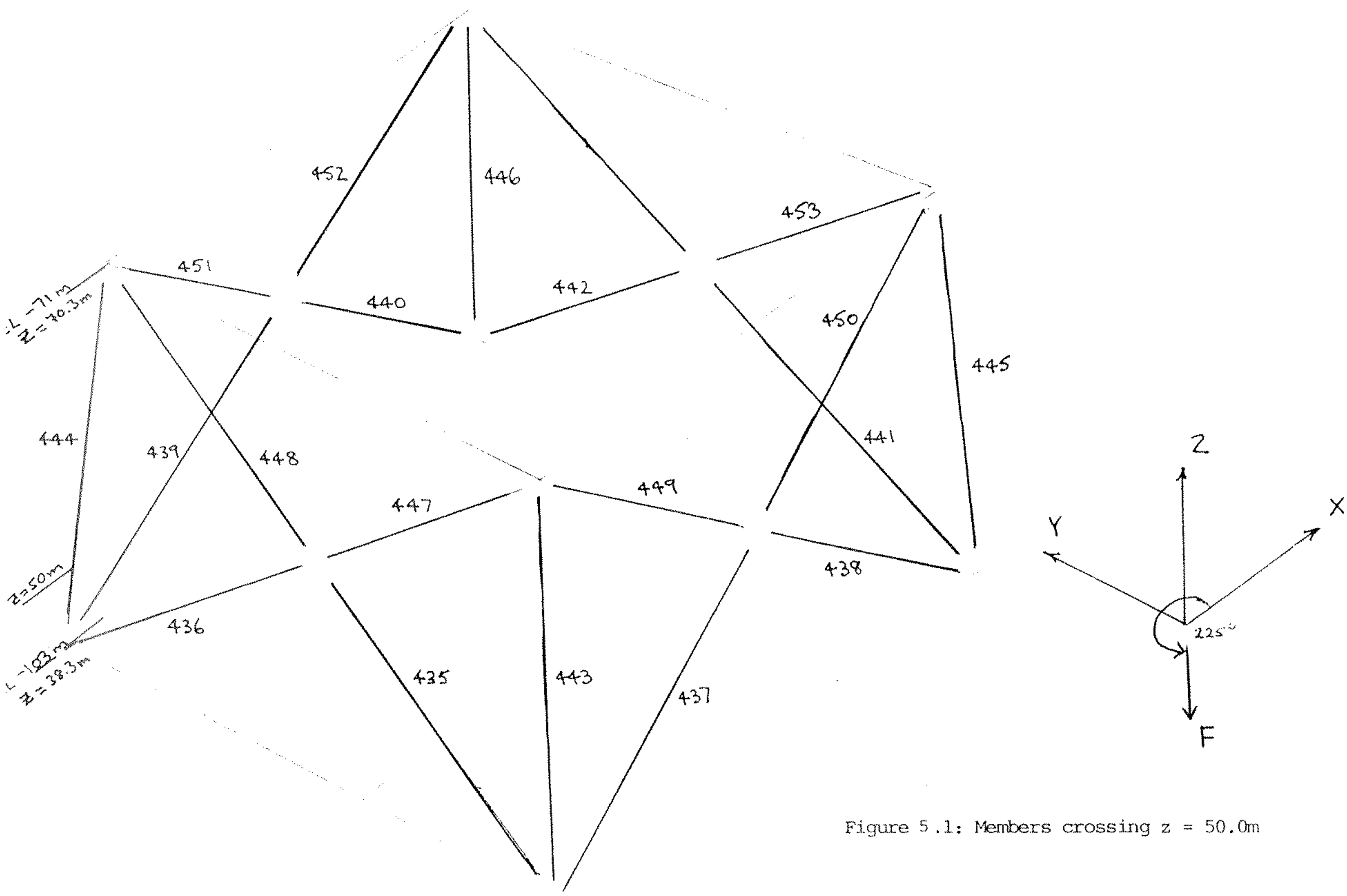


Figure 5.1: Members crossing z = 50.0m

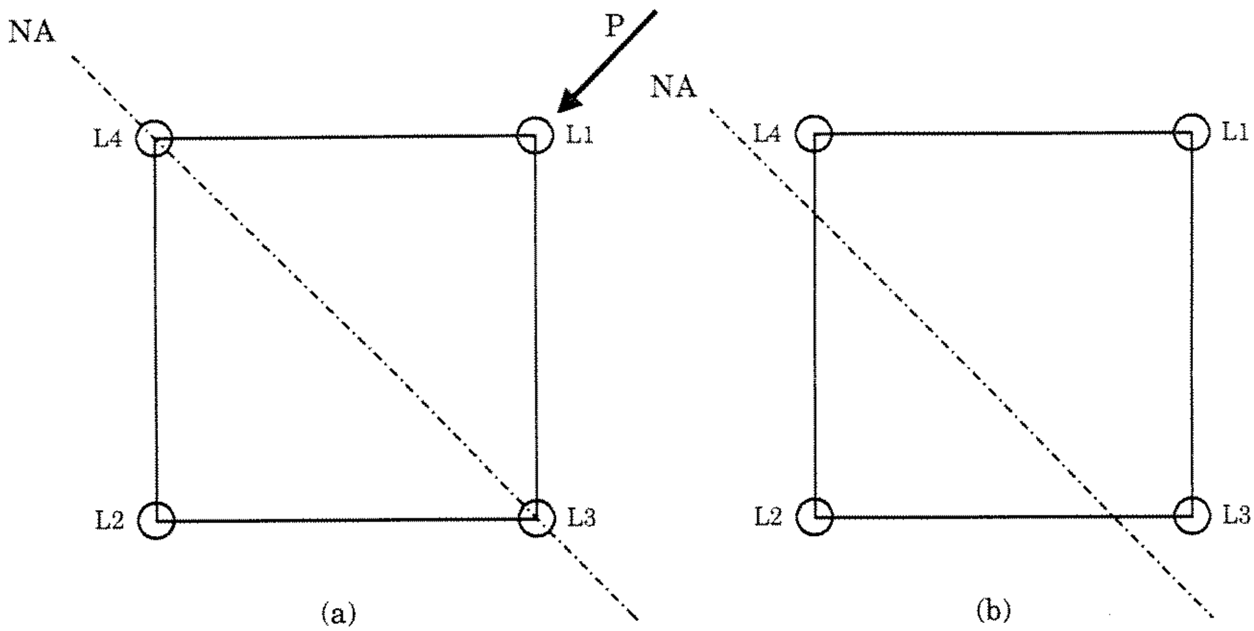


Figure 5.2: Position of neutral axis during loading

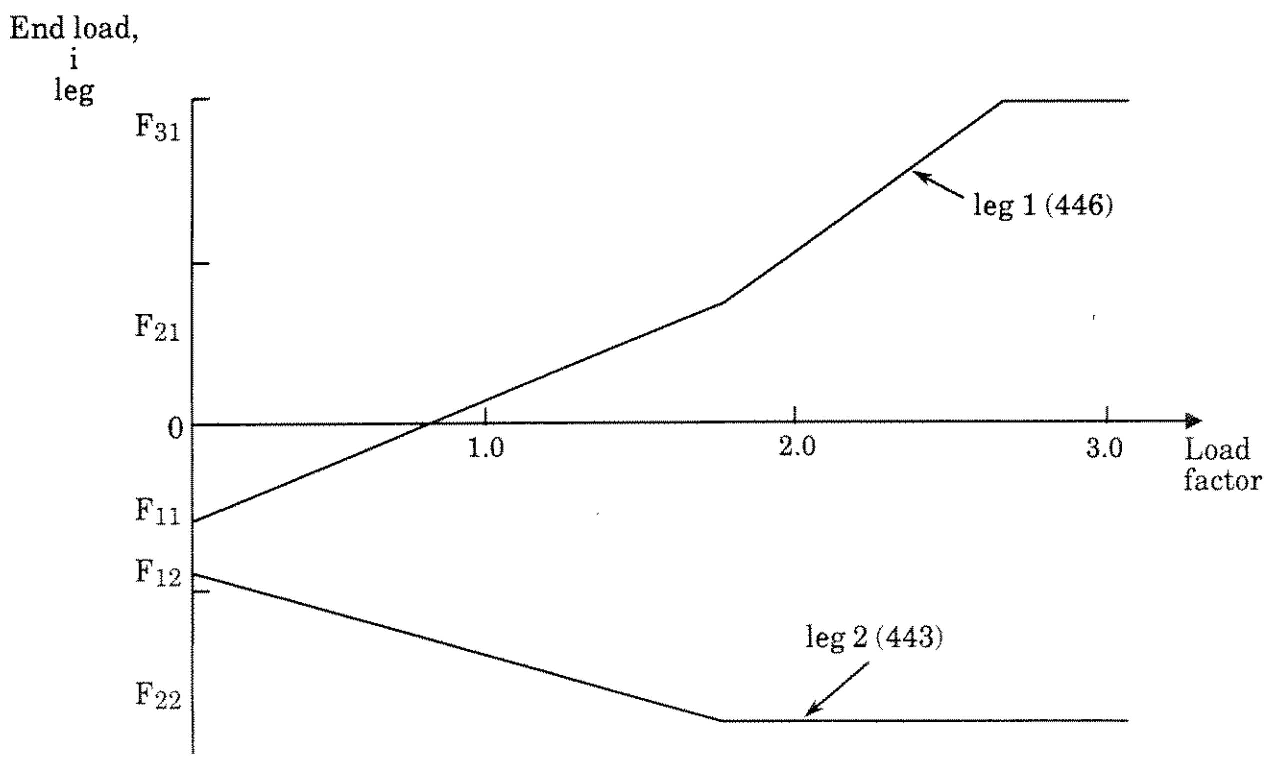
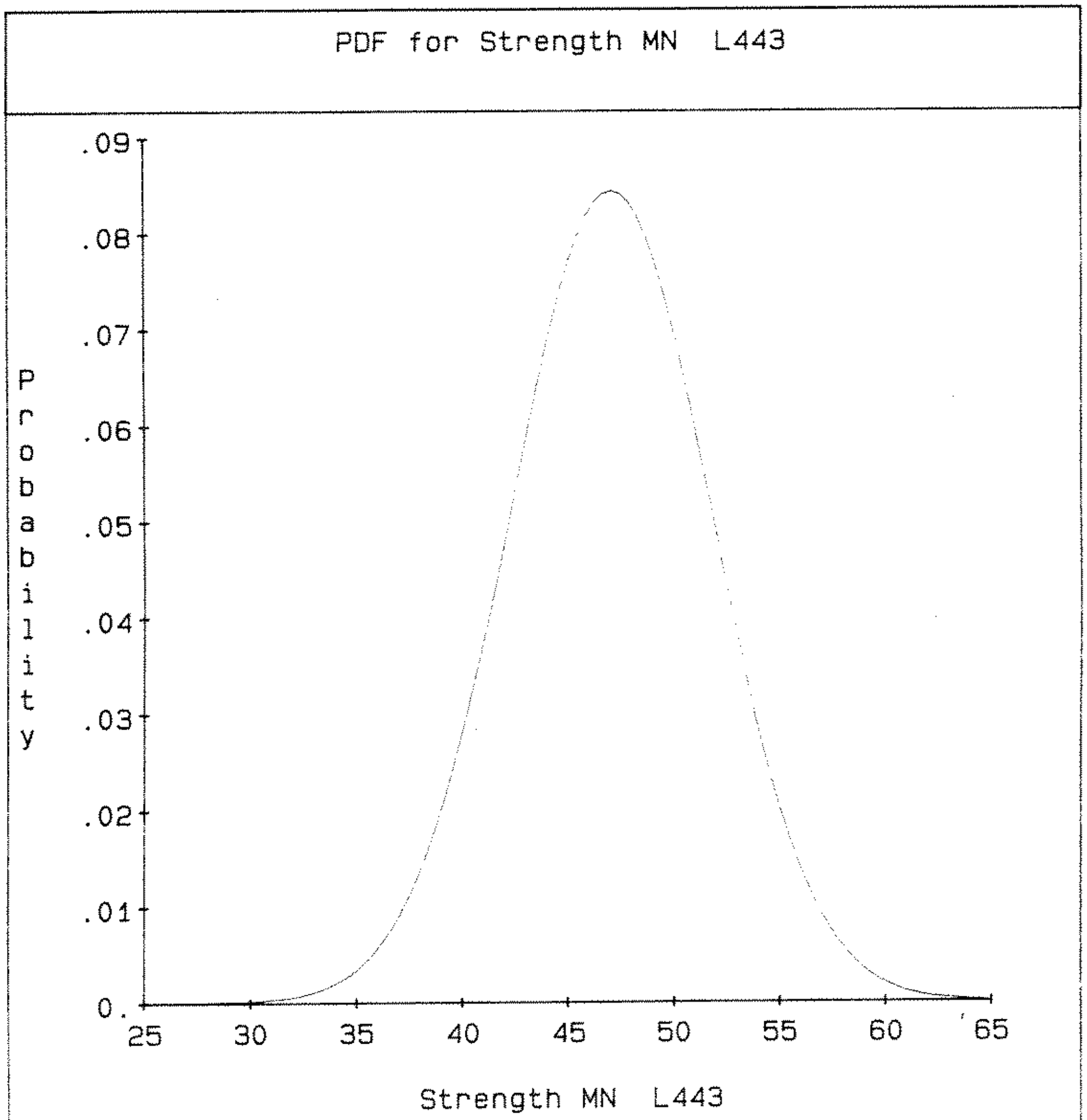


Figure 5.3: Compression and tension in legs of critical bay



Overall Strength based on the Failure of the leg member 443 + part adjustment for the leg members 444 & 445

Figure 5.4

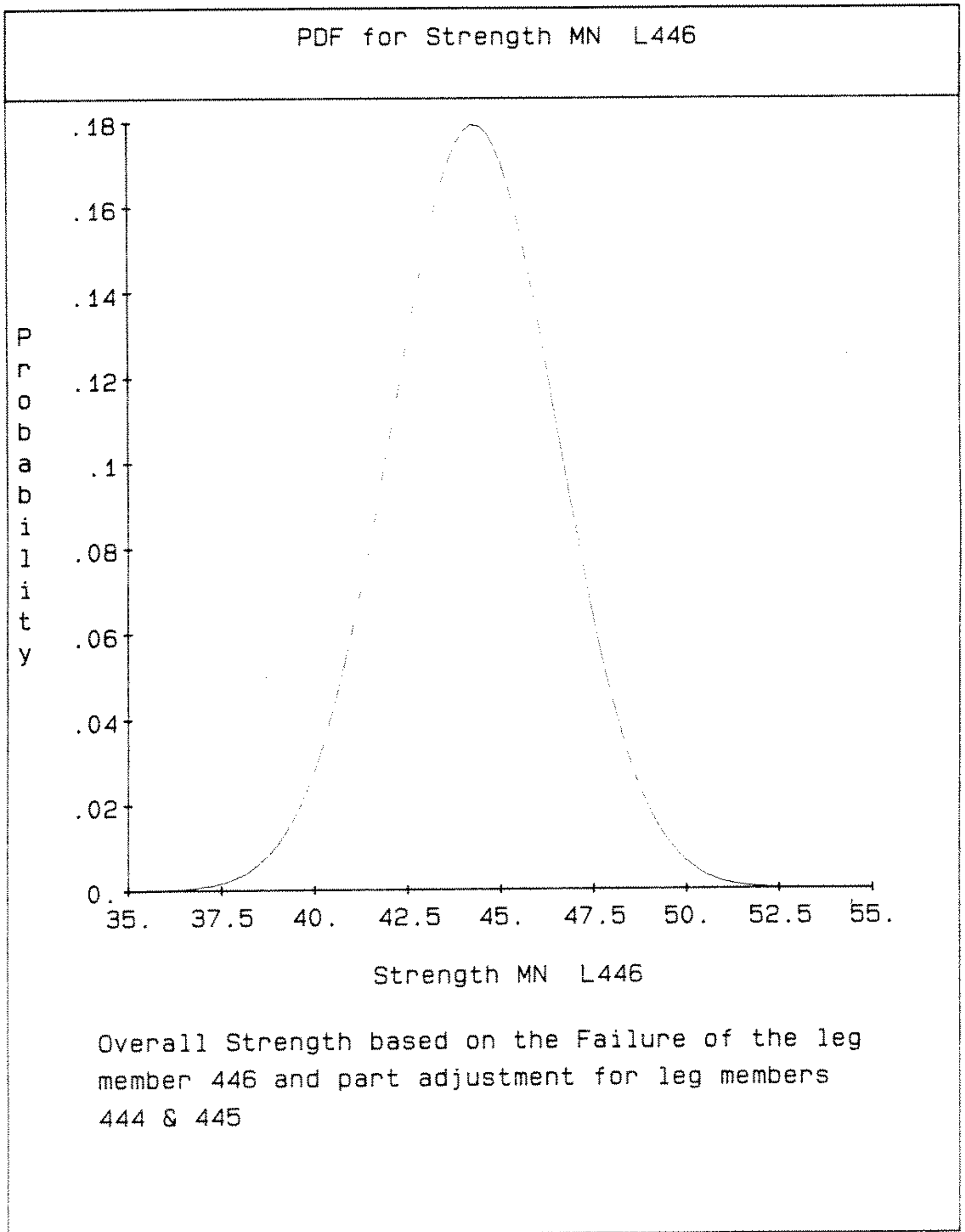

PDF for Strength MN L446
.18
.16
.14
.12
.1
.08
.06
.04
.02
0.
Probability
35.
37.5
40.
42.5
45.
47.5
50.
52.5
55.
Strength MN L446
Overall Strength based on the Failure of the leg member 446 and part adjustment for leg members 444 & 445

Figure 5.5

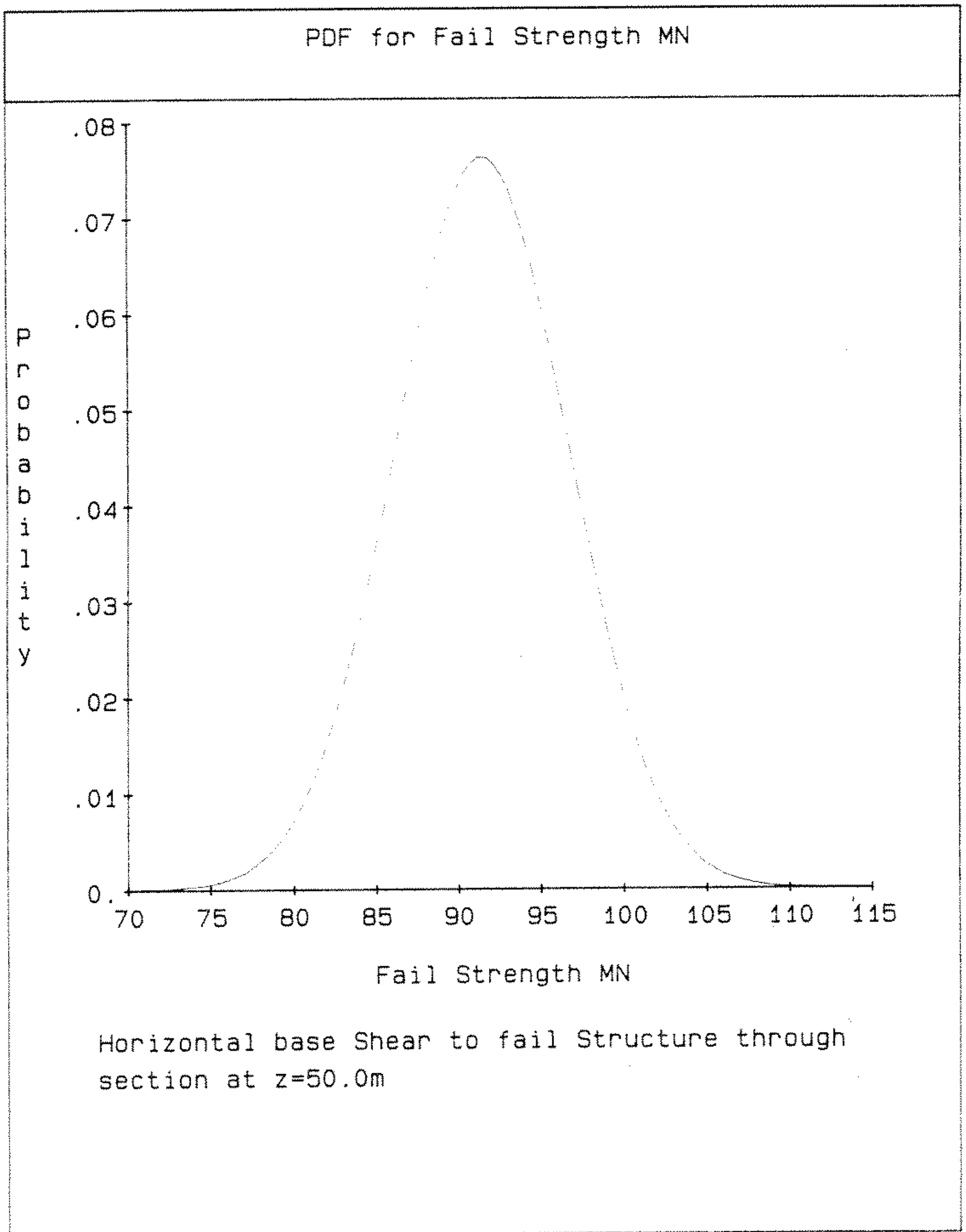

PDF for Fail Strength MN
Probability
.08
.07
.06
.05
.04
.03
.02
.01
0.
70
75
80
85
90
95
100
105
110
115
Fail Strength MN
Horizontal base Shear to fail Structure through
section at z=50.0m

Figure 5.6

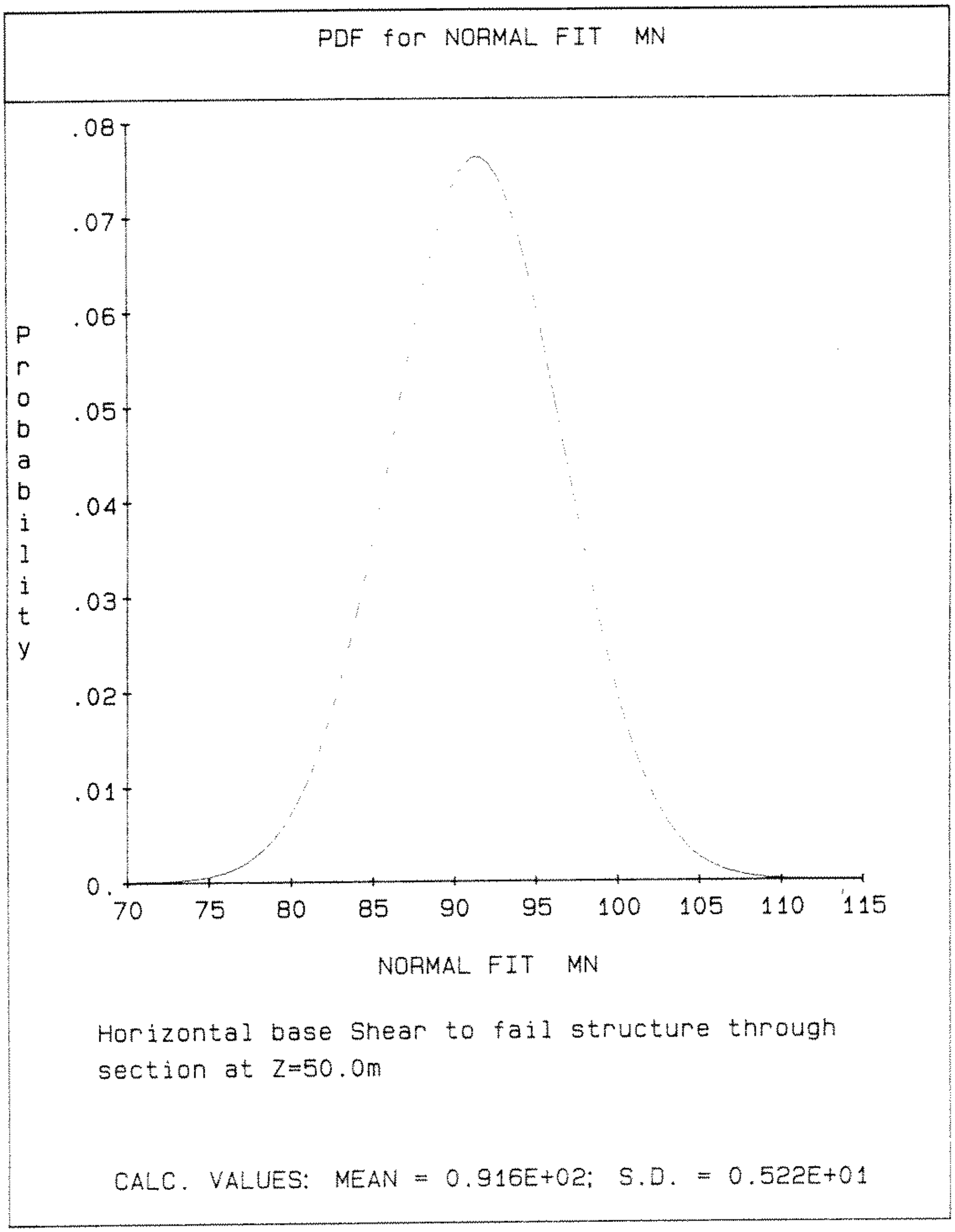

PDF for NORMAL FIT MN
.08
.07
.06
.05
.04
.03
.02
.01
0.
Probability
70
75
80
85
90
95
100
105
110
115
NORMAL FIT MN
Horizontal base Shear to fail structure through section at Z=50.0m
CALC. VALUES: MEAN = 0.916E+02; S.D. = 0.522E+01

Figure 5.7

Appendix A

Stochastic collapse strength of a pin-jointed framework

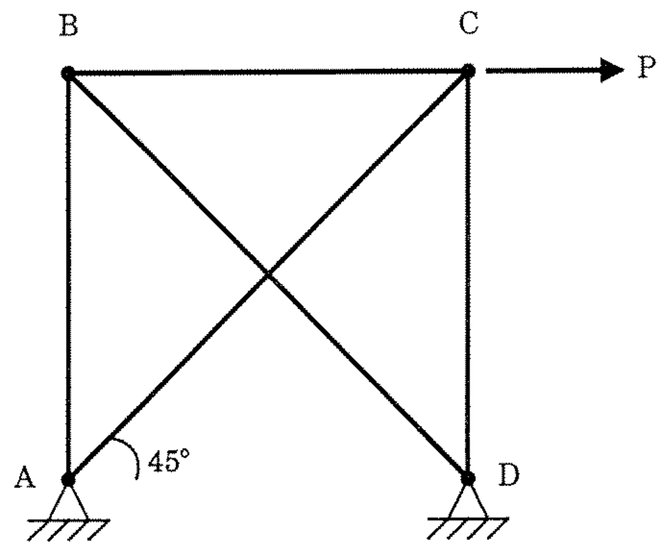


Figure A.1: Idealised pin jointed framework

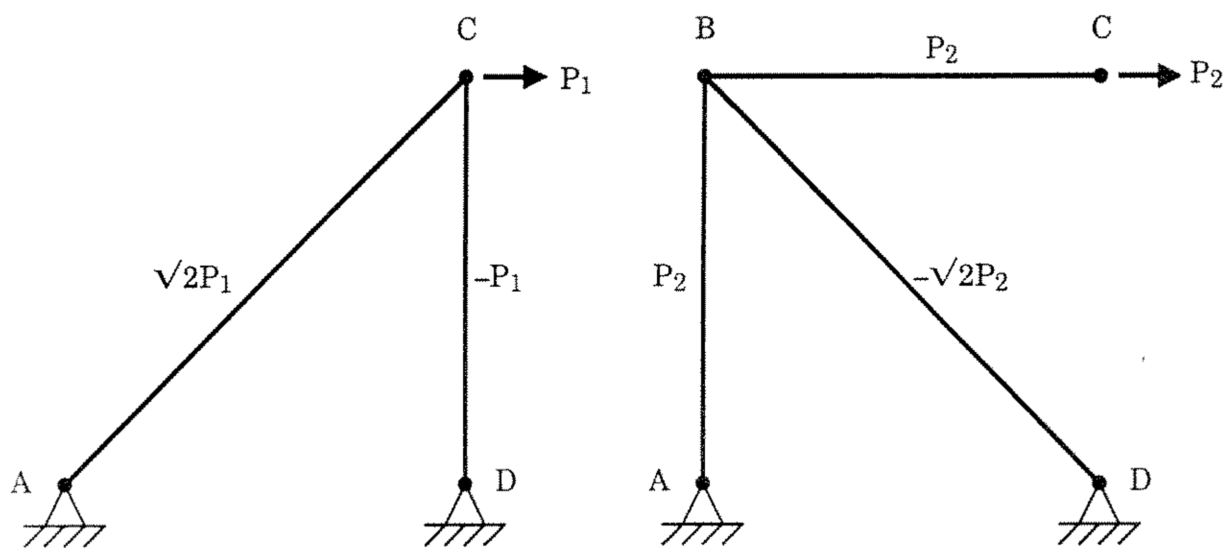


Figure A.2: Tension forces along member loadpaths

Loadpath	Member	Force	Utilisation
$P_1 = 20$	CD	–20	0.8
	AC	28.28	1.0
$P_2 = 15$	BC	15	0.9
	BD	–21.21	1.0
	AB	15	0.7

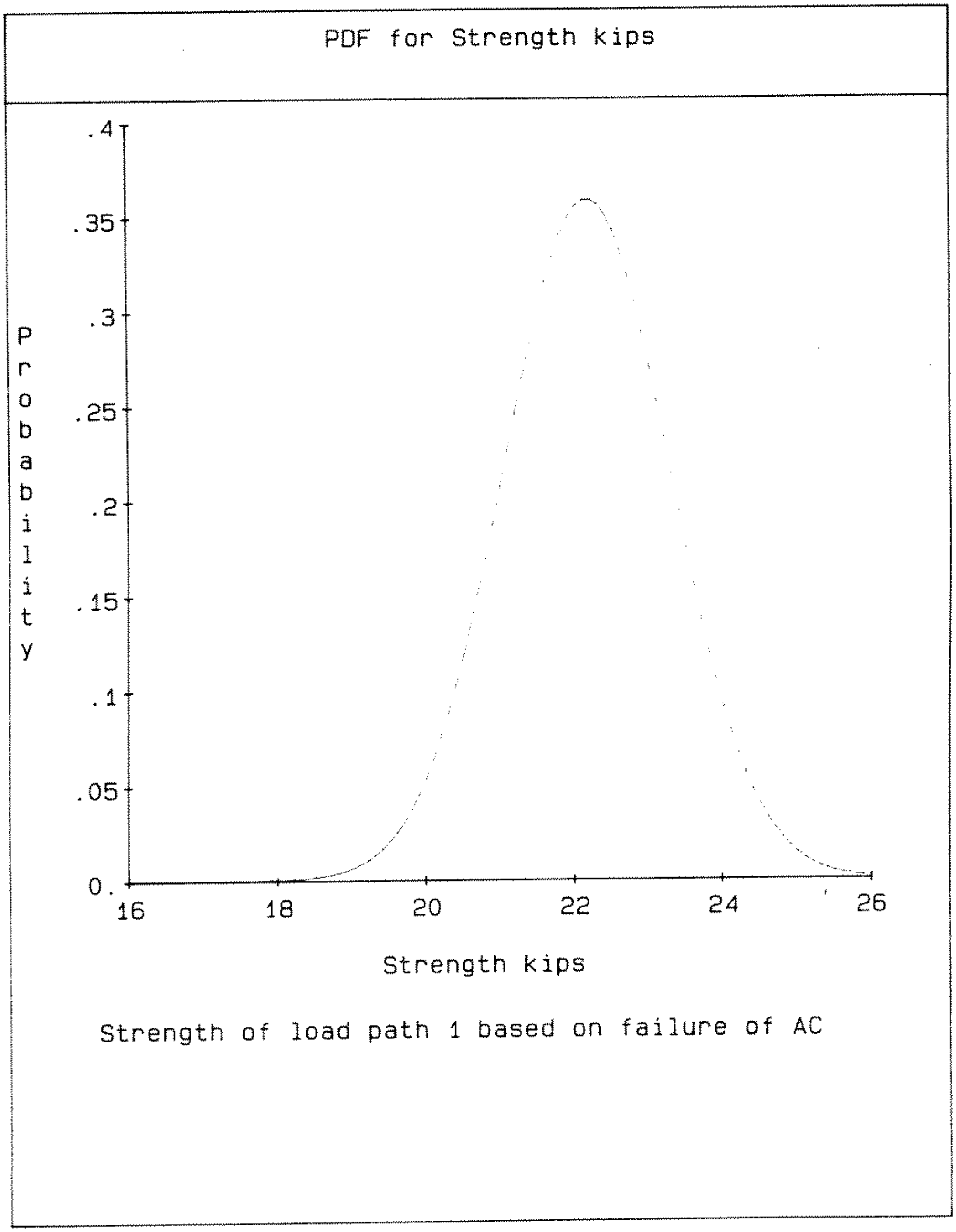
Table A.1: Member forces and utilisation ratios from deterministic collapse analysis

Member type	Safety ratio	Coefficient of variation
Compression	0.8	0.1
Tension	0.9	0.05

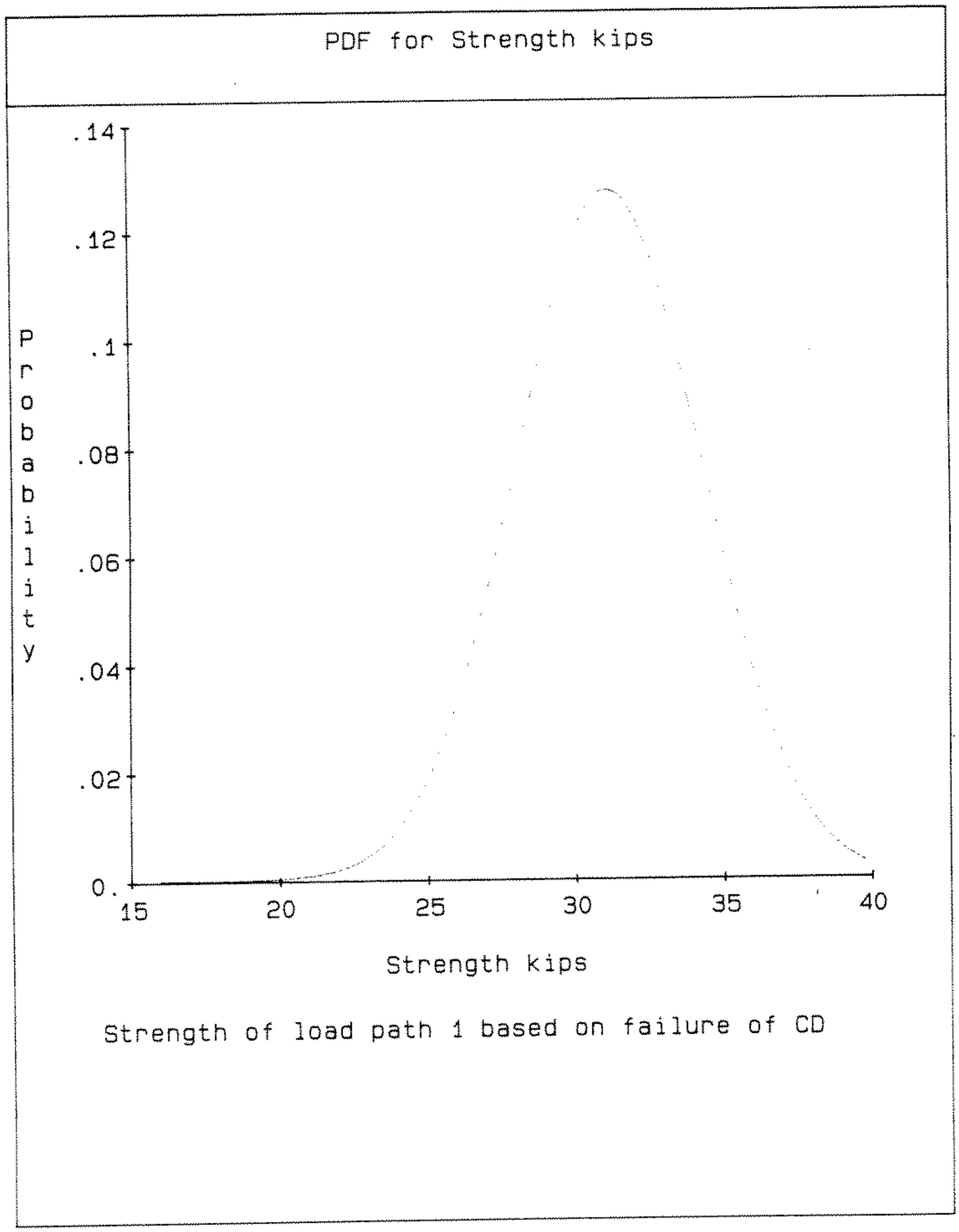
Table A.2: Statistical data for member types

Loadpath	Member	Loadpath mean strength	Loadpath standard deviation
P_1	CD	31.25	3.125
	AC	22.22	1.11
P_2	BC	18.51	0.925
	BD	18.75	1.875
	AB	23.80	1.19

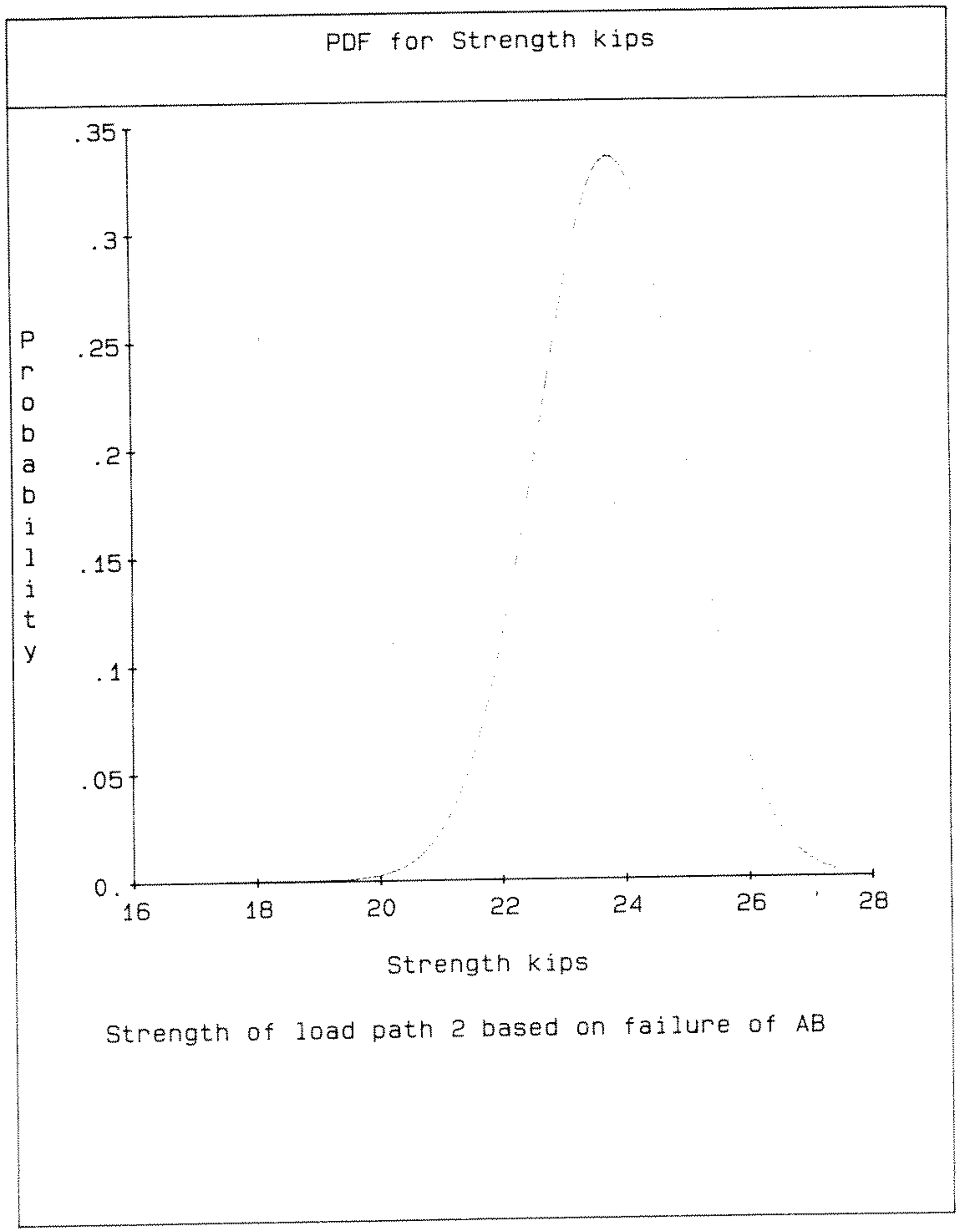
Table A.3: Loadpath mean strengths and standard deviations based on specified member failures


PDF for Strength kips
Probability
.4
.35
.3
.25
.2
.15
.1
.05
0.
16
18
20
22
24
26
Strength kips
Strength of load path 1 based on failure of AC

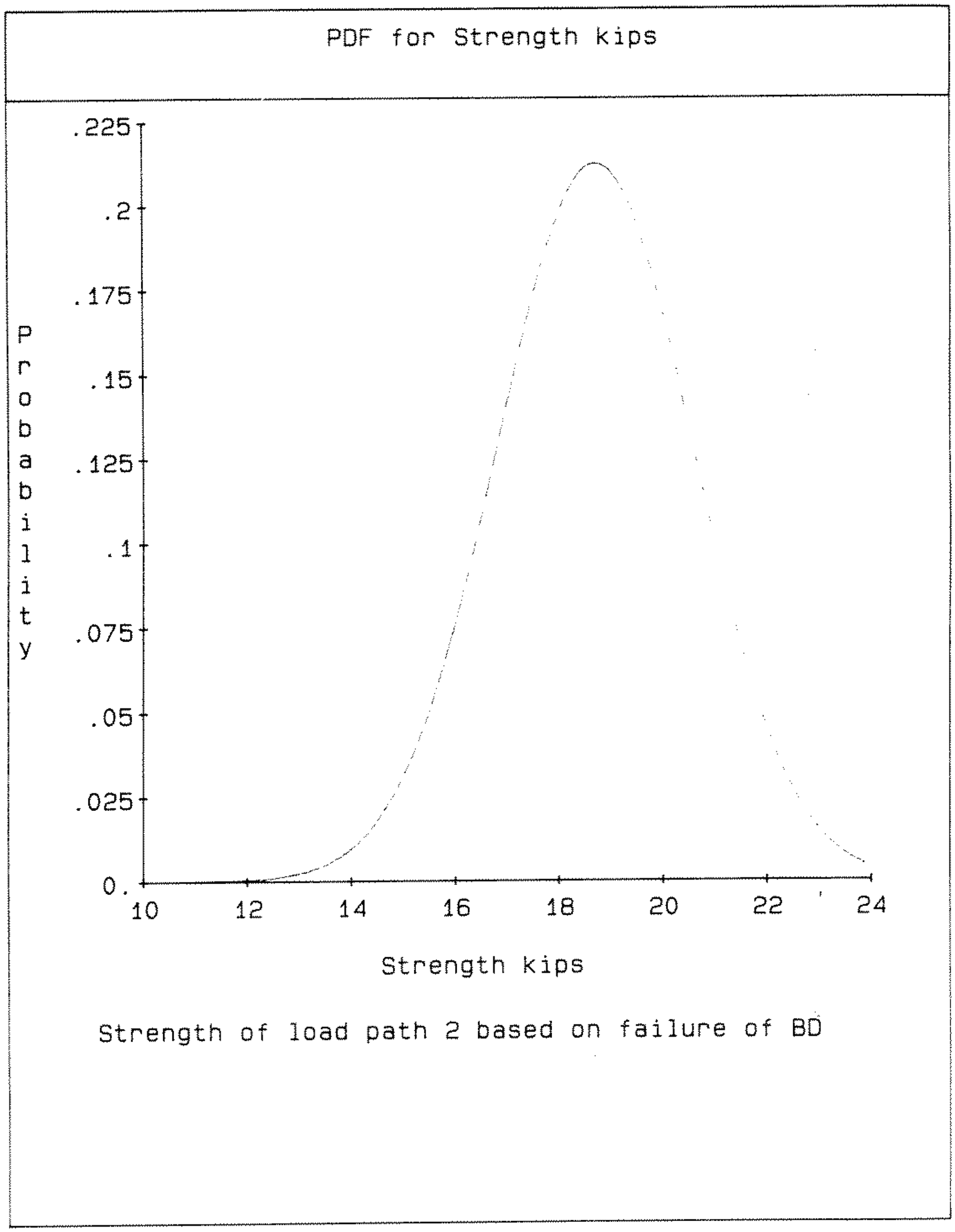
Plot A.1


PDF for Strength kips
.14
.12
.1
.08
.06
.04
.02
0.
Probability
15
20
25
30
35
40
Strength kips
Strength of load path 1 based on failure of CD

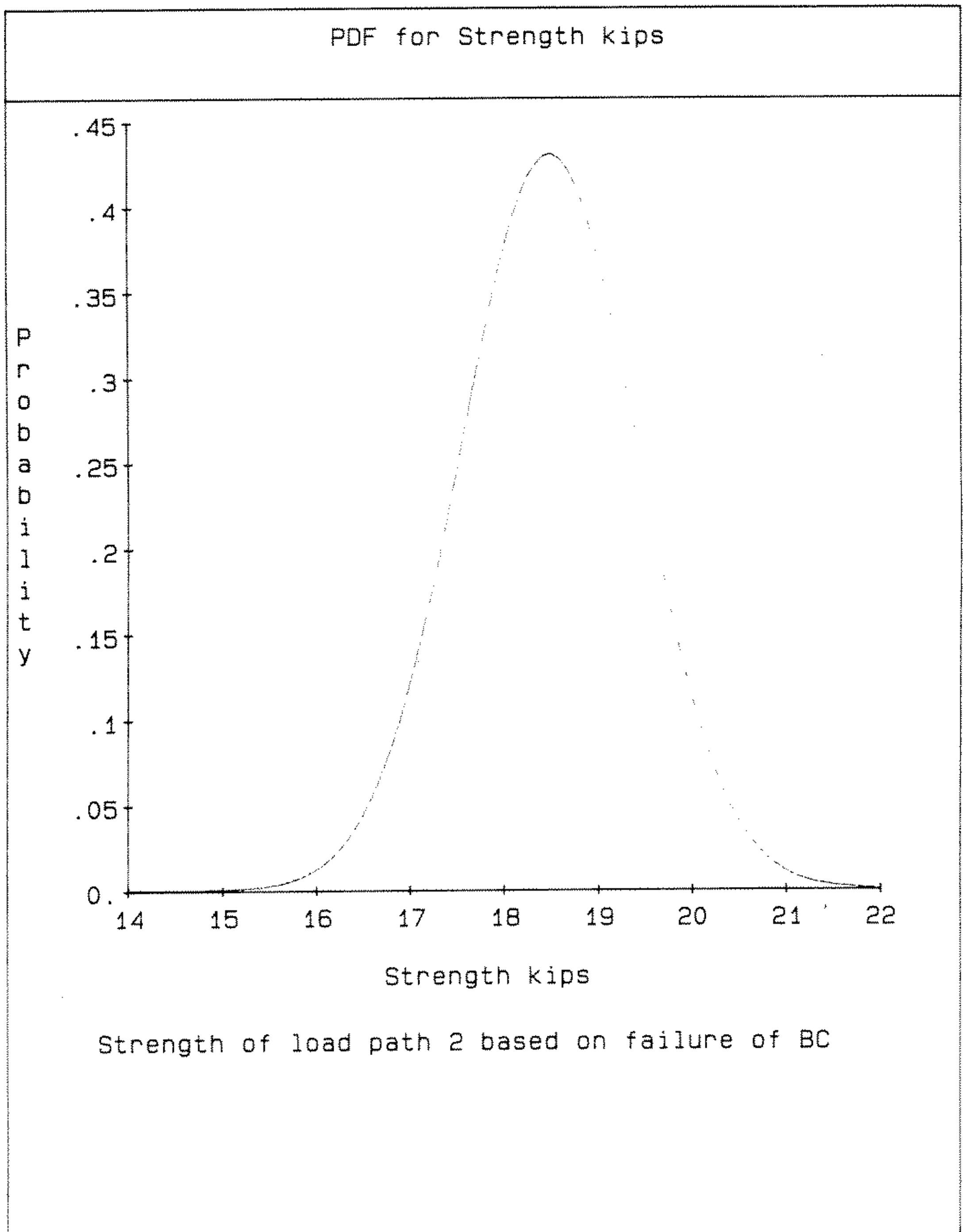
Plot A.2


PDF for Strength kips
Probability
.35
.3
.25
.2
.15
.1
.05
0.
16
18
20
22
24
26
28
Strength kips
Strength of load path 2 based on failure of AB

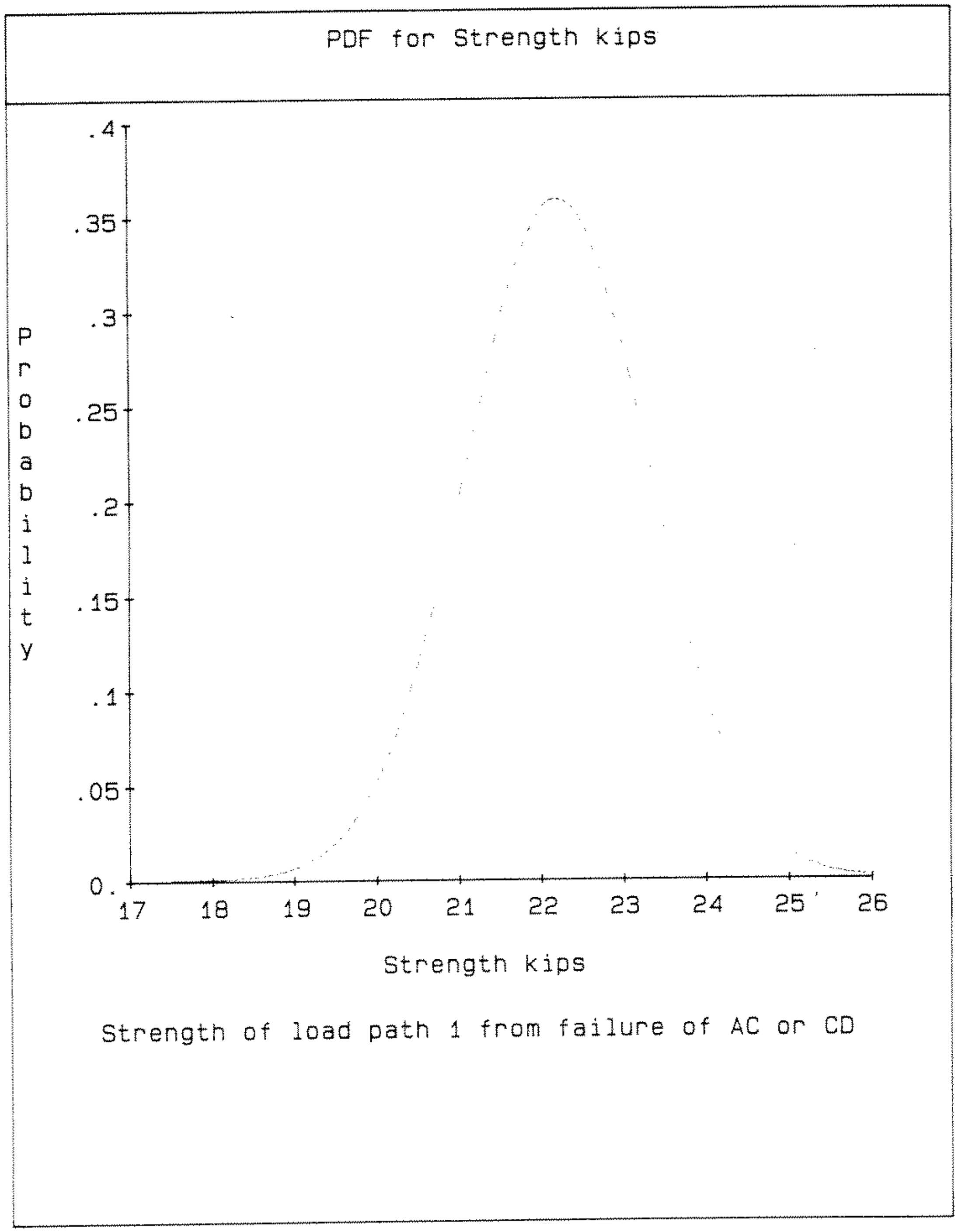
Plot A.3


PDF for Strength kips
Probability
.225
.2
.175
.15
.125
.1
.075
.05
.025
0.
10
12
14
16
18
20
22
24
Strength kips
Strength of load path 2 based on failure of BD

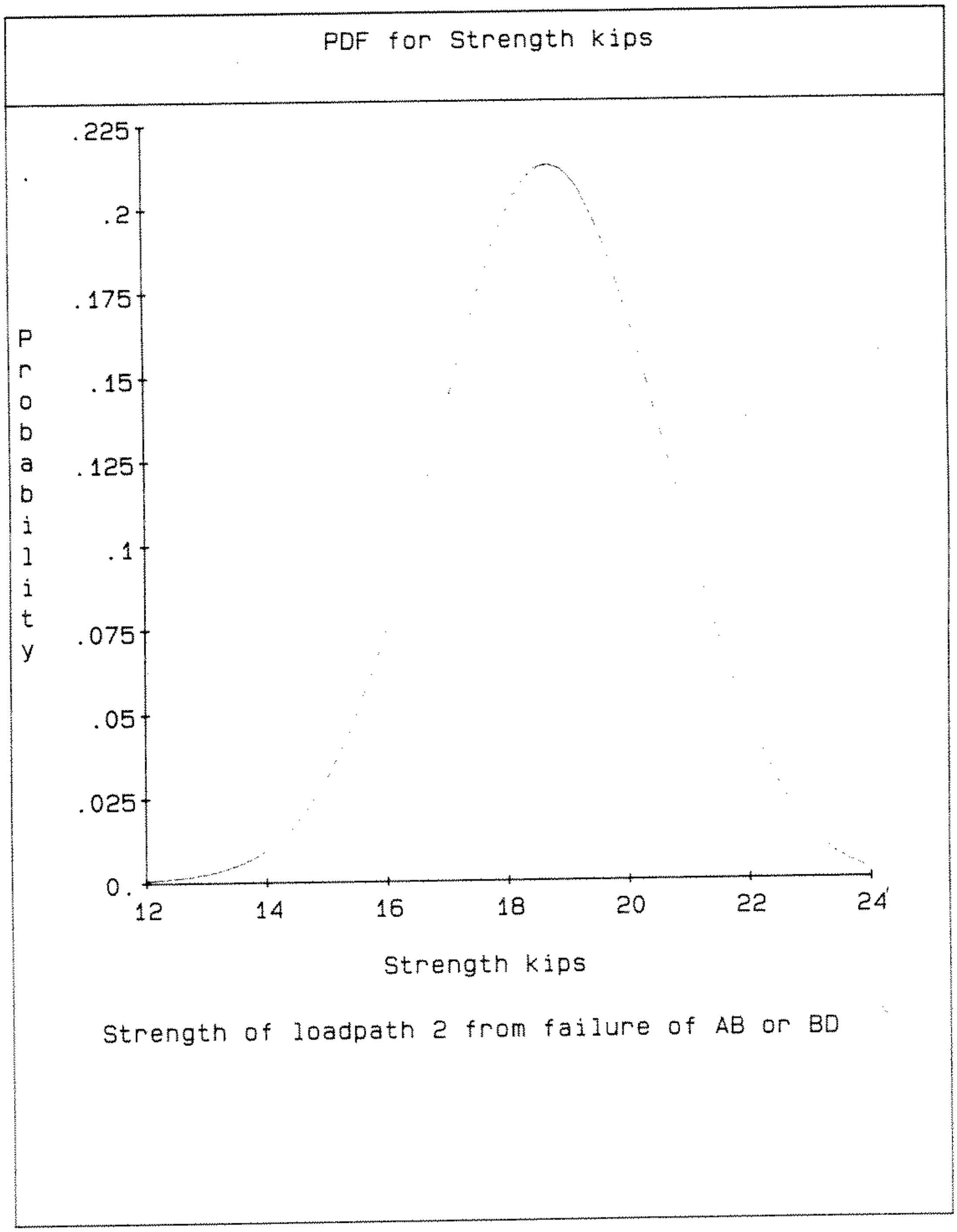
Plot A.4


PDF for Strength kips
Probability
.45
.4
.35
.3
.25
.2
.15
.1
.05
0.
14
15
16
17
18
19
20
21
22
Strength kips
Strength of load path 2 based on failure of BC

Plot A.5

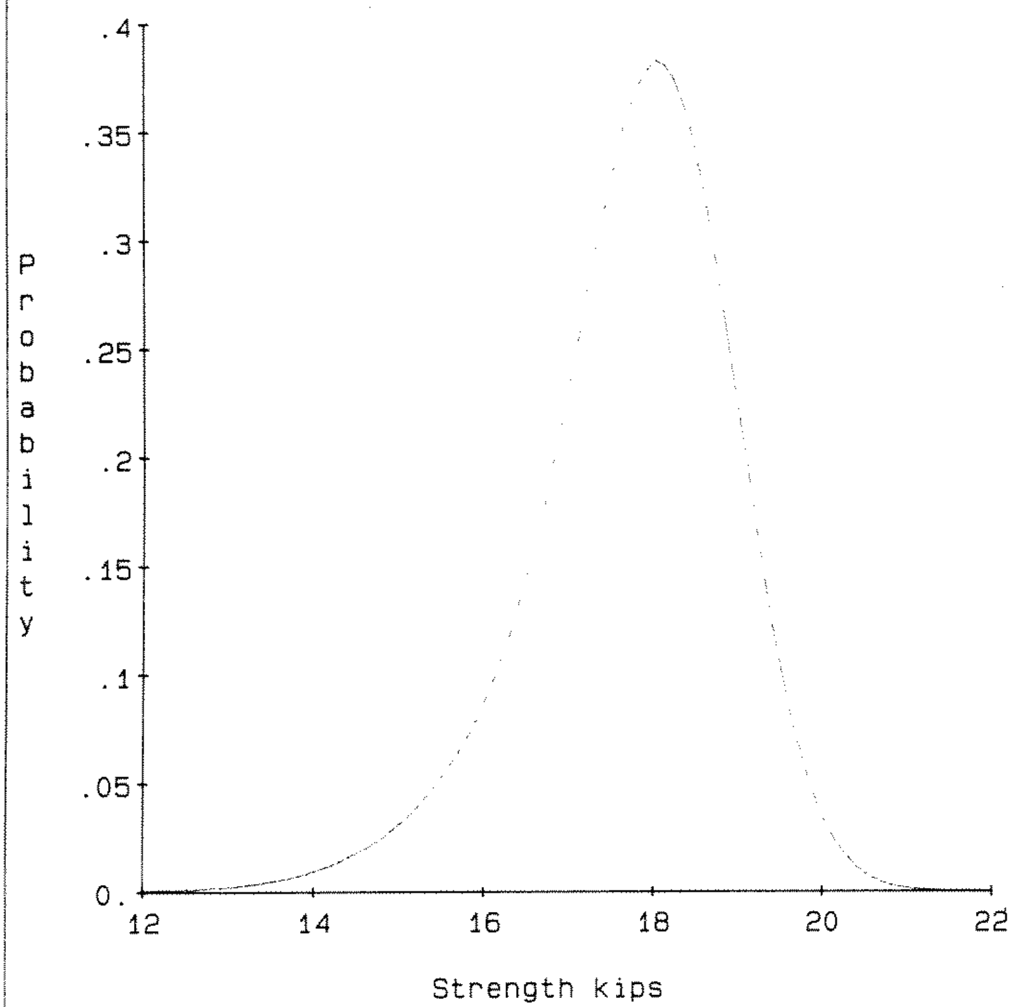

PDF for Strength kips
Probability
.4
.35
.3
.25
.2
.15
.1
.05
0.
17
18
19
20
21
22
23
24
25
26
Strength kips
Strength of load path 1 from failure of AC or CD

Plot A.6


PDF for Strength kips
Probability
.225
.2
.175
.15
.125
.1
.075
.05
.025
0.
12
14
16
18
20
22
24
Strength kips
Strength of loadpath 2 from failure of AB or BD

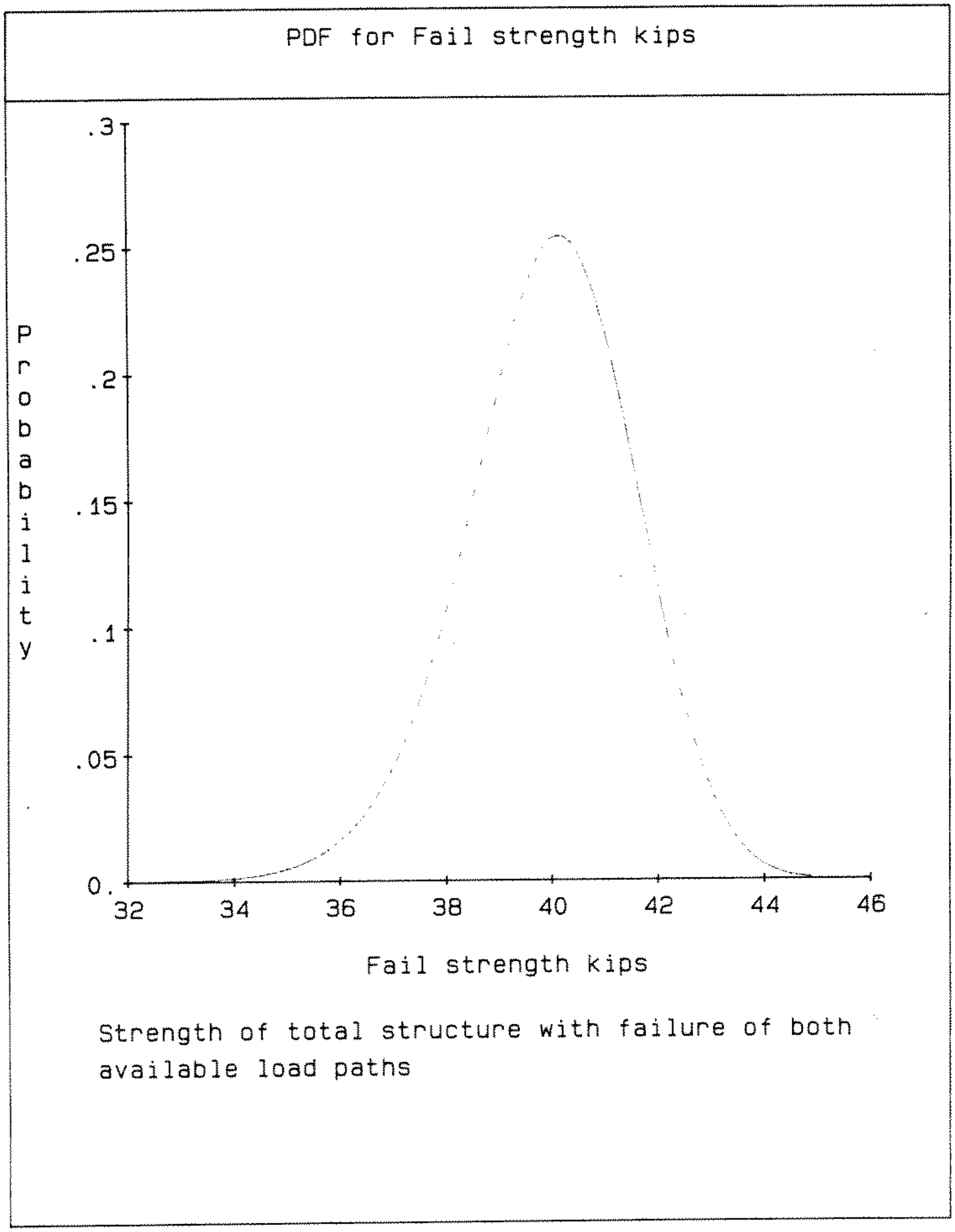
Plot A.7

PDF for Strength kips



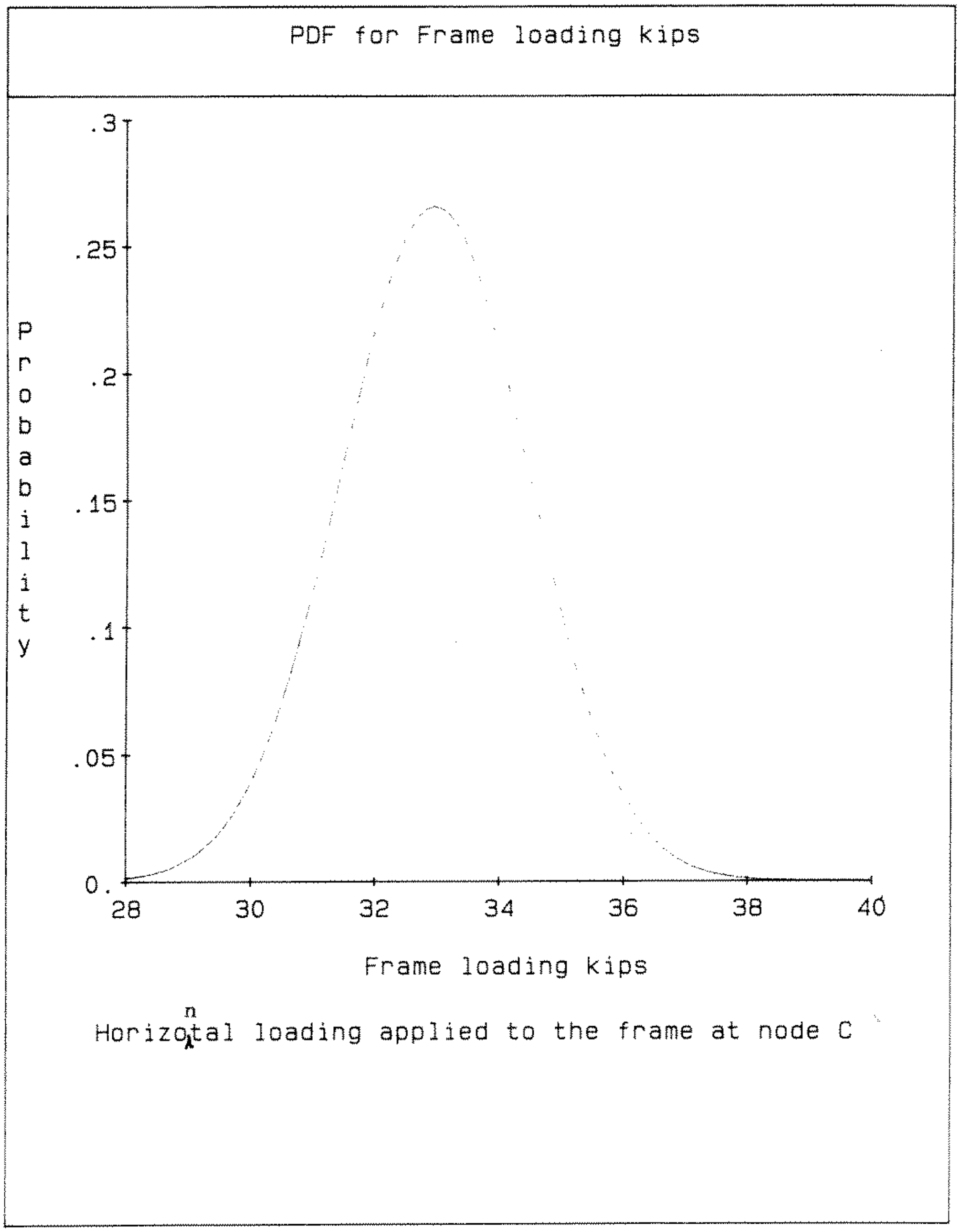
Strength of loadpath 2 from failure of AB
or BD or BC

Plot A.8

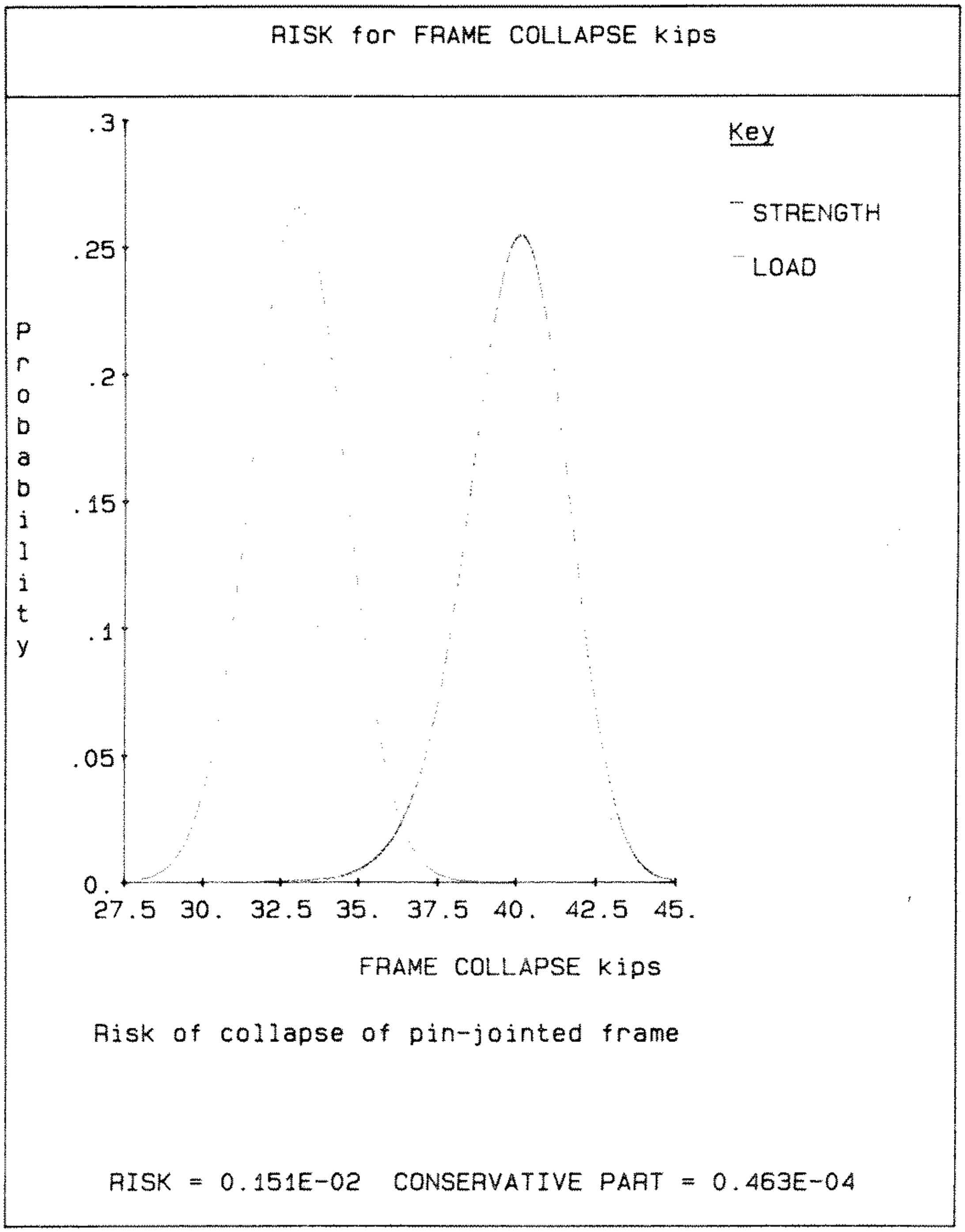


PDF for Fail strength kips
Probability
.3
.25
.2
.15
.1
.05
0.
32
34
36
38
40
42
44
46
Fail strength kips
Strength of total structure with failure of both available load paths

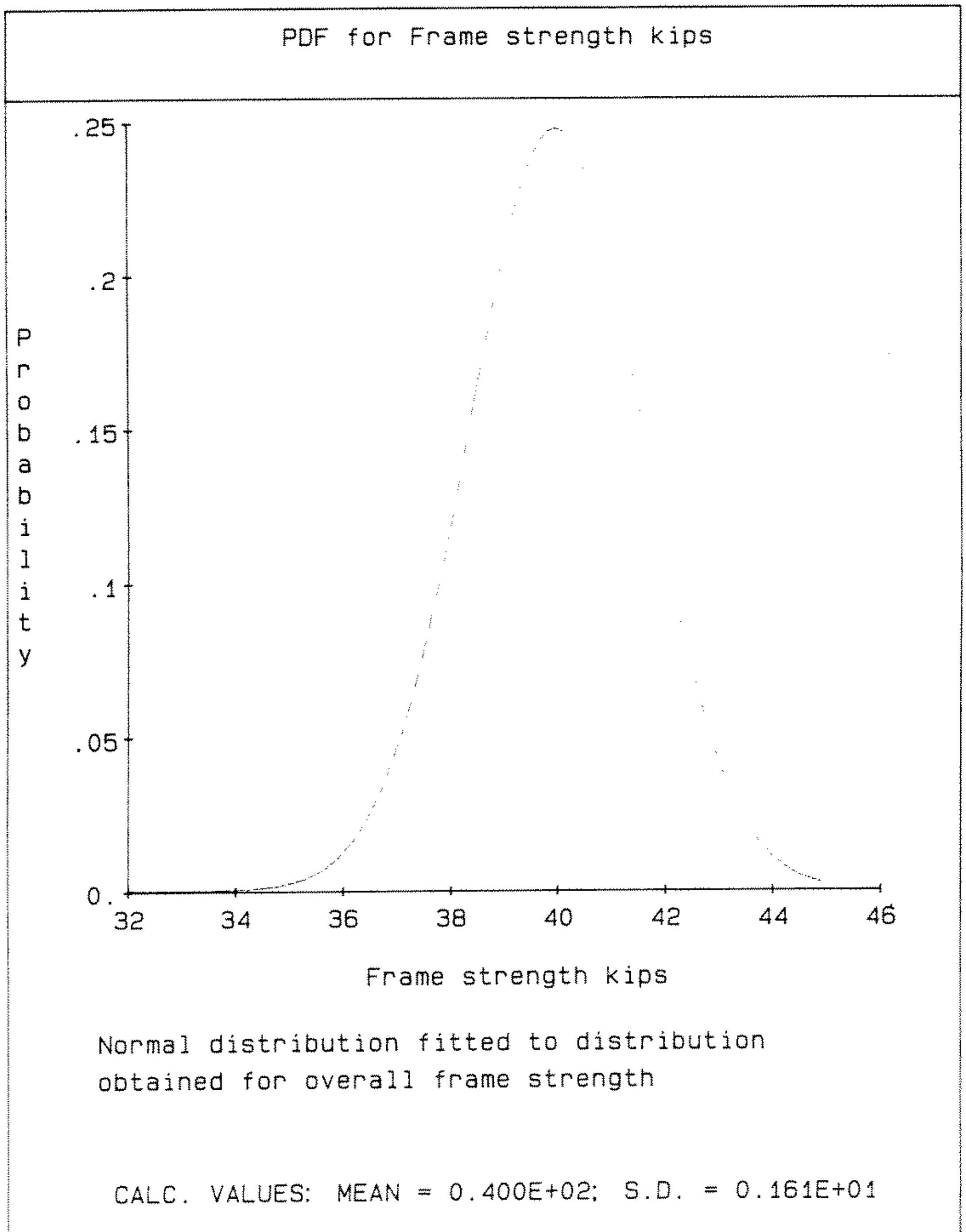
Plot A.9


PDF for Frame loading kips
Probability
.3
.25
.2
.15
.1
.05
0.
28
30
32
34
36
38
40
Frame loading kips
Horizontal loading applied to the frame at node C

Plot A.10


RISK for FRAME COLLAPSE kips
Key
STRENGTH
LOAD
Probability
.3
.25
.2
.15
.1
.05
0.
27.5 30. 32.5 35. 37.5 40. 42.5 45.
FRAME COLLAPSE kips
Risk of collapse of pin-jointed frame
RISK = 0.151E-02 CONSERVATIVE PART = 0.463E-04

Plot A.11


PDF for Frame strength kips
.25
.2
.15
.1
.05
0.
Probability
32
34
36
38
40
42
44
46
Frame strength kips
Normal distribution fitted to distribution
obtained for overall frame strength
CALC. VALUES: MEAN = 0.400E+02; S.D. = 0.161E+01

Plot A.12

Appendix B

Stochastic collapse of tubular test frame

LLOYD'S REGISTER : OCEAN ENGINEERING DEPARTMENT.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : RRMRRM_10

Combined Name : COMB3

Units : Force = N

Members cutting Height : 8.50m ie Height for member forces listed

Safety Factor Removed

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 8.50m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

HYTotal : Horizontal force in Y direction applied above height 8.50m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal N	HXOverall N	HYTotal N	HYOverall N
101	-.360E+06	-.360E+06	0.000E+00	0.000E+00

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC
20	101	-.177E+06	111.	-.177E+06	0.492	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.513
21	101	-.177E+06	111.	-.177E+06	0.492	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.390
22	101	0.000E+00	-.275E+04	-.275E+04	0.763E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.096
23	101	0.000E+00	-.275E+04	-.275E+04	0.763E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.076

Table B.1

LLOYD'S REGISTER : OCEAN ENGINEERING DEPARTMENT.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : RRMRRM_10

Combined Name : D15$D

Units : Force = N

Members cutting Height : 8.50m ie Height for member forces listed

Safety Factor Removed

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 8.50m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

HYTotal : Horizontal force in Y direction applied above height 8.50m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal N	HXOverall N	HYTotal N	HYOverall N
101	-.780E+06	-.780E+06	0.000E+00	0.000E+00

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC
20	101	-.165E+06	544.	-.164E+06	0.211	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.524 *
21	101	-.455E+06	-358.	-.455E+06	0.583	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.995
22	101	0.000E+00	-.799E+05	-.799E+05	0.102	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.738
23	101	0.000E+00	-.809E+05	-.809E+05	0.104	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.649

* Member limited by Joint Failure

Table B.2

LLOYD'S REGISTER : OCEAN ENGINEERING DEPARTMENT.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : RRMRRM_10

Combined Name : D24$D

Units : Force = N

Members cutting Height : 8.50m ie Height for member forces listed

Safety Factor Removed

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 8.50m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

HYTotal : Horizontal force in Y direction applied above height 8.50m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal N	HXOverall N	HYTotal N	HYOverall N
101	-.840E+06	-.840E+06	0.000E+00	0.000E+00

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC
20	101	-.165E+06	544.	-.164E+06	0.195	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.524 *
21	101	-.455E+06	-358.	-.455E+06	0.542	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.995
22	101	0.000E+00	-.104E+06	-.104E+06	0.124	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.915
23	101	0.000E+00	-.117E+06	-.117E+06	0.139	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.858

* Member limited by Joint Failure

Table B.3

LLOYD'S REGISTER : OCEAN ENGINEERING DEPARTMENT.

Output of Components of Member forces in a given horizontal direction for members cutting a given horizontal plane.

Name of Platform : RRMRRM_10

Combined Name : D33$D

Units : Force = N

Members cutting Height : 8.50m ie Height for member forces listed

Safety Factor Removed

Axial X comp : X component of the axial force.
Shear X comp : X component of the shear force.
Hor.Force X comp : Horizontal force in X direction.

Axial Y comp : Y component of the axial force.
Shear Y comp : Y component of the shear force.
Hor.Force Y comp : Horizontal force in Y direction.

HXTotal : Horizontal force in X direction applied above height 8.50m for each combined case.
HXOverall : Overall horizontal force in X direction for each combined case.

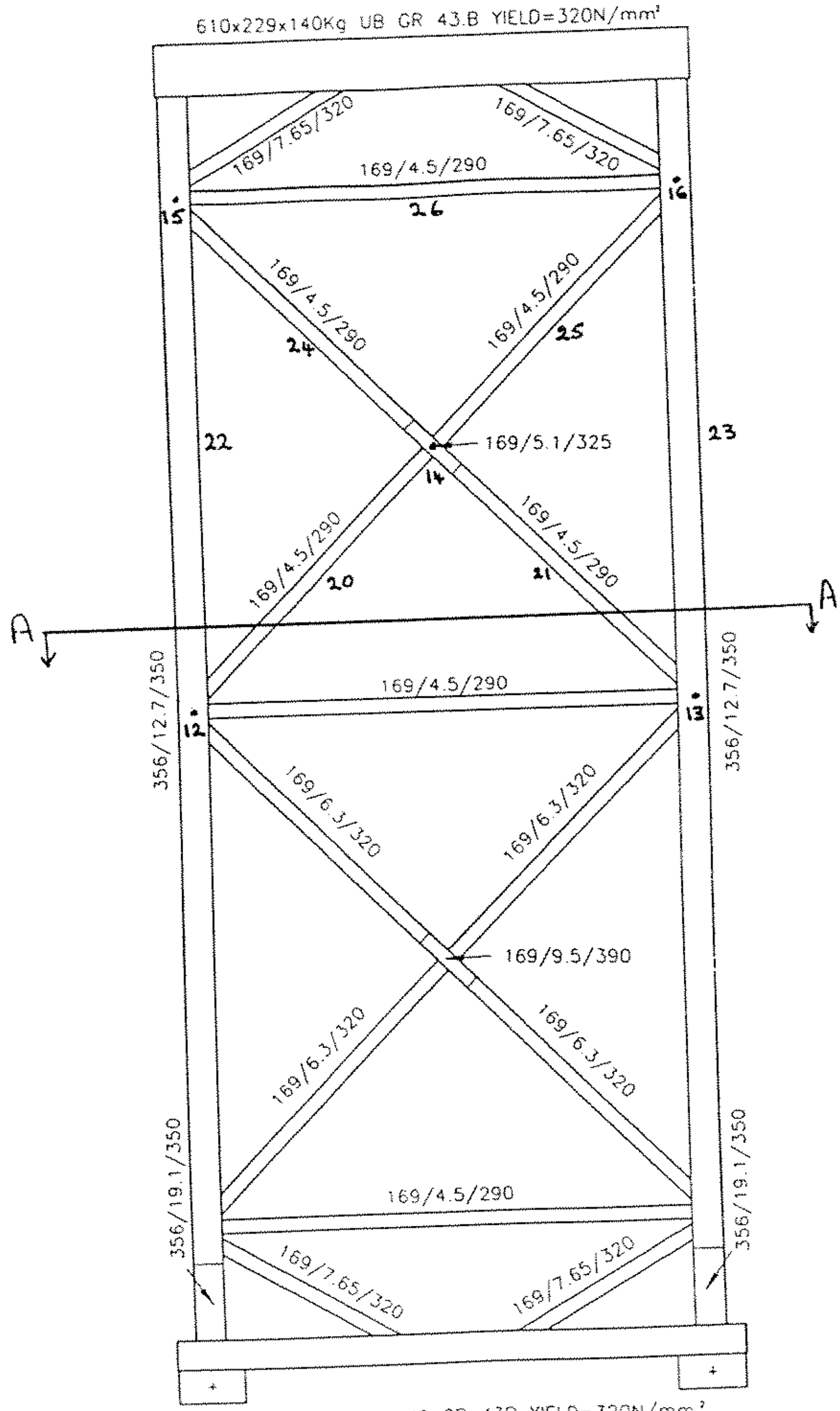
HYTotal : Horizontal force in Y direction applied above height 8.50m for each combined case.
HYOverall : Overall horizontal force in Y direction for each combined case.

Combined Case Nº	HXTotal N	HXOverall N	HYTotal N	HYOverall N
101	-.852E+06	-.852E+06	0.000E+00	0.000E+00

Member Nº	Combined Case Nº	Axial X comp	Shear X comp	Hor.Force X comp(HX)	Ratio HX/HXtotal	Axial Y comp	Shear Y comp	Hor.Force Y comp(HY)	Ratio HY/HYtotal	Interaction Ratio - AISC
20	101	-.165E+06	544.	-.164E+06	0.193	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.524 *
21	101	-.455E+06	-358.	-.455E+06	0.534	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.995
22	101	0.000E+00	-.109E+06	-.109E+06	0.128	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.951
23	101	0.000E+00	-.124E+06	-.124E+06	0.145	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.901

* Member limited by Joint Failure

Table B.4



KEY: 356/12.7/350 : OUTSIDE DIAMETER = 356mm,
WALL THICKNESS = 12.7mm
YIELD STRESS = 350N/mm²

Figure B.1

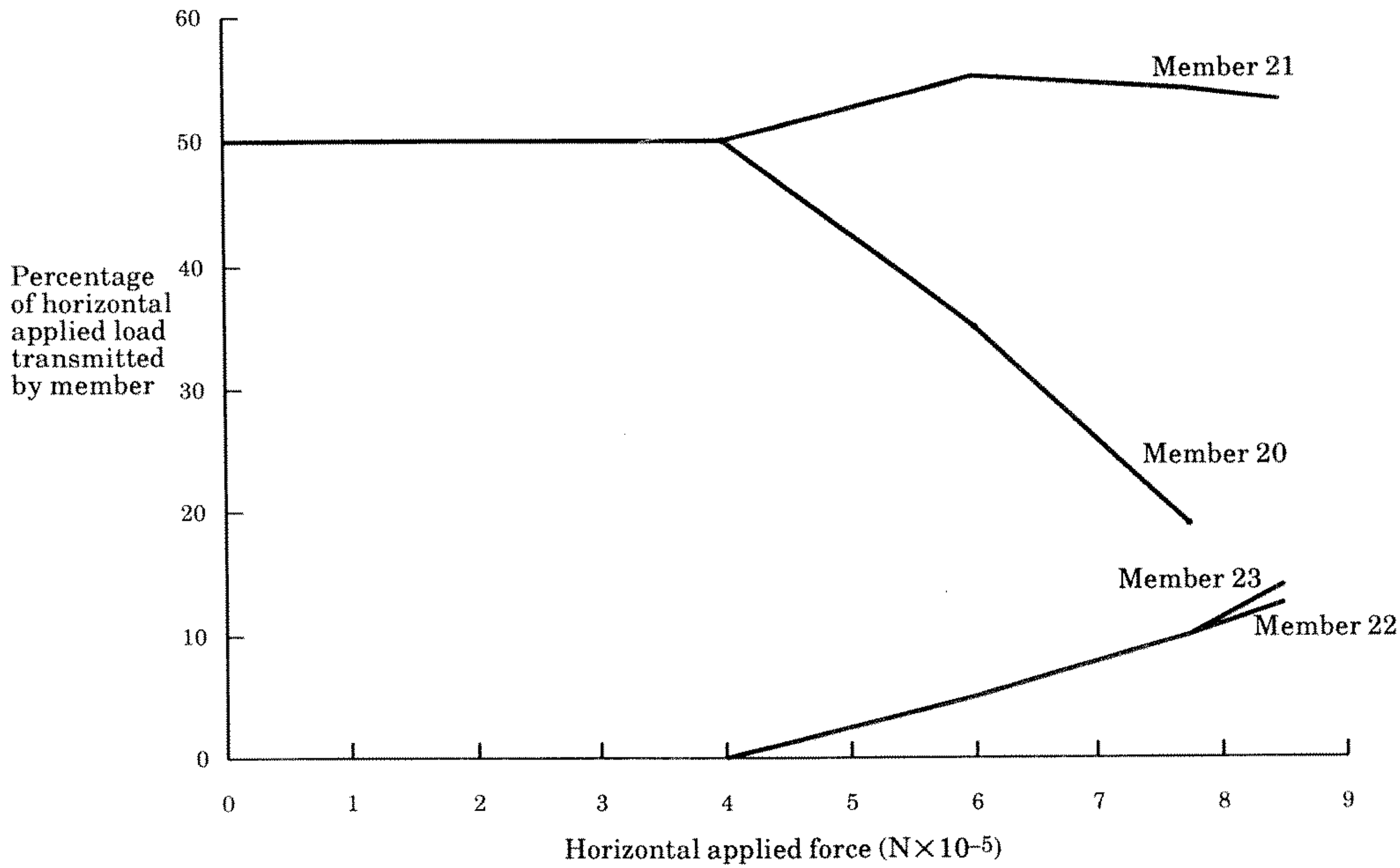

60
50
40
30
20
10
0
Percentage of horizontal applied load transmitted by member
Member 21
Member 20
Member 23
Member 22
0
1
2
3
4
5
6
7
8
9
Horizontal applied force (N×10-5)

Figure B.2