Reliability of Tubular Joints

part 1

Sørensen, John Dalsgaard; Thoft-Christensen, Palle

Publication date:
1986

Document Version
Publisher's PDF, also known as Version of record

INSTITUTTET FOR BYGNINGSTEKNIK

INSTITUTE OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING

AALBORG UNIVERSITETSCENTER · AUC · AALBORG · DANMARK

STRUCTURAL RELIABILITY THEORY
PAPER NO. 16

J. D. SØRENSEN & P. THOFT-CHRISTENSEN
RELIABILITY OF TUBULAR JOINTS, PART 1

JANUARY 1986

ISSN 0105-7421 R8601

INSTITUTTET FOR BYGNINGSTEKNIK

INSTITUTE OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING

AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

STRUCTURAL RELIABILITY THEORY
PAPER NO. 16

J. D. SØRENSEN & P. THOFT-CHRISTENSEN

RELIABILITY OF TUBULAR JOINTS, PART 1

JANUARY 1986

ISSN 0105-7421 R8601

1. INTRODUCTION

In this paper the preliminary results obtained by tests on tubular joints are presented. The joints are T-joints and the loading is static. It is the intention in continuation of these tests to perform tests on other types of joints (e.g. Y-joints) and also with dynamic loading.

The purpose of the tests is partly to obtain empirical data for the ultimate load-carrying capacity of tubular T-joints and partly to obtain some experience in performing tests with tubular joints.

It is well known that tubular joints are usually designed in offshore engineering on the basis of empirical formulas obtained by experimental test results. Therefore, there is a need for performing experimental tests in this area.

2. TEST SPECIMENS, SET-UP, AND PROCEDURE

The test specimens are shown in figure 1. The specimens were designed to have properties equivalent to those of real joints in offshore structures. The ratio of the branch-to-chord diameters $\beta = 0.41$ is in the mid range for most joint types. Also, the chord thinness ratio $\gamma = 34.2$ is typical for offshore tubular joints. The chord length was selected on the basis of research work (see Hoadley & Yura [1]) showing that chord lengths greater than about eight times the chord diameter eliminate any significant influence from shear. The chord diameter was selected to fulfil the requirements stated in Yura et al. [2]. Fulfilment of these conditions requires that the diameter exceeds 130 mm.

The speciments were prepared by Horsens Tekniske Skole, Horsens, Denmark. All branch material came from the same heat and all chord material from the same heat. Nominally, the materials are steel quality St. 35. All welds except the weld between the tubes are fillet welds. All welds between the tubes are of the complete joint penetration groove weld type.

Five tensile tests were performed to determine the material properties of the specimens. Table 1 presents the results of the five coupon tests. These coupons were machined out of the same

coupon	area [mm^2]	yield force [kN]	ult. force [kN]	yield stress [N/mm^2]	ult. stress [N/mm^2]
1	30.0	9.06	12.4	302	414
2	30.0	9.30	12.8	310	428
3	28.5	8.64	11.9	304	418
4	27.3	7.98	11.2	293	412
5	30.0	9.06	12.9	302	430
		expected value		302	420
		standard deviation		12.2	16.4
		coefficient of variation		0.040	0.039

Table 1. Results of coupon tensile tests.

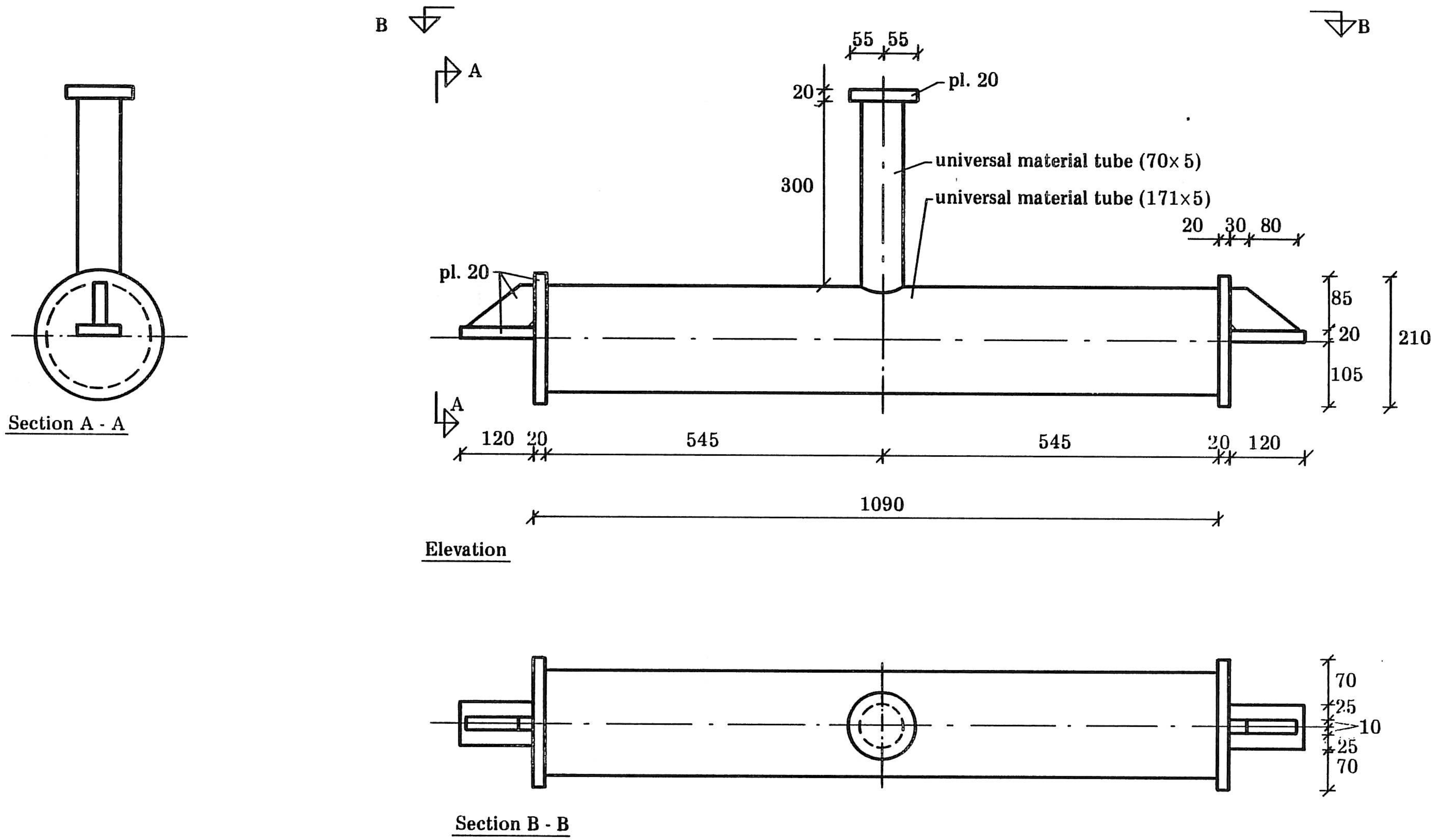


Figure 1. Specimen details (all dimensions in mm).

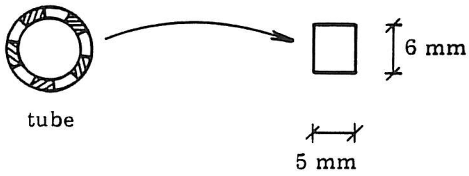
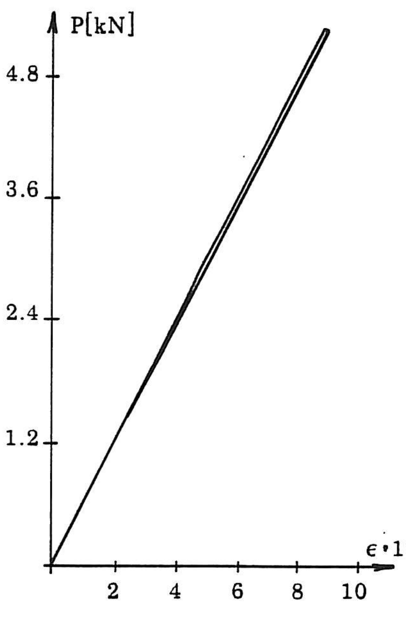


Figure 2. Coupon for material test.



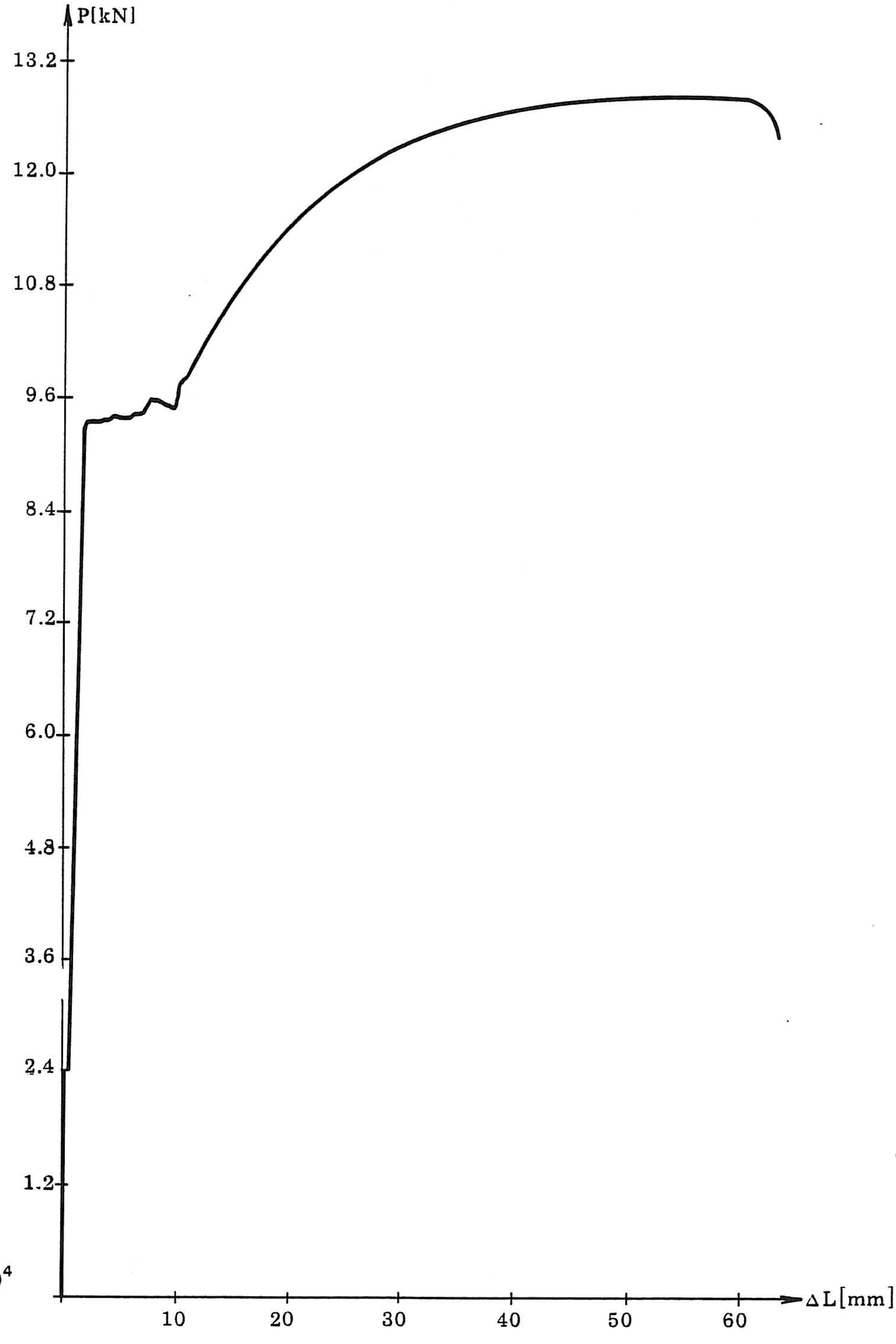


Figure 3. Coupon tensile test (area of coupon 30 mm^2 and length between jaws of the tensile test machine 245 mm).

tube as illustrated in figure 2. First, the coupons were loaded by a load which was half the expected yield load and then unloaded. Next, the coupons were loaded to failure. The tensile tests were performed in accordance with the specifications in DS 10110. A typical load-deformation plot is shown in figure 3.

The test set-up should only be capable of applying axial compression in the branch. The test set-up is shown in figure 4. The load is applied using a 200 kN hydraulic load cell.

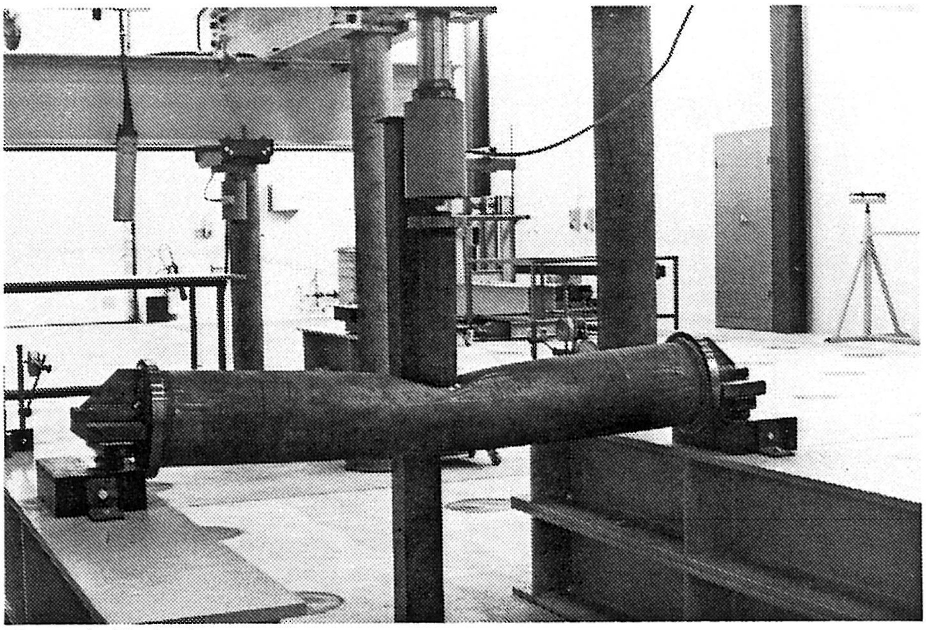
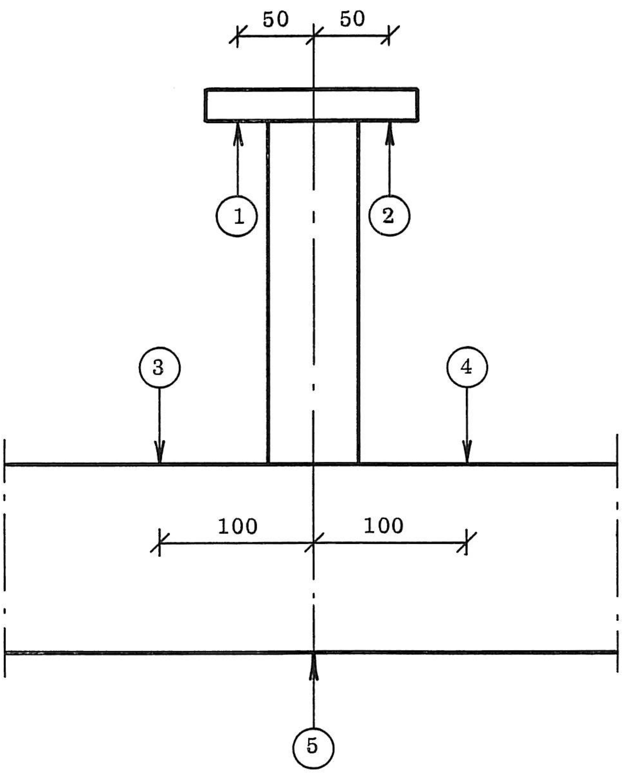


Figure 4. Test set-up.



The same test procedure was followed in the testing of all specimens. The load was applied monotonically. Simultaneously the deformation of five points of the specimen was registered. The five points are placed in the plane of symmetry of the specimen, see fig. 5.

Figure 5. Measurement of deformation (all dimensions in mm).

3. TEST RESULTS

Five tests were conducted on identical T-joints loaded axially in compression. The recorded measurements are shown in the appendix. The measured ultimate load-carrying capacities are shown in table 2. From the table it is seen that the expected value of the ultimate load-carrying capacity is 79.3 kN and the coefficient of variation is 4.9%. As expected the coefficient of variation of the ultimate load-carrying capacity is greater than the coefficient of variation of the yield stress (4.0%) of the material.

In figure 6 the load-displacement behaviour for the five specimens is shown. The displacement shown is the difference between the displacement of point 5 and the mean of the displacements of points 1 and 2, see figure 5.

specimen	ultimate load-carrying capacity [kN]
1	79.0
2	84.0
3	76.0
4	75.2
5	82.5
expected value	79.3
standard deviation	3.9
coefficient of variation	0.049

Table 2. Ultimate load-carrying capacities.

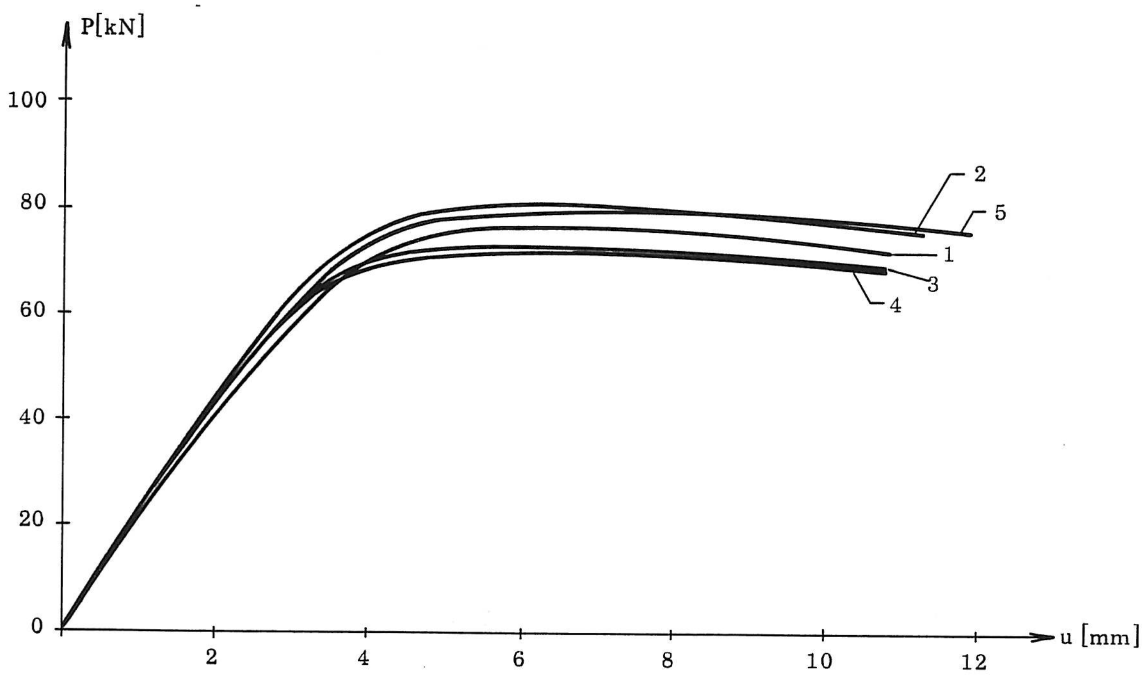


Figure 6. Load-displacement characteristics of the specimens.

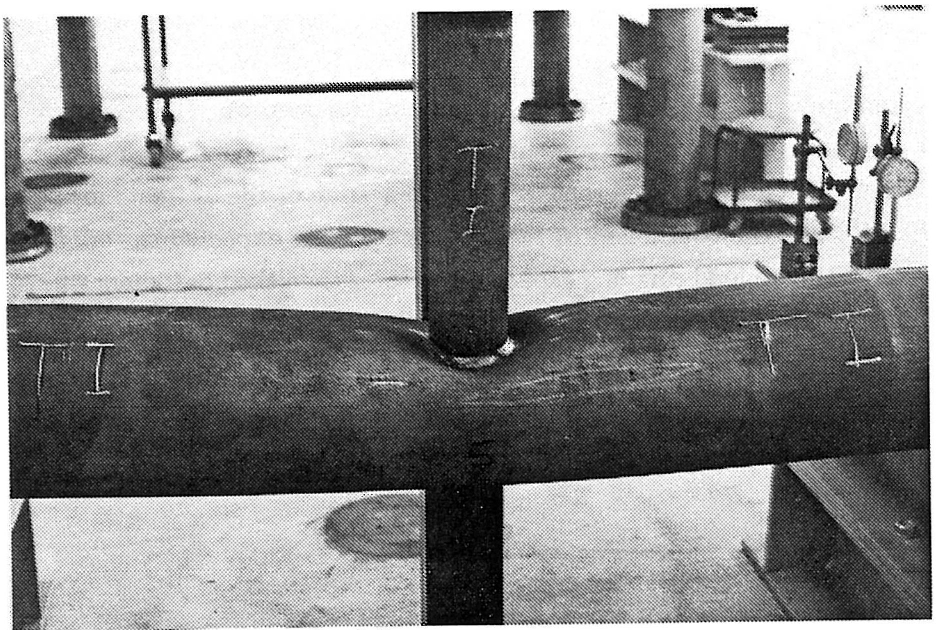


Figure 7. A tubular joint after failure.

Figure 8. Detail of figure 7.

In figs. 7 and 8 details of a specimen after failure are shown. From these figures and from figure 6 it is seen that the joints fail in a ductile manner. The chord wall in the vicinity of the connection is severely deformed.

4. COMPARISONS WITH EMPIRICAL FORMULAS

In this section the test results are compared with the empirical formulas of Billington et al. [3], Yura et al. [2], and Kurobane et al. [4]. The empirical formulas are as follows:

Billington ($\beta \leqslant 0.6$):

$$P_u = \sigma_y T^2 (4.1 + 20.3\,\beta) \tag{1}$$

Yura (lower bound):

$$P_u = \sigma_y T^2 (3.4 + 19\,\beta) \tag{2}$$

Kurobane:

$$P_u = \sigma_y T^2\, 4.83 (1 + 4.94\,\beta^2)\, \gamma^{0.233}\, (L/D)^{-0.45} \tag{3}$$

where

β is the ratio of the branch-to-chord diameters
γ is the chord thinness ratio
T is the thickness of the chord
σ_y is the yield stress
L is the length between the supports of the chord
D is the diameter of the chord

For the test specimens used here $\beta = 0.41$ and $\gamma = 34.2$. The other dimensions are shown in figure 1. The test results from section 4 are compared with the estimates of the empirical formulas in figure 9 ($\sigma_y = 302$ N/mm^2).

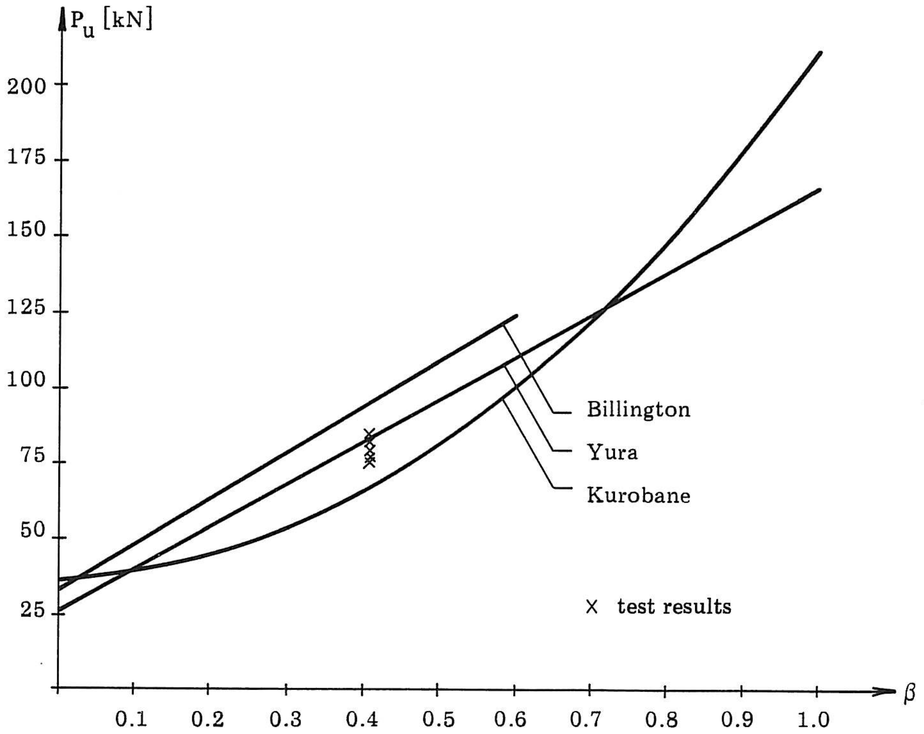


Figure 9. Comparison of empirical formulas with test results.

From figure 9 it is seen that the formula proposed by Yura et al. gives the best correspondence with the test results, although the estimate of Yura et al. is not a lower bound. The formulas of Billington et al. and Kurobane et al. give estimates which are 18% greater and 20% lower, respectively.

5. CONCLUSIONS

The experimental tests described in this report have given us some experience in performing tests with tubular joints. The test set-up used has appeared to function very well.

The test results are compared with empirical formulas. The mean value of the ultimate axial load-carrying capacity in compression of the five tubular T-joints is estimated at 79.3 kN and the coefficient of variation at 4.9%. Comparison with the empirical formulas shows that the test results are close to the estimate by Yura et al. [2], considerably lower than the estimate by Billington et al. [3], and considerably greater than the estimate by Kurobane et al. [4].

6. ACKNOWLEDGEMENT

The authors would like to thank Dr. L. Pilegaard Hansen and laboratory technicians H. Andersen and J. Hasselgren fro their help with the experimental tests.

7. REFERENCES

[1] Hoadley, P. W. & Yura, J. A.: *Ultimate Strength of Tubular Joints Subjected to Combined Loads.* Phase II Report. Phil M. Ferguson Structural Eng. Lab., University of Texas, Austin, December 1983.

[2] Yura, J. A., Zettlemayer, N. & Edwards, I. F.: *Ultimate Capacity Equations for Tubular Joints.* OTC 3690, Offshore Technology Conference, Houston, Texas, 1980.

[3] Billington, C. J., Lalani, M. & Tebbett, I. A.: *Background to New Formulae for the Ultimate Limit State of Tubular Joints.* OTC 4189, Offshore Technology Conference, Houston, Texas, 1982.

[4] Kurobane, Y., Makino, Y. & Ochi, K.: *Ultimate Resistance of Unstiffened Tubular Joints.* ASCE, Journal of Structural Engineering, Vol. 110, No. 2, 1984, pp. 385-400.

APPENDIX. DATA FROM EXPERIMENTS WITH TUBULAR T-JOINTS

T-joint No. 1

Axial compressive force	Displacement of point no. (see fig. 5) 1	2	3	4	5
kN	1/100 mm				
0	621	722	4491	4548	696
5	642	742	4473	4529	707
10.1	666	764	4449	4507	718
15.1	689	789	4428	4484	729
20.2	713	814	4405	4462	740
25.1	736	838	4383	4440	750
30.0	762	864	4360	4417	760
35.1	789	891	4335	4395	770
39.9	814	917	4312	4369	779
44.8	841	945	4287	4345	788
50.0	871	975	4261	4320	797
54.9	900	1006	4235	4293	806
59.8	932	1040	4206	4265	815
64.7	969	1078	4175	4234	824
69.8	1016	1128	4137	4196	834
74.3	1084	1201	4083	4145	848
76.3	1160	1282	4032	4096	861
76.3	1335	1468	3926	3993	888
72.0	1685	1821	3738	3815	937

Max. force: 79.0 kN

T-joint No. 2

Axial compressive force	Displacement of point no. (see figure 5) 1	2	3	4	5
kN	1/100 mm				
0	998	1040	2882	3234	498
5.3	1022	1063	2862	3213	509
10.2	1042	1082	2843	3194	518
14.9	1063	1103	2824	3174	528
20.2	1086	1127	2802	3151	538
25.0	1107	1146	2782	3132	548
29.9	1130	1168	2761	3111	558
35.0	1154	1191	2741	3091	567
40.0	1178	1215	2720	3069	575
45.1	1204	1241	2696	3046	584
49.9	1227	1265	2675	3025	592
54.9	1254	1291	2653	3002	600
59.9	1282	1318	2629	2978	607
64.8	1313	1348	2604	2953	615
69.9	1350	1384	2574	2924	624
74.5	1398	1429	2539	2889	633
76.8	1426	1457	2519	2868	639
79.0	1471	1499	2490	2838	646
79.9	1526	1551	2453	2803	654
81.0	1621	1642	2396	2745	668
80.2	1763	1779	2318	2664	688
75.5	2139	2152	2129	2472	738

Max. force: 84 kN

T-joint No. 3

Axial compressive force	Displacement of point no. (see figure 5) 1	2	3	4	5
kN	1/100 mm				
0	980	942	2760	3298	606
5.0	999	960	2740	3277	618
10.0	1023	985	2720	3256	629
15.1	1046	1009	2703	3234	640
19.9	1070	1031	2677	3214	650
25.0	1092	1053	2657	3193	660
30.0	1114	1078	2636	3171	669
34.9	1139	1101	2615	3150	678
40.0	1163	1125	2592	3129	687
45.0	1189	1151	2569	3106	695
49.9	1214	1177	2546	3084	703
54.8	1241	1203	2522	3050	711
59.8	1275	1236	2495	3034	720
64.8	1316	1276	2462	3001	729
69.8	1383	1338	2416	2954	742
72.8	1528	1478	2325	2865	768
72.3	1756	1702	2201	2740	804
69.1	2060	2005	2050	2584	846

Max. force: 76 kN

T-joint No. 4

Axial compressive force	Displacement of point no. (see figure 5) 1	2	3	4	5
kN	1/100 mm				
0	960	1130	3178	2887	589
5.0	980	1149	3158	2867	602
10.0	1006	1175	3136	2845	613
15.0	1028	1197	3114	2823	624
19.9	1050	1220	3094	2803	633
24.9	1073	1243	3072	2781	643
29.9	1095	1267	3051	2760	653
34.9	1117	1292	3029	2738	663
40.2	1144	1318	3006	2714	673
44.9	1168	1343	2985	2694	681
49.8	1193	1371	2961	2670	689
54.7	1221	1400	2937	2646	698
59.8	1255	1435	2909	2619	707
64.7	1294	1477	2877	2586	717
69.2	1364	1551	2828	2536	731
71.8	1550	1740	2715	2425	762
70.7	1784	1977	2587	2302	797
68.3	2023	2219	2464	2184	831

Max. force: 75.2 kN

T-joint no. 5

Axial compressive force	Displacement of point no. (see figure 5) 1	2	3	4	5
kN	1/100 mm				
0	1194	883	2664	3512	453
5.0	1216	904	2645	3491	464
9.9	1238	927	2625	3469	476
15.2	1263	949	2602	3447	487
19.9	1283	970	2581	3427	496
24.9	1305	993	2560	3406	505
29.9	1328	1018	2539	3384	513
34.9	1352	1042	2517	3362	522
39.9	1376	1066	2495	3340	530
44.8	1400	1092	2472	3318	538
49.7	1424	1118	2448	3293	546
54.7	1453	1147	2425	3269	554
59.7	1482	1178	2398	3242	563
64.6	1514	1211	2371	3215	571
69.5	1549	1249	2341	3185	579
74.3	1605	1303	2300	3142	590
78.2	1705	1410	2229	3071	606
79.3	1910	1622	2103	2945	640
77.9	2178	1894	1953	2796	680
75.7	2367	2084	1854	2696	706

Max. force: 82.5 kN

STRUCTURAL RELIABILITY THEORY SERIES

PAPER NO. 1: J. D. Sørensen & P. Thoft-Christensen: *Model Uncertainty for Bilinear Hysteretic Systems*, IFB/A 8302.

PAPER NO. 2: P. Thoft-Christensen & J. D. Sørensen: *Reliability Analysis of Elasto-Plastic Structures*, IFB/A 8303.

PAPER NO. 3:. P. Thoft-Christensen: *Reliability Analysis of Structural Systems by the β-unzipping Method.* (Preprint of a chapter of the new textbook: »Reliability of Structural Systems») ISSN 0105-7421 R8401.

PAPER NO. 4: J. D. Sørensen: *Pålidelighedsanalyse af statisk og dynamisk belastede elasto-plastiske ramme- og gitterkonstruktioner.* ISSN 0105-7421 R8402. (Ph.D. Thesis - in Danish).

PAPER NO. 5: P. Thoft-Christensen: *Reliability of Structural Systems.* ISSN 0105-7421 R8403.

PAPER NO. 6: P. Thoft-Christensen & J. D. Sørensen: *Optimization and Reliability of Structural Systems.* ISSN 0105-7421 R8404.

PAPER NO. 7: P. Thoft-Christensen & J. D. Sørensen: *A Bibliographical Survey of Structural Reliability.* 1st edition. ISSN 0105-7421 R8408.

PAPER NO. 8: P. Thoft-Christensen: *Structural Reliability Theory.* ISSN 0105-7421 R8409.

PAPER NO. 9: G. Sigurdsson, J. D. Sørensen & P. Thoft-Christensen: *Development of Methods for Evaluating the Safety of Offshore Structures, Part 1.* ISSN 0105-7421 R8501.

PAPER NO. 10: J. D. Sørensen & P. Thoft-Christensen: *Modelling and Simulation of Wave Loads.* ISSN 0105-7421 R8503.

PAPER NO. 11: J. D. Sørensen, P. Thoft-Christensen & G. Sigurdsson: *Development of Applicable methods for Evaluating the Safety of Offshore Structures, Part 2.* ISSN 0105-7421 R8504.

PAPER NO. 12: P. Thoft-Christensen & J. D. Sørensen: *A Bibliographical Survey of Structural Reliability.* 2nd edition. ISSN 0105-7421 R8505.

PAPER NO. 13: J. D. Sørensen & P. Thoft-Christensen: *Structural Optimization with Reliability Constraints.* ISSN 0105-7421 R8507.

PAPER NO. 14: M. H. Faber & P. Thoft-Christensen: *Reliability Analysis of a Plane Lattice Structure with Local Imperfections.* ISSN 0105-7421 R8512.

PAPER NO. 15: P. Thoft-Christensen: *Reliability Modelling of Structural Systems.* ISSN 0105-7421 R8514.

PAPER NO. 16: J. D. Sørensen & P. Thoft-Christensen: *Reliability of Tubular Joints, Part 1.* ISSN 0105-7421 R8601.

INSTITUTE OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
THE UNIVERSITY OF AALBORG
SOHNGAARDSHOLMSVEJ 57, DK-9000 AALBORG
TELEPHONE: (08) 142333