TALAT Lectures 2703

Construction and Dynamic Testing of Aluminium Nodes

13pages, 10 figures

Basic Level

prepared by Åke Oma, Hydro Aluminium Structures, Karmoy

Objectives:

- This case study demonstrates, how optimum design and fabrication of extruded space frame members joined by welding can lead to significant weight savings, high service life and economy under fatigue loading conditions.

Prerequisites:

- basic knowledge of structural engineering, extrusion design, welding and fatigue
- TALAT lectures No. 1302, 1501, 2200, 2302, 2400

Date of Issue: 1994

2703 Construction and Dynamic Testing of Aluminium Nodes

Contents

2703.01 Case History

To evaluate the feasibility of aluminium alloys in dynamic loaded structures, a 3-year joint industry project was initiated in 1984 called “Aluminium Offshore”.

Subproject 5, “Aluminium Structural Node” concluded with a recommendation for further work on the basis that all the nodes investigated could be further developed to obtain even higher properties than those obtained at that time. It was recommended to optimize the design for fabrication with minimum amount of welds and to maximize the inspectability of welds.

Hence a follow-up project called “Aluminium Nodes” was initiated in 1987 as a 3-year joint industry project between:

- Norsk Teknisk-Naturvitenskapelig Forskningsråd
- Hydro Aluminium
- Hydro Aluminium Structures a.s
- Raufoss a.s
- Statoil

The objective of the project was to study by design, fabrication, inspection and testing of nodes in full-scale to reach safer use of aluminium in dynamically loaded offshore structures. This problem can be divided into the following aspects:

- to design a maximum size node by using single profiles as chord- and brace-members. Largest hollow profile cross section of the complexity in question available in Europe and Norway for chord- and brace-members, respectively

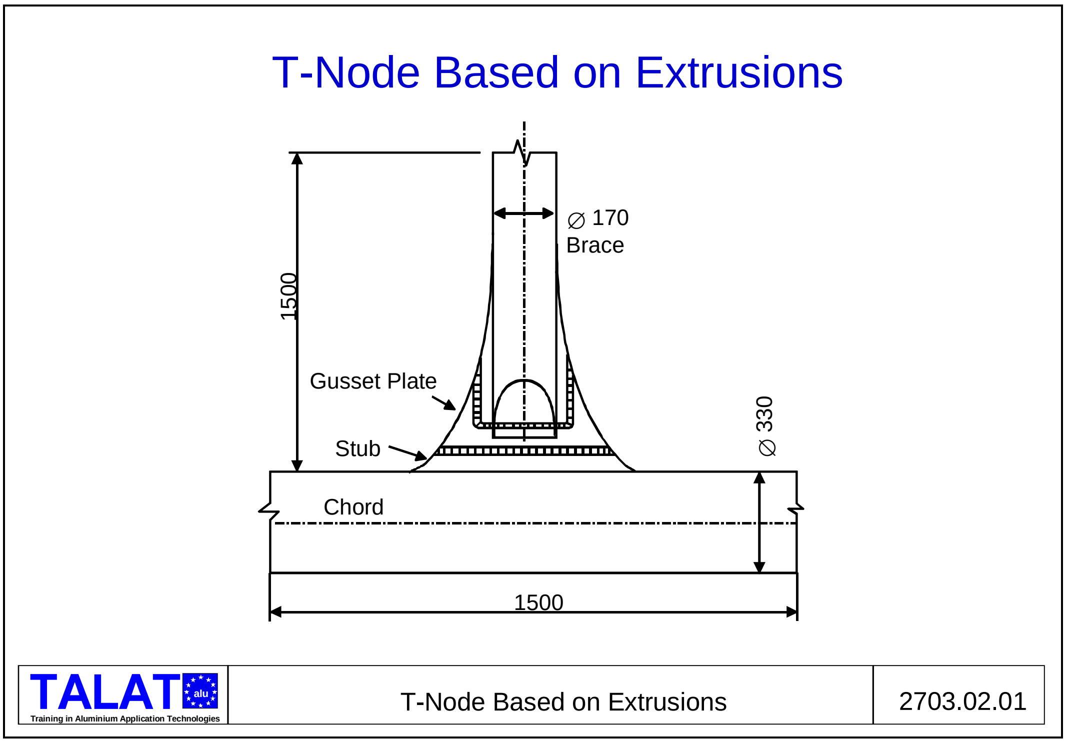
- to make a concept through experience for design, fabrication procedures, manufacture and testing of nodes, including testing of selected, questionable features

- to test a full-scale T-node with respect to fatigue as the most severe node configuration with respect to stress concentrations

- to design K-, Y- and KY- nodes based on chosen T-node design to evaluate stress distribution in these configurations compared to stress distribution in the T-node design

- to design a dynamically loaded aluminium structure with the actual node designs integrated

- to make a lifetime calculation for the structure exposed to relevant dynamic and static loads based on the results from full-scale fatigue testing of nodes and node/member joints



2703.02 Optimization of Design

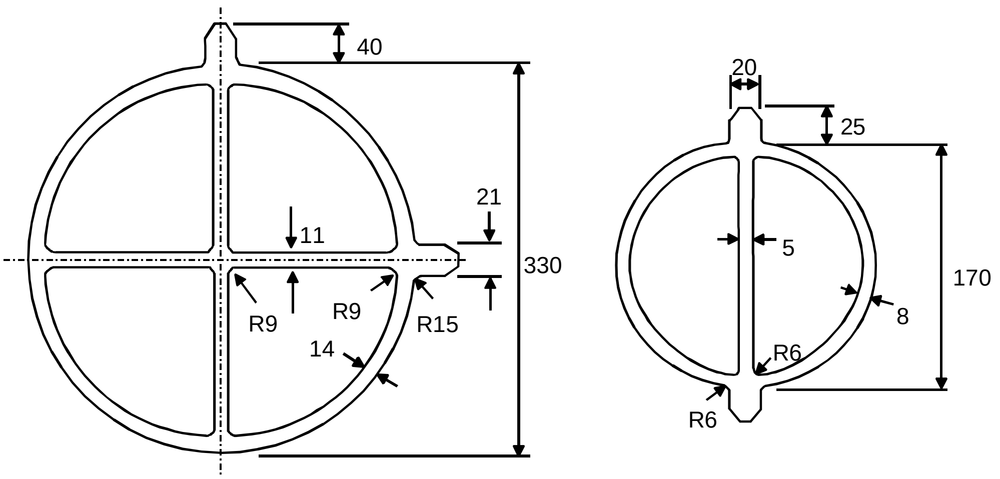
The essential idea is to avoid stress concentrated on the weld positions. The fatigue behaviour of welded aluminium structures can be dramatically improved if peak stresses at the weld positions can be avoided. The stress peaks will then be in parent material with much better fatigue properties. Also, the design should permit easy access for both, welding and non-destructive testing (**Figure 2703.02.01**).

The Extrusions Used for the Node

The node is designed in such a way that full advantage is taken from the extrusion process. This made it possible to integrate several functions in one profile. The two profiles used for the node are given in **Figure 2703.02.02** with their primary dimensions.

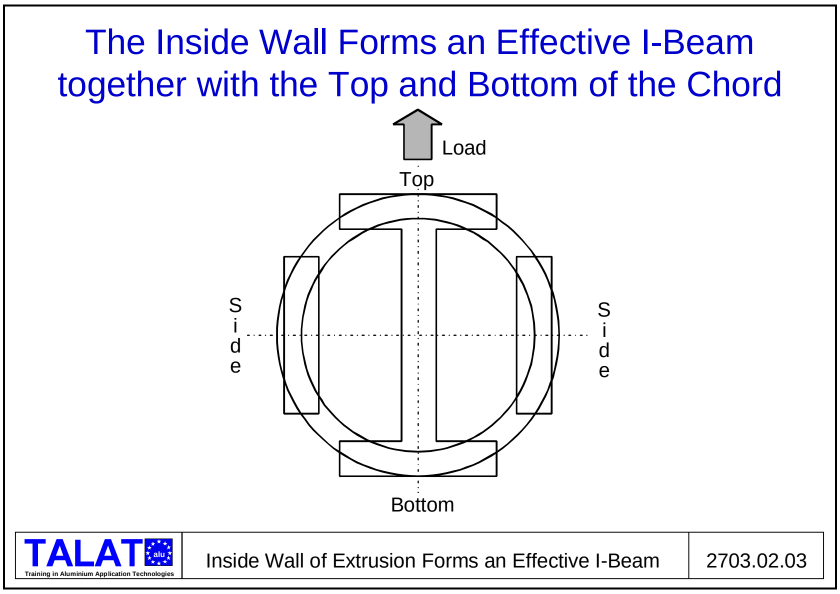
To maximize the size of the node, the maximum possible extrusions available in Europe were chosen for the chord member while maximum possible extrusions available in Norway were chosen for brace members.

Profiles used for the node
with their primary dimensions

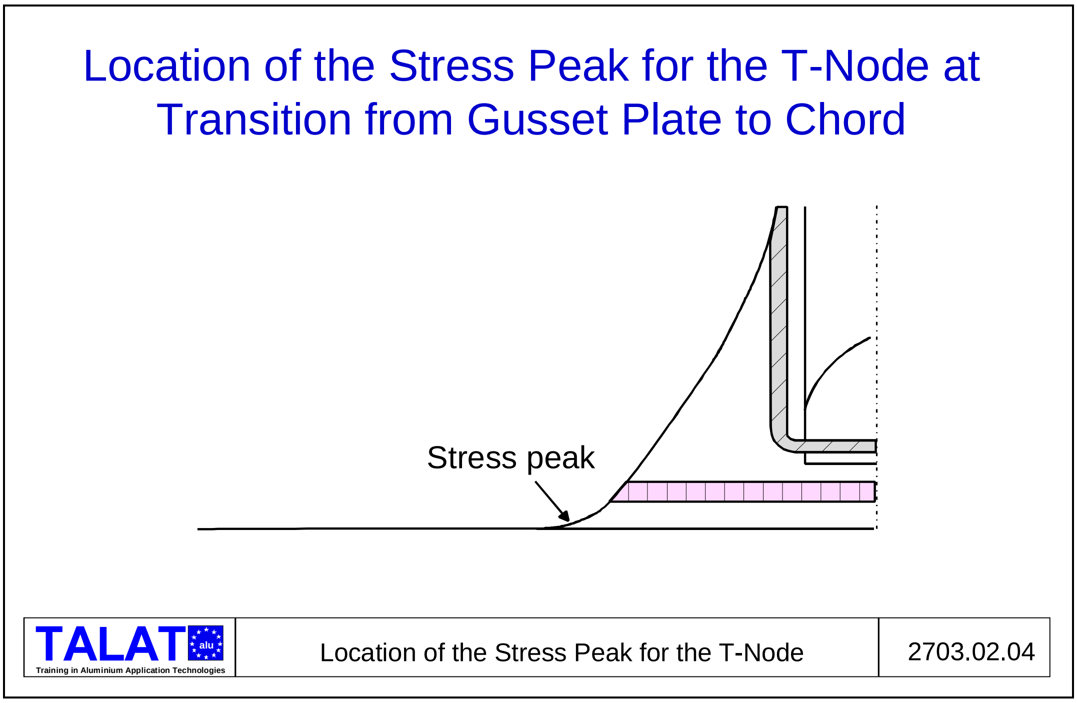


TALAT Training in Aluminium Application Technologies | Node-Profiles with Primary Dimensions | 2703.02.02

The extrusion for the cord of the node uses an inside wall to take up the transverse load. Together with a part of the tube itself, an effective I-beam is constructed (**Figure 2703.02.03**). This avoids ovalization of the cord and therefore reduces the stress level considerably. To be able to use the profile in a real three dimensional structure, a cross inside the tube is needed.



To introduce the transverse load without creating peak stresses at the weld, a small part of the gusset plate is extruded as a stub on the chord, as can be seen in **Figure 2703.02.04.** After welding of the gusset plate to this stub it is essential that the stube is machined down to the wall of the tube to remove welding run-on/run-off. In this way the weld is lifted away from the area with the peak stress caused by the start of the gusset plate. **Figure 2703.02.04** shows a sketch with the location of the stress peak showing a stress concentration of 2.78 found from finite element analysis. At the weld, the stresses are about 35% lower than at the peak.



Also the profile for the bracing has integrated a small part of the gusset plate in the extrusion (see **Figure 2703.02.04**). This again removes the weld from the stress peak caused by the start of the gusset plate and is well adapted for manufacture and inspection. The profile has a thin wall inside which prevents ovalization, and corresponding high stress levels in the bracing. Without this inside wall, excessive ovalization of the bracing was seen when optimizing the node.

2703.03 Fabrication of Test Nodes

Specifications for machining and welding procedures combined with applicable non destructive examinations were made. The requirements for the material were set as follows:

Element	Alloy	$R_{p0,2}$ (MPa)	R_m (MPa)	A_5 (%)
Extrusions	AlMgSi1 (AA6082)T6	≥ 260	≥ 310	≥ 10
Plate	AlMg4.5Mn (AA5083)W28	≥ 125	≥ 275	≥ 17
Welding Consumables	AlMg5Mn (AA 5183)			

The fabrication procedures were made applicable to cover prefabrication by certified welders and inspection personnel.

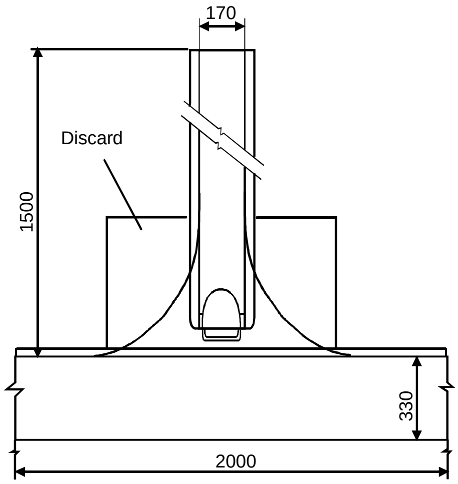
The chord and brace members and gusset plates were cut and prepared with welding grooves. The size of the gusset plate were made as to allow for removing of welding run-on/run-off.

Just prior to welding, all surfaces in and around welding zones were brushed and degreased. The nodes were welded and, were necessary, repaired with appropriate specifications (see **Figure 2703.03.01**).

Visual inspection, penetrant and radiographic examination were performed on all welds. Ultrasonic examination was performed on most welds and irregularities and defects exceeding acceptance criterias were repaired.

Finally, the nodes were finished, first by coarse cutting and than by grinding, filing and brushing ball to make the edges smooth.

T-Node as-welded and finished to its final shape



TALAT Training in Aluminium Application Technologies	T-Node as-welded and finished to final shape	2703.03.01

2703.04 Dynamic Testing

Fatigue testing of a full scale node is the most effective way to prove the liability of a dynamic loaded welded aluminium structure.

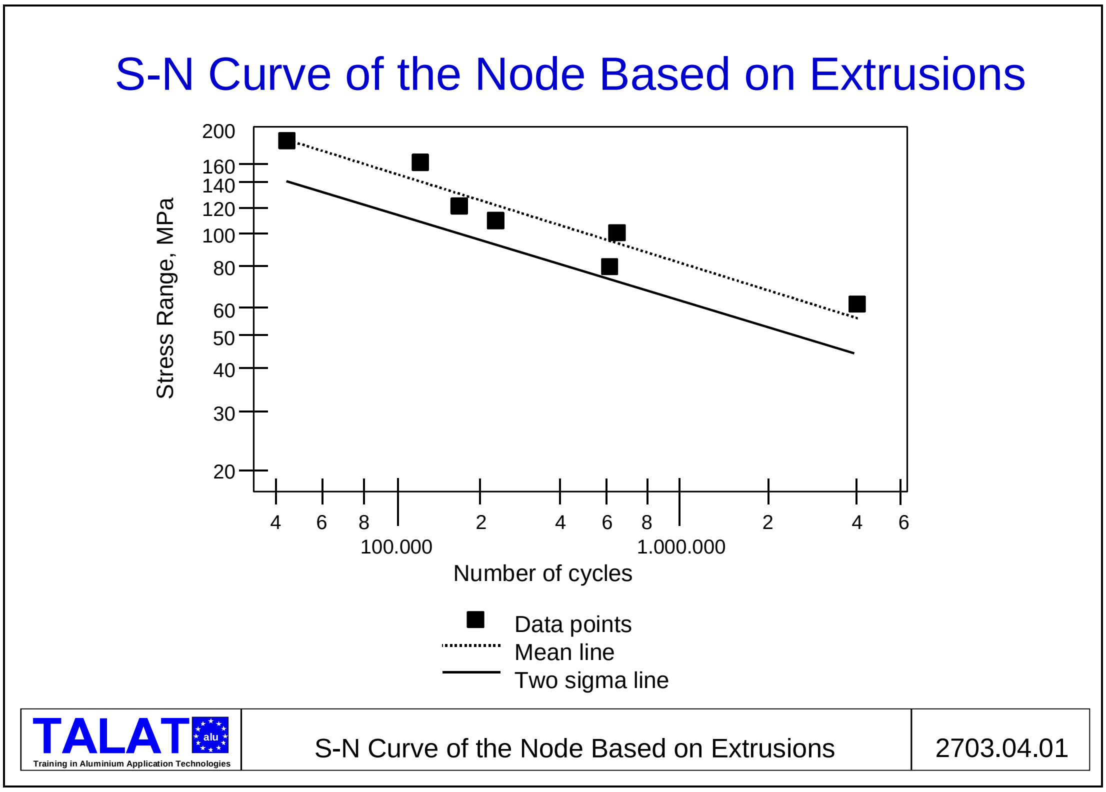
The nodes were extensively instrumented and fitted into a special rig for testing with a stress ratio of R = -1, equal compression and tension amplitudes. Seven nodes were tested at a wide range of constant amplitude fatigue loads to obtain a S-N curve.

The results from the testing showed:

- good agreement between the finite element analysis and the test results. The maximum stress concentration factor from the test was found to be 2.09. Due to a coarser transition from chord to gusset plate the finite element analysis gave a factor of 2.78.

- In all the test specimens the fatigue crack initiated on the transition from the gusset plate to the chord stub. For all the nodes except one, the crack started in the highest stress point at the heat affected zone outside the weld. For one node the crack started in the weld.

The S-N curve was then constructed on the basis of the actual stresses at the point of crack initiation (**Figure 2703.04.01**). The crack propagation life of the nodes was short compared to the crack initiation time and is therefore disregarded as part of the fatigue life of the structure.



In using the present results for estimating the fatigue lives of aluminium nodes, the following conditions should be fulfilled:

1. The geometry should be similar, stress raisers should be of similar nature. K- and Y-nodes may be cases where the present fatigue data is applicable.

2. The S-N curve is valid for butt weld connections and their heat affected zones.

3. The materials used, tube and plate materials as well as filler materials, should conform to those used for the tested nodes.

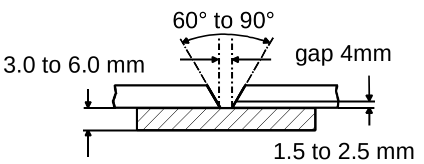
Node-To-Member Joint

To integrate the nodes in a space frame structure, dynamic tests were also required for providing a S-N curve on the one-sided buttweld representing the node to member joint. This weld was made using a permanent backing ring (**Figure 2703.04.02**).

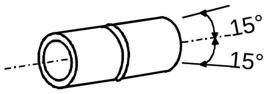
Fatigue Test Results

The results from the dynamic testing are presented in S-N curves (**Figure 2703.04.03**). It is important to note that the curves for the nodes are based on actual peak stresses at the crack initiation points, while the curves of the buttwelds are based on nominal stresses. The actual peak stresses at the crack initiation for the one sided butt welds are very difficult to measure.

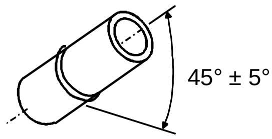
Joint Configuration and Welding Positions Used in Welding of Test Samples on One-Sided Buttwelds Using Permanent Backing



Pipe fixed: All	Permanent aluminium backing ring. 1st run to penetrate and fuse backing ring. 2nd and subsequent runs to fill and cap as required.



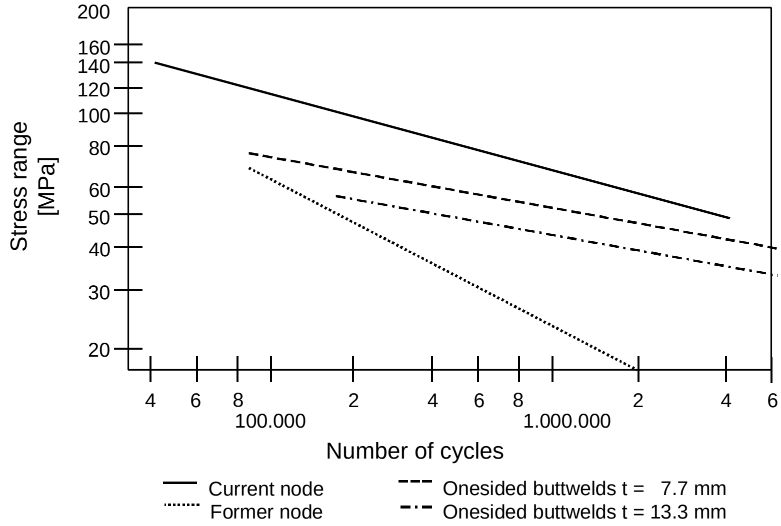
Test Position 1G
(Pipe horizontal and rotated)



Test position 6G
(Pipe inclined (45° ± 5°) and fixed)

TALAT alu Training in Aluminium Application Technologies	Joint Configuration and Welding Positions for One-Sided Buttwelds Using Permanent Backing	2703.04.02

S-N Curves for the Current Node, the One-sided Butt Welds
and the Former Node (Minus Two Sigma Lines)

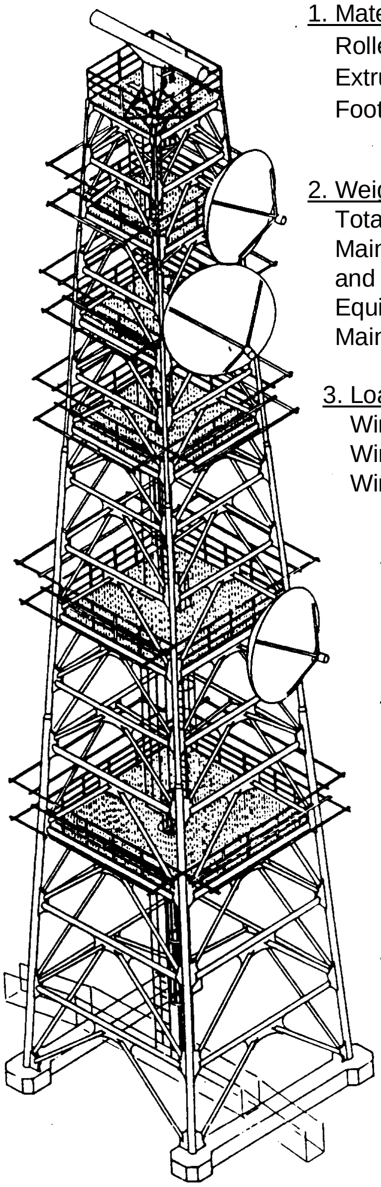


TALAT Training in Aluminium Application Technologies	S-N Curves for the Current Node, the One-sided Butt Welds and the Former Node	2703.04.03

2703.05 Practical Application of Results

Aluminium T-nodes based on extrusions are developed which are easy to reproduce and inspect, with a very low measured stress concentration factor (SCF) of 2.09 compared to SCF in a conventional node of at least 7. K- and Y-nodes have been analyzed, and capacity of such nodes are at least the same as for the T-node.

To evaluate the quality of the aluminium node, it was adopted in the design of an aluminium antenna tower comparable to the steel antenna tower at Oseberg A (see **Figure 2703.05.01**).



1. Material:
Rolled Products (Plates) Al-Mg 4.5 Mn
Extruded Products (profiles) Al-Si-1Mg
Footing Structure, Steel Part Grade I

2. Weights:

Total Weight	15,218 kg
Main Structure (Main Members and Node Plates):	9,225 kg
Equipment (Ladder, Grating Maindrails, Cable-Gates, Antennas etc.	5,993 kg

3. Loads:

Wind Rating: 3 sec Gust Wind = 68 m/ s	
Wind Load Resultant Normal to Face:	685 KN
Wind Load Resultant Diagonal:	744 KN

4. Design Life:
40 Years
Design Fatigue Factor: 2

5. Overall Dimensions

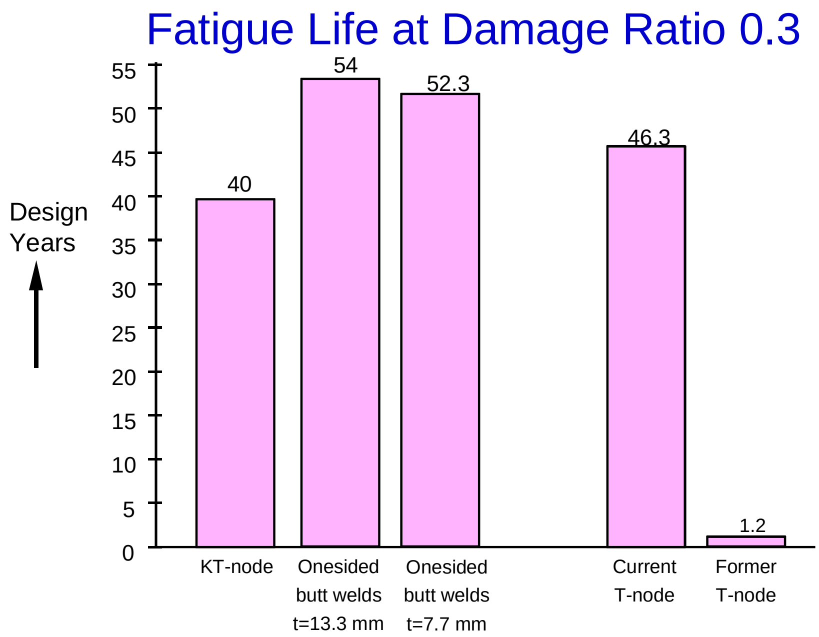
Total Height, From Footing Plate to C_L Top Horizontal Brace	36.00 m
Total Width at Base (Square) Max Dimension	7.50 m
Total Width at Top (Square) at Main Legs	2.87 m

6. Equipment:
Only Existing Equipment is shown, except for small Antennas and Lights

TALAT Training in Aluminium Application Technologies	Aluminium Antenna Tower 36 m	2703.05.01

As a consequence of the design work on the antenna tower, the nodes were optimized with respect to fabrication, low node complexity, splicing of members, transition between members of unequal size, transition to steel foundation, supports for secondary structures and equipment, access for inspection and finally weight and cost.

Conservative lifetime calculations using fatigue results from testing of nodes based on extrusions and node-to-structure joints, show that a lifetime of at least 40 design-years is easy to reach (**Figure 2703.05.02**)



TALAT Training in Aluminium Application Technologies | Design Fatigue Life for the Different Structural Details | 2703.05.02

The total weight of the aluminium tower using Oseberg A as a case, is 15 tonnes. This is a reduction of 56% or 19 tonnes compared to the Oseberg A steel communication tower in use.

The estimated delivery price of an aluminium structure in question was estimated to be at or below the delivery price of a similar steel structure.

All the work related to design and fabrication is made to make a concept for safe and cost efficient use of aluminium in structures exposed to fatigue loads.

Through this project, aluminium has become a feasible alternative to steel in dynamically loaded structures.

2703.06 List of Figures