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The Effect of Fabrication and Erection Tolerances on the Strength of Lattice Steel Transmission Towers

Working Group
B2.08

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Abstract

Transmission tower designs are based on structural models idealized as pin jointed frames, and assumed as perfect with all dimensions in accordance with the drawings. However, the fabrication and erection of towers is inevitably subject to tolerances which result in a certain level of imperfection that is considered acceptable in practice. In order to evaluate the structural reliability of the transmission line supports, it is necessary to evaluate the impact of these imperfections on the real tower strength. For this purpose, the same prototypes previously tested by the Cigré SCB2.08 TF4 have now been modeled with imperfect geometry. Afterwards, the member forces under the imperfect condition were compared to member forces under the normal design condition. The brochure shows that most of the fabrication and erection tolerances do not induce large forces on the tower bars as compared to external load effects.

1. Introduction

Currently the towers are fabricated and erected according to the dimensions indicated in the workshop drawings assuming certain limits of tolerance. As comprehensive standards do not exist for such tolerances, a questionnaire (see Annex TF2.4 Questionnaire: “Tolerances for steel supply / manufacture / assembly and erection”) issued and circulated by the task force Cigré TF2.4 of WGB2.08, in order to get an overview about the international industry practices. The values of tolerances received, are based on professional experiences on what is reasonable to be obtained and possible to be measured. The purpose of the study is try to quantify the effect on tower member forces of some identified fabrication tolerances, such as, length of members, position of holes, and erection imperfections like tower vertical inclination, foundation settlement, etc. During the studies carried out, it became evident the difficulties in mathematically model the reality. For this reason, the numerical simulations undertaken, in many circumstances, were just simplifications of reality somewhat unrealistic.

Three geometrically similar tower models having different degrees of determination from isostatic (determinate) to hyperstatic were used for this investigation (see table and Figure 1). These structures had already been analysed and load tested regarding predicted and measured member forces by the Cigré TF 4 of WGB2.08 (see Cigré Technical Brochure reference [1]).

For the purpose of this study, five groups of bars of the three prototype towers were selected for structural analysis:

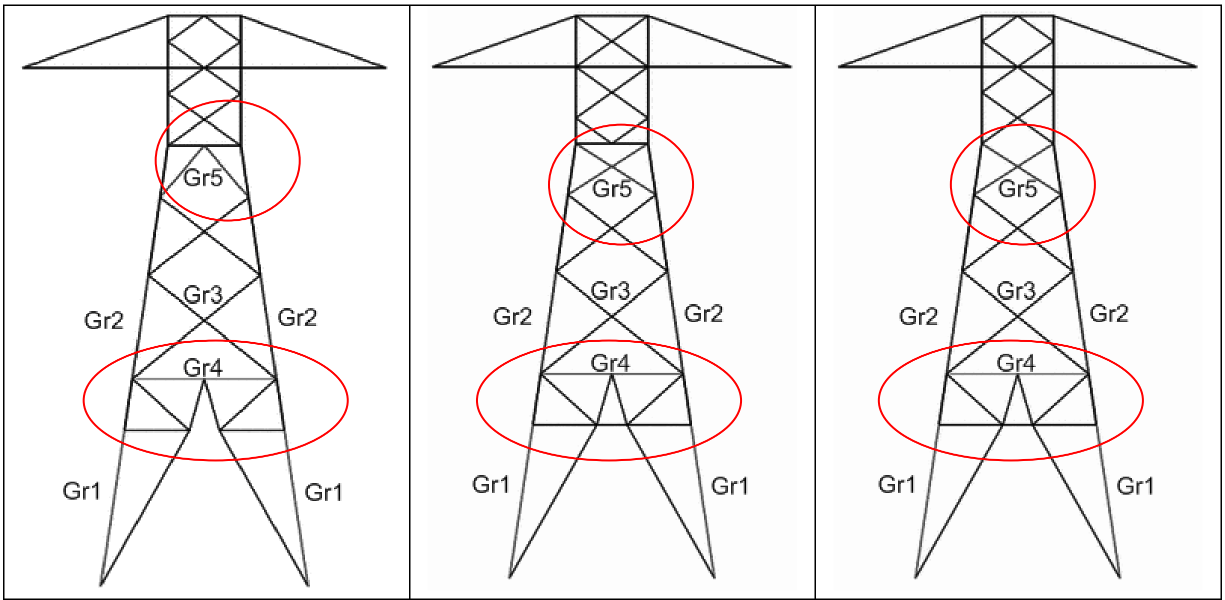
- Groups 1 and 2: Main members (Legs);
- Groups 3 and 5: Diagonal bracings;
- Group 4: Diaphragm bars.

For the structural analyses carried out, the advanced software named ADINA was used. As the ADINA program was able to reflect well the measured member forces of the former Cigré tested tower models, the following fabrication and erection tolerances were now simulated:

- Effect of member length,
- Effect of tower vertical inclination,
- Effect of foundation displacement.

The affects of a simulation of foundations displacement on a real-scale tower was tested in the above mentioned study of Cigré (as per Cigré report [2]). The results of the theoretically ADINA calculations were compared with the measured values during the tests. The actual internal forces (built-in member stresses) could be quantified and the importance of considering the erection tolerances justified.

Table 1: Characteristics of the three towers tested by Cigré



	TOWER 1			TOWER 2			TOWER 2A		
	Area (mm^2)	**Length (mm)**	**Type**	**Area (mm^2)**	**Length (mm)**	**Type**	**Area (mm^2)**	**Length (mm)**	**Type**
Group1	1060	3069	90x90x6.0	1060	3069	90x90x6.0	1060	3069	90x90x6.0
Group2	1060	2046	90x90x6.0	1060	2046	90x90x6.0	1060	2046	90x90x6.0
Group3	631	3193	65x65x5.0	631	3193	65x65x5.0	631	3193	65x65x5.0
Group4	480	1388	50x50x5.0	480	1388	50x50x5.0	480	1388	50x50x5.0
Group5	631	1320	65x65x5.0	631	1853	65x65x5.0	631	1853	65x65x5.0

Structure 1 **Structure 2** **Structure 2A**

Figure 1: Tower prototypes in the Test Yard

2. Imperfection in Member Length

2.1. Fabrication and erection tolerances in member length

As said before, to investigate the worldwide industry tolerances on fabrication and erection practices, a questionnaire (see Annex) was circulated among WG08 members.

According to the responses of that questionnaire, positions of holes are punched or drilled within 1mm of tolerance over the nominal value. Hole diameters for the tower bolts are oversized by 0.8mm. During the erection process, the oversized hole results in a fabrication tolerance on the member lengths of 1mm or less. This allowable fabrication imperfection was used in this exercise as the tower leg member length tolerance.

Still in accordance with such questionnaire, dimensions of the tower width are defined by erection tolerances of about 0.1% of the horizontal dimension of the tower base. For bracing members, length tolerances are about 0.15% of the member length.

2.2. Effect of fabrication and erection tolerances in member length

In order to evaluate the effects of fabrication and erection tolerances on member forces of actual member length, finite element analyses were performed with the ADINA software. The ADINA model was able to predict very well the forces in the members measured during the prototype tests previously performed by Cigré. The same models were used to determine the effect due to variation on member length. The lengths of members were varied as shown in the figure 2. Effects on the towers are represented on the figure 3.

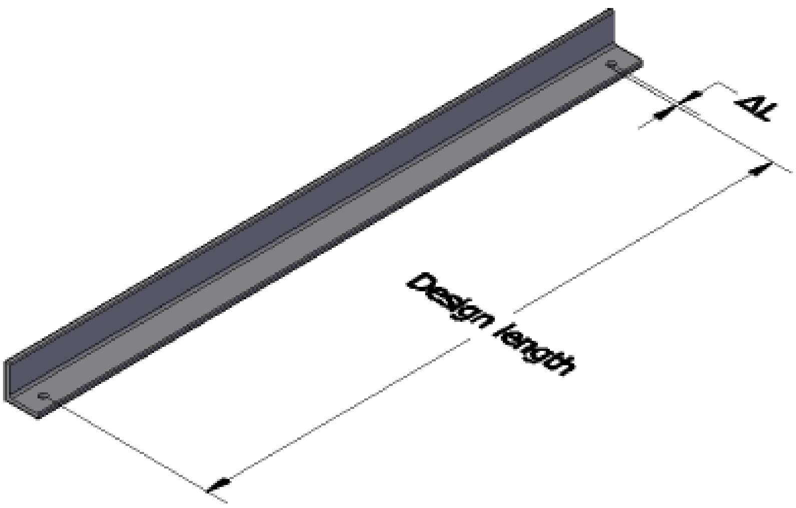


Figure 2: Member length variation

For the calculations, it was assumed that 99% of the members have a length as specified by the plans.

Assuming that the imperfections follow a normal distribution, this was used to determine a standard deviation of the imperfections and to run statistical analyses on the effect of tolerance on member length. The forces generated by those deviations are then compiled in order to get the standard deviation from each element.

Depending on the type of member (legs, bracings, diaphragms), the relevant results (ΔL = 1mm or ε = 0.15%) are retained. Thus, for the groups 1 and 2, the ΔL=1mm results were used since these groups are composed by leg members. The groups 3, 4 and 5 are composed of bracings and diaphragm bars, so the ε = 0.15% results were used.

Results of the relevant calculations are presented in the table 2 for the five groups of bars. In the column "imperfection", the member forces (in 99% of the time) are provided for each group according to tolerances (imperfections) of 0.15% for bracings and 1mm for leg members. The column labeled "Test" is the results measured during the real-scale test for load case 4D at the 100% level (see reference [1].

It can be seen that, in some cases, the forces are very small and in some other cases quite significant. According to the calculations carried out, the diaphragm bars are the members more loaded due to "members length tolerances." It should be remarked, however, that these members are not currently subjected to very high forces under external loads.

The model used in this exercise does not take into account bolts slippage and other factors, like clearances on holes that would allow for a significant decrease of the calculated loads. This will be further discussed in section 4. As the model here used is a truss analysis model, in the real structures, some of the loads will be redistributed in bending through the connections which will not behave as simple connections in all cases. As it has been seen when designing members, the bending moment can have a smaller influence in practice than calculations may prove, as bending moment effect is limited by yielding.

Finally, it is curious to note that tower 1 and 2A have responded generally better to the "member length imperfection effect" than tower 2. Maybe this can be explained by the higher level of statical indeterminacy of this tower.

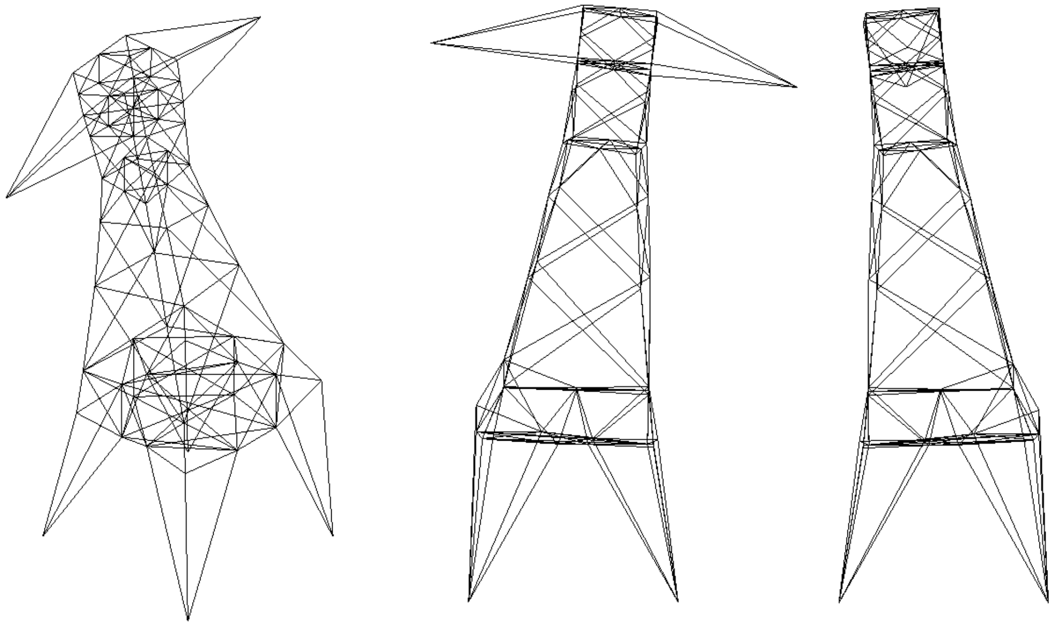


Figure 3: Effects of one member longer than nominal (displacements blown up for clarity)

Table 2: Member forces comparison – Length Tolerances Effect.

	Tower 1 (kN)			
	Dead load	**Test**	**Imperfection**	**Ratio**
Gr1	-2,53	-247,84	26,45	0,11
Gr2	-1,69	-227,97	24,88	0,11
Gr3	-0,06	-29,83	12,30	0,41
Gr4	-0,10	12,91	6,29	0,49
Gr5	-0,06	-62,13	10,63	0,17

	Tower 2 (kN)			
	Dead load	**Test**	**Imperfection**	**Ratio**
Gr1	-1,98	-210,35	34,48	0,16
Gr2	-1,70	-224,19	28,88	0,13
Gr3	-0,09	-32,92	78,47	2,38
Gr4	0,28	31,43	44,56	1,42
Gr5	-0,08	-48,05	66,52	1,38

	Tower 2A (kN)			
	Dead load	**Test**	**Imperfection**	**Ratio**
Gr1	-1,96	-211,63	34,35	0,16
Gr2	-1,54	-215,77	24,61	0,11
Gr3	-0,18	-42,16	11,88	0,28
Gr4	0,32	36,80	40,10	1,09
Gr5	-0,22	-61,07	10,06	0,16

3. Effect of Tower Vertical Inclination

3.1. Vertical Inclination Tolerances

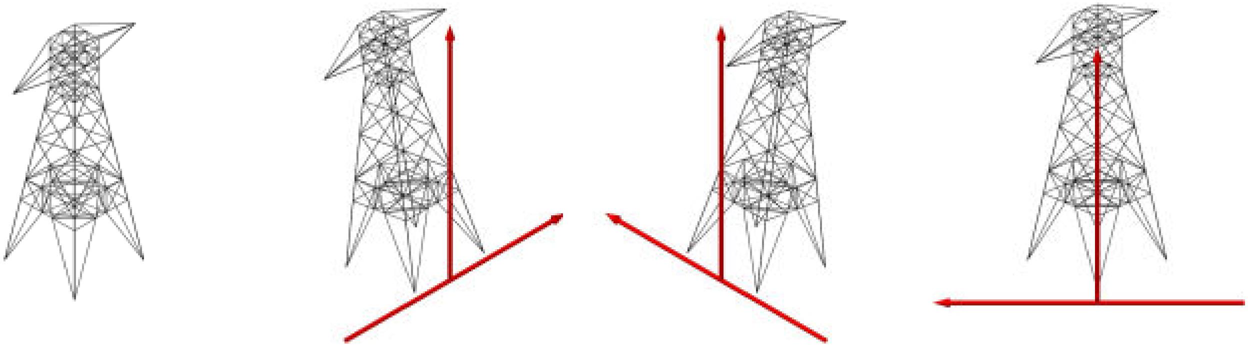
Instead of being on vertical position, towers can be vertically inclined. This can be mainly due to imperfect erection works or even the actual setting position of the foundations.

According to the answers received from the questionnaire, industry tolerances on tower vertical inclination are generally around 0.3% from vertical.

3.2. Numerical simulation

Using again the Cigré three prototypes, models were evaluated inclined by 0.3% from its vertical axis. Since those towers are 11 m high, the top of the structures were displaced 33 mm from the nominal position. While being inclined, the testing loads were applied to the towers. Inclinations on the three models were applied along the three main directions, along the axis of the conductor, perpendicular to the conductor, and 45 degrees from the longitudinal direction of the line (see figure 4). With all the loads applied (dead and external loads) non-linear analysis were performed taking into account the large displacement effects.

Results are shown at Table 3. From these results, it can be seen that the non-linear effects due to tower vertical inclinations are very small and negligible for practical purposes. This conclusion could be extended to other types of wide base towers, but the effect could be higher for narrow base ones. However, from these calculations it was felt that the 0.3% industry tolerance is satisfactory to limit second order effect in most of the cases. All results are based on load case 4D, as per Cigré experiment reference [1].



Normal | **Transverse** (Perpendicular to Conductors Axis) | **Longitudinal** (Along the Conductor Axis) | **45 degrees** (From the Conductor Axis)

Figure 4: Inclined tower

Table 3: Members forces (largest) from tower inclination

	Tower 1 (kN)			Tower 2 (kN)			Tower 2A (kN)		
	Test load (normal)	**Inclined**	**Ratio**	**Test load (normal)**	**Inclined**	**Ratio**	**Test load (normal)**	**Inclined**	**Ratio**
Group 1	-247,84	-248,23	1,002	-210,35	-210,60	1,001	-211,63	-211,62	1,000
Group 2	-227,97	-228,31	1,001	-224,19	-224,51	1,001	-215,77	-216,91	1,005
Group 3	-29,83	-29,84	1,000	-32,92	-33,17	1,007	-42,16	-41,35	0,981
Group 4	12,91	12,95	1,003	31,43	31,44	1,000	36,80	36,20	0,984
Group 5	-62,13	-62,13	1,000	-48,05	-48,40	1,007	-61,07	-60,35	0,988

4. Effect of Foundation Displacement

4.1. Tolerances on foundation position

According to responses from the questionnaire received by the members, the largest practical tolerances on foundation positions reported were of about 25 mm in the horizontal and/or vertical directions. Normal foundation setting tolerances limits can be seen at Cigré reference [3].

4.2. Numerical simulation

For a numerical simulation of a foundation displacement, one of the support legs has been moved in various positions:

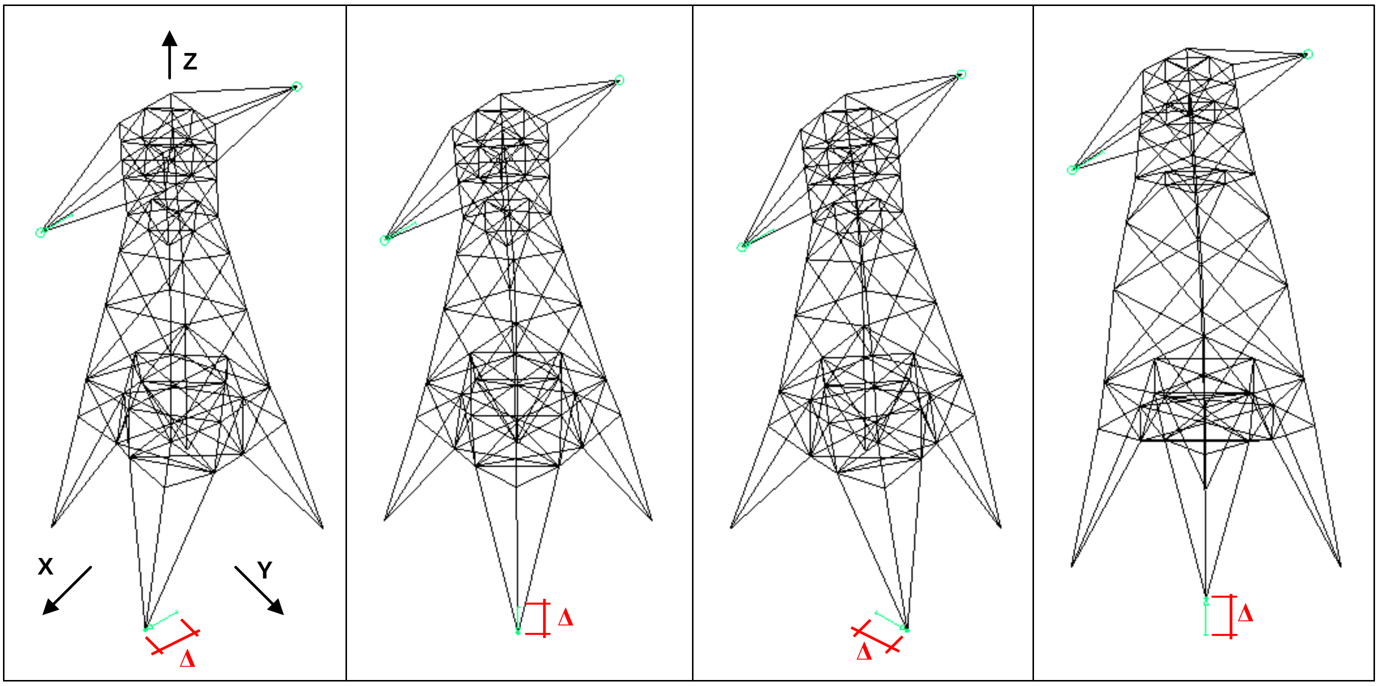
- ± 25mm perpendicular to the axis of conductor(±X)
- ± 25mm in the diagonal direction (±XY)
- ± 25mm in the axis of the conductor (±Y)
- ± 25mm vertically (±Z)

The foundation displacement effects are illustrated at Figure. 5.

The analysis carried out to account for the effects of large displacements were non-linear. Only one support leg is affected each time. The displaced leg is considered pinned like the other supports.

Table 4 shows the largest internal forces due to foundation displacement (in the column "highest"). For most of the members, the loads are quite high. The proper displacement combined with the proper loading can induce very high forces in the members. It is interesting to note that regardless of the tower types (1, 2 or 2A), the ratios are similar for each group. The only difference comes from the group 4 which is a diaphragm group, thus being sometimes difficult to predict, which is common for this member type.

The vertical displacements affect the towers much more than the horizontal ones.



Perpendicular to the Axis of the Conductor (±X) | **Diagonal Direction (±XY)** | **Axis of the Conductor (±Y)** | **Vertical Axis (±Z)**

Figure 5: Foundation displacement scenarios

Table 4: Member forces (largest) from foundation displacements

	Tower 1 (kN)			Tower 2 (kN)			Tower 2A (kN)		
	Test load (normal)	Analysis	Ratio	Test load (normal)	Analysis	Ratio	Test load (normal)	Analysis	Ratio
Group 1	-247,84	-428,50	1.73	-210,35	-385,30	1.83	-211,63	-416,81	1.97
Group 2	-227,97	-361,76	1.59	-224,19	-380,67	1.70	-215,77	-372,12	1.72
Group 3	-29,83	-38,86	1.30	-32,92	-45,45	1.38	-42,16	-53,19	1.26
Group 4	12,91	27,45	2.13	31,43	81,58	2.60	36,80	74,02	2.01
Group 5	-62,13	-80,63	1.30	-48,05	-66,27	1.38	-61,07	-77,15	1.26

4.3. Experimental approach

During the previous Cigré prototype tests, conducted in South Africa, a special device was constructed to simulate foundation vertical displacements. After theoretical analysis done by the WG08 group, it was concluded that:

- Prototype 2 should be selected (see Table 1 and Figure 1) for simulating such test due to its highest degree of hyperstaticity (indeterminate) or rigidity condition that could maximize the effects on the bar loads.

- Previous calculations had shown that only vertical foundation movements tending to force one foundation out of the plane of the other three will induce forces in the structure. For this reason, the most critical condition for the tower regarding foundation displacements (as per [2]) is differential “uplift or settlement” in only one of the tower legs. This way, one of the prototype 2 feet was raised and lowered during those tests (see figures 6 and 7).

- It was agreed that a maximum displacement of about 25mm “up and down” should be simulated since those values, according to the WG members professional experiences, reflected well the current industry practices. As per the previous calculation, failure on the lowest main member would occur when the foundation displacement would reach about 45 mm upward displacement.

- The other tower footings were considered to be rigid and, as such, does not represent reality; whereby, movement of the other footings would normally occur and consequentially redistribution of the tower member forces.

- It was also a common understanding that, the foundation displacement tests, should be carried out with the structure unloaded by external loads. This would permit a better interpretation about the impact of those effects isolated from the other loads.

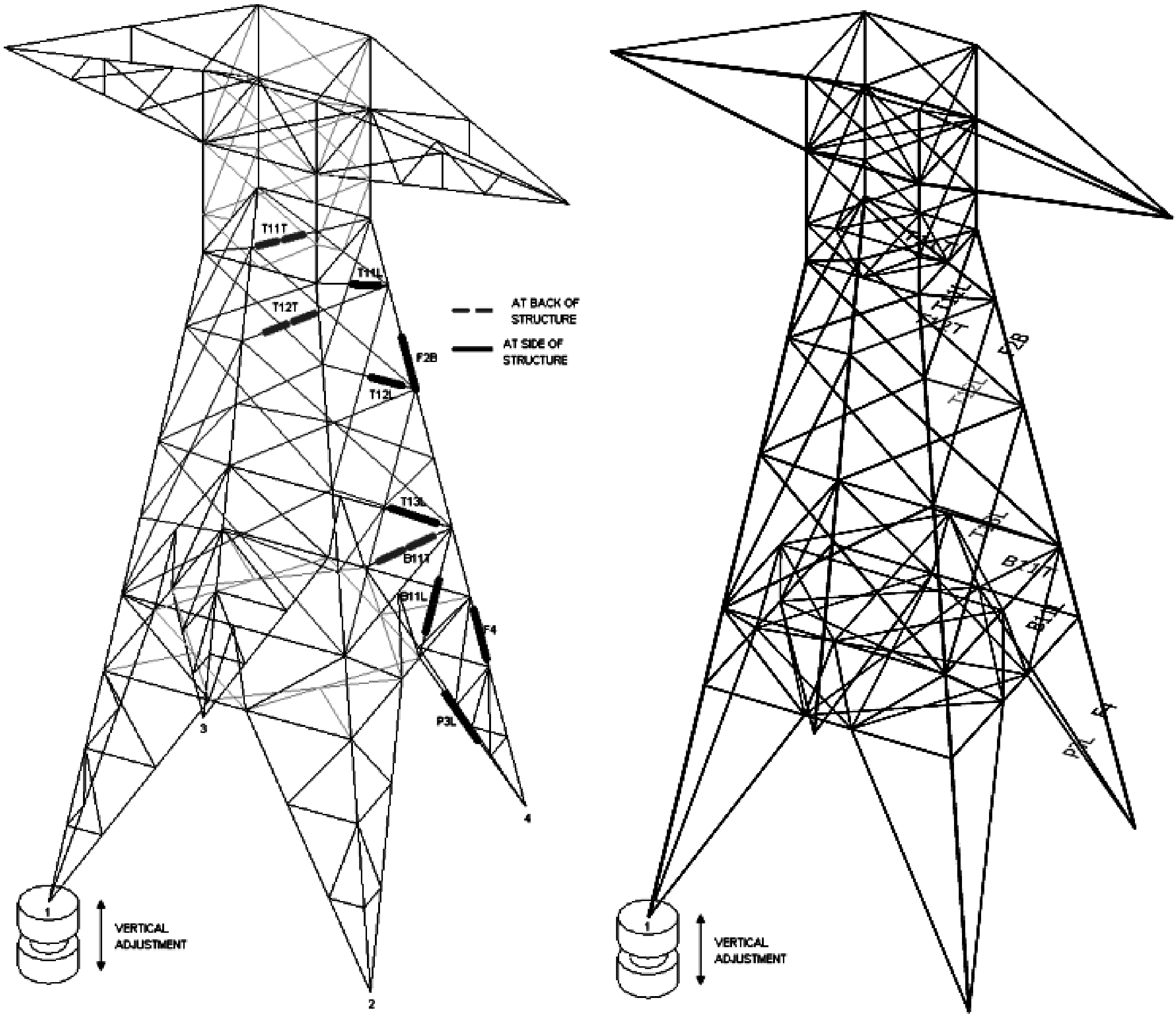


Figure 6: Prototype 2 vertical foundation movements

Figure 7: Device designed for foundation displacements

Table 5: Bar loads due to foundation vertical displacements

	Test (kN)		ADINA (kN)	
	Tension	**Compression**	**Tension**	**Compression**
F2B	70,55	-58,75	125,30	-124,04
P3L	13,62	-17,97	80,43	-65,66
F4	90,85	-82,70	152,16	-172,51
T12L	9,13	-1,99	15,86	-14,41
T13L	10,18	-0,39	11,50	-12,68
T12T	1,27	-7,49	15,52	-14,70
B11L	0,00	-10,00	17,64	-1,82
T11L	0,00	-15,99	17,03	-18,25
B11T	10,35	0,00	17,64	-1,82
T11T	15,18	-1,78	16,69	-18,65

It was therefore defined that, the main objective of the tests, would be to qualify the effects of the foundation “uplift and settlement movements” on several relevant tower members, which would be real time strain-gage monitored during the tests. Figure 6 shows the bars retained during those tests and their numerical corresponding structure elements.

Table 5 shows the highest values, both in tension and compression, reached by each monitored bar during the tests, as compared with those values obtained with the ADINA simulation.

It is important to remark that, as already commented on item 2.2, no “bolt slippage” or “clearances of holes” were taken into account for the theoretical simulations performed on this exercise. Therefore, the “load-reliever” effects exerted by the bolt slippage or the grips on joints, could not be accounted for during this analysis. As a consequence, the real structural behavior is not exactly as estimated by the calculations herein carried out by the ADINA simulation. Figures 8 and 9 show the “loading pattern” of the elements F2B and B11L. It is interesting to note that if the displacement is increasing or decreasing, the load values are not the same for the same vertical displacement. This effect is mainly due to the bolt slippages (and/or hole clearances movements) on joints which were not accounted for in the simulations. If taken into consideration, those effects would result in reduction on the tower stiffness (that is lower on the real structure than in the model) and therefore in lower internal forces in the simulation results. Also note the existence of non-uniform hysteresis behaviors of members as can be seen on Figures 8 and 9.

As a general trend, the maximum bar force values estimated by the software ADINA were higher than experimental values measured during the field tests. Figure 10 shows such comparisons for all the prototype 2 monitored members. It is important to note that for the leg members (F2B, F4) the simulated values are consistently higher than the experimental results, on average, about twice the measured values of member forces. For bracing elements, the simulated member forces could be as much as ten times the tested member force.

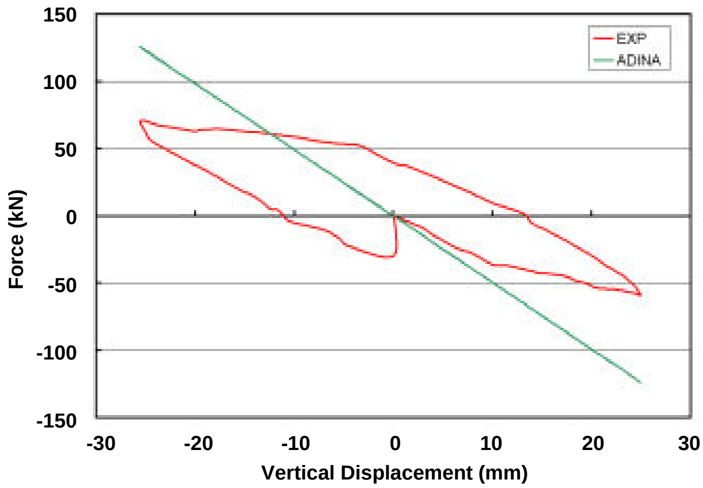


Figure 8: F2B loading pattern

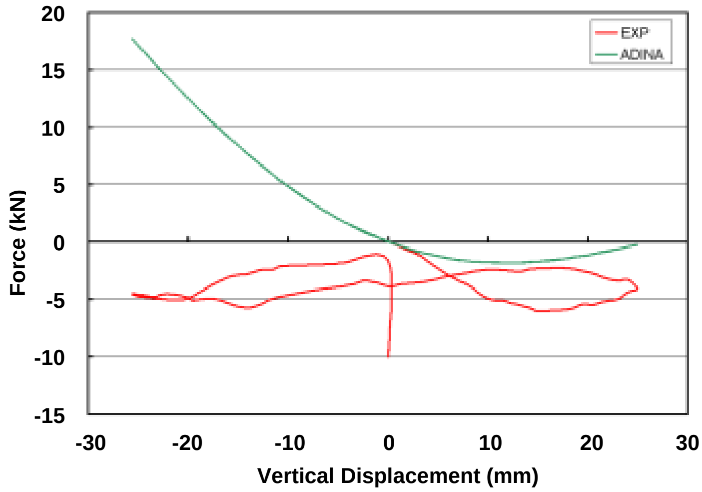


Figure 9: B11L loading pattern

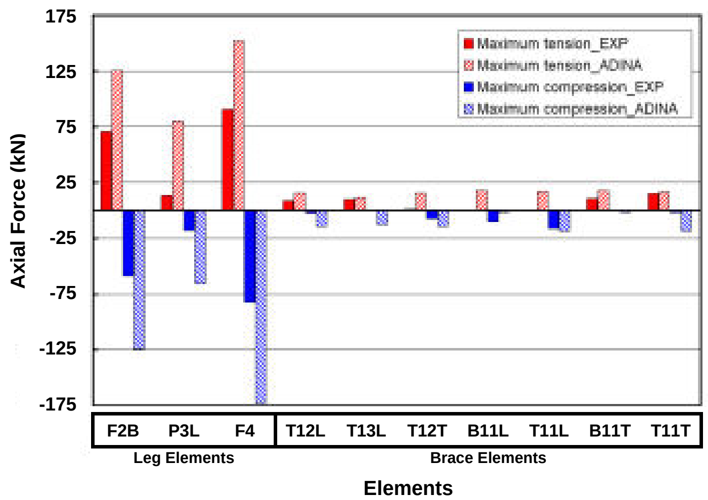


Figure 10: Simulated versus measured member forces – Effect of foundation displacement

5. Conclusions

The article presents the prediction of the effect of three types of fabrication and erection industry tolerances on tower member forces, namely allowable imperfection in member length, overall vertical tolerances of tower and foundation location or displacement.

Based on numerical simulations, field tests and comparison with the professional experiences, it is possible to conclude that the impact of the fabrication and erection industry tolerances can be relevant or not. It will strongly depend on the quality of fabrication and erection. The same tolerances that induce internal forces (built-in member stresses), can act as a load/stress reliever. To occur this, it is mandatory that the imperfections be compatible with the tolerances and that they are provided by good fabrication and erection practices.

Regarding the fabrication and erection imperfections studied in this exercise, it was possible to see that the variation on members length and the location (or displacement) of foundations may have significant effect on the actual member forces of the towers. Any how, it is important to remark that, towers are constructed of a ductile material capable of considerable plastic deformation. This implies that increased stresses in members due to lack of fit probably does not imply a corresponding reduction of the failure load of the structure as a whole.

It is clear, however, that tower inclination has much less or even no impact on increasing member forces of almost all kind of self supporting towers.

The ADINA simulation model using truss element and perfect hinged connections could not properly predict the behavior of bolt assembled members of lattice structures as analyzed in this exercise. In reality connections in towers usually have moment capacity and eccentricities which are not considered in structural models. This way bolt slippage and “clearance of hole” movements may play an important role to predict accurately the forces in members when performing any structural analysis on lattice towers.

Future researches should be focused on using real towers to check internal member forces after construction. These “built-in” member stresses could therefore be taken into account in a method where accuracy in fabrication and erection could be rewarded with higher strength factors than lower quality of fabrication and erection workmanship.

6. Acknowledgments

B2.08 Group recognizes the support received from Sherbrooke University, ABB and ESKOM for this investigation.

The convener thanks the reviewers N. Cuer and C. Thorn for their valuable work of revision and comments.

7. References

[1] Influence of the Hyperstatic Modeling on the Behavior of Transmission Line Lattice Structures.

[2] On the Structural Interaction Between Transmission Line Towers and Foundations.

[3] Foundation Installation – An Overview
Cigré Technical Brochure nr. 308

Annex

WG B2.08 TF2.4- Questionnaire

“Tolerances for steel supply / manufacture / assembly and erection”

Part A: Mill tolerances for equal and unequal angle sections and plates

Part B: Manufacture tolerances for nuts, bolts and washers

Part C: Tolerances for post-fabrication checks for equal / unequal angle and plate sections

Part D: Tolerances employed for the check assembly supports

Part E: Erection tolerances for supports

Tolerances for steel supply / manufacture / assembly and erection

B2-WG08-TF2.4

prepared by David Hughes

Introduction

When a tranmission line is designed employing probabilistic techniques it is necessary to have a knowledge of the strength (resistance) of all of its component parts (characteristic strength and associated standard of deviation). One of the main components of a transmission line are the supports (tangent towers and tension towers) and it is clear that our knowledge of their characteristic strength (Rc) and associated standard deviations (σ) is not sufficiently well known to enable the designer to make economies whilst maintaining the required level of risk-of-failure. IEC 826 assumes the coeffficient of variation (COV) for tangent towers is 10%; it is the intention of B2-WG08-TF2 to attempt to verify the suitability of this figure or establish a methodology of determining a more realistic value.

From raw steel to finished product various tolerance allowances are inherently built into the overall process and, principally, these are determined by economic consequences of their own. These tolerances include :-

a) tolerance limits for raw materials (steel sections / plates / bolts) received from the mill at the fabrication factory;
b) tolerances employed by the fabrication factory during the fabrication process;
c) tolerances employed during the check assembly of the support and, finally;
d) tolerances employed during the erection process (including those for foundation construction as well as tower erection).

All the tolerances, a) to d), will effect the overall strength of the finished product, namely the transmission line. To determine the magnitude of this effect it is necessary to determine what checks are, in fact, imposed during each of the above stages and what variations are considered permissible by the industry. Having this knoweldge will permit analysis of the estimated residual overall strength and COV of the tangent and tension supports and, hence, the transmission line itself.

B2-WG08 (TF2.1) has already published a paper covering item a) entitled "Variability of the mechanical properties of materials for Transmission Lines steel towers", published in ELECTRA No 189, April 2000 (please contact HughesDavid@PBWorld.com for a copy). This paper addressed the effect on support resistance from the actual variation of phyiscal and mechanical properties of equal and unequal angles as delivered to the fabrication factory (allowable variations stated by the supply standard and the actual variations as measured during the "Material Receipt" tests upon delivery to the factory. The paper was based on a limited survey of the materials delivered to one company in Brazil.

It is intended to expand the findings of TF2.1 from a local to a world-wide basis by the issue of this questionnaire.

This questionnaire is split into six parts:-

Part 1 : (this worksheet) - **Introduction, Definitions and Basic Reference Data relating to the respondee. (see below to complete initial data)**

Part 2 : Worksheet - "Mill Steel". The tolerances employed by the manufacturing Mill / supplier of the raw (black) steel to determine the acceptability of the steel being supplied. It is presumed the same limits will be applied by the end user / tower fabricator for acceptance of the raw material delivered to the factory.

Part 3 : Worksheet - "Bolt Supply". The tolerances employed by the bolt manufacturer to determine the acceptability of the nuts, bolts and washers being supplied. It is presumed the same limits will be applied by the end user / tower fabricator for acceptance of the material delivered to the factory

Part 4 : Worksheet - "Fabrication". The tolerances employed by the fabricator to determine the acceptability of the fabricated steel work (limited to the fabrication of angle sections). It is presumed the same limits will be applied by the end user for acceptance of the delivered material

Part 5 : Worksheet - "Assembly". The tolerances employed by the fabricator during the checks on the fabricated steelwork to determine the suitability of the steelwork detailing and the actual fabrication process. These checks are usually made on galvanised steelwork. It is presumed the same limits will be applied by the end user for acceptance of the delivered material to site

Part 6 : Worksheet - "Erection". The tolerances employed by the constructor / erector (or imposed by the customer) to determine the acceptability of the erected steel work. These tolerances include those tolerances employed during the construction of the foundations and the erection of the steelwork. It is presumed these same limits will be applied by the end user for acceptance of the final erected material that will be put into service.

IMPORTANT REQUEST

The questions asked in this questionnaire apply to the implementation of a quality control process which, normally, require records to be maintained of all achieved results. It is recognised the answers to this questionnaire will only provide the upper and lower tolerance bounds as dictated by others (standards, customer specifications, etc.) whereas the ACTUAL bounds could be determined from an analysis of the factory / contractor quality records.

THE ANALYSIS OBJECTIVES OF CIGRE B2-WG08-TF2.4 WOULD BE GREATLY ENHANCED IF YOU COULD MAKE YOUR FACTORY / CONSTRUCTION QUALITY CONTROL RECORDS AVAILABLE TO THE WORKING GROUP. PLEASE INDICATE ON THE FOLLOWING WORKSHEETS IS SUCH RECORDS CAN BE PROVIDED

Definitions

NOTE : the following definitions are applicable to all work sheets (specific definitions are given in each worksheet)
N/A = Information is NOT AVAILABLE (assumed default for items left blank)
N/R = Item is NOT RELEVANT or NOT APPLICABLE (give reasons)
All units are considered to be metric (dimension = mm; force = N) unless stated in "Other Definitions" below
Steel sections considered in this exercise are equal and uneaqual angle sections and plates only
Symbols with suffix ('), i.e. r2', indicate tolerances
The tolerances requested are those imposed by the mill, the fabrication works, the designer or by the customer / country utility during your normal process of structure fabrication for angles or bolts. These may be independent of those quoted by standards.

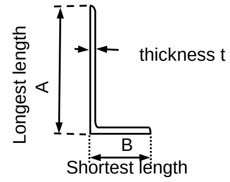
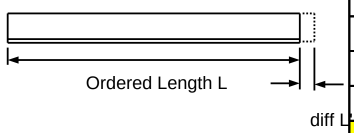
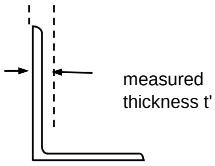
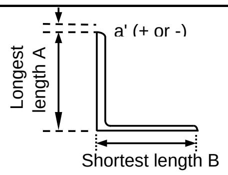
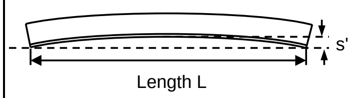
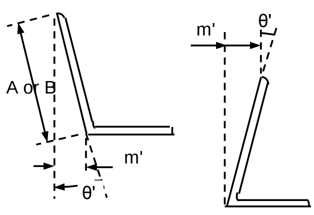
Respondee / Source	**(please enter here who you are and who you represent)**
Contact Details	**advise contact details for Respondee (email address, telephone number)**
Other Definitions	
State dimension units employed	**millimeters (mm) or inches (in)**
State force units employed	**Newtons (N), Kilogrammes force (kgf), Kips, or other**
Other definitions employed by respondee	**(advise the definitions for any other abreviations or symbols employed in your response)**

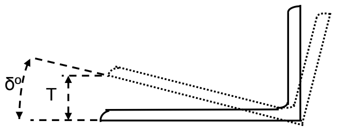
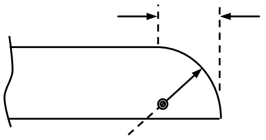
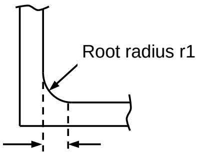
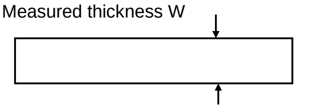
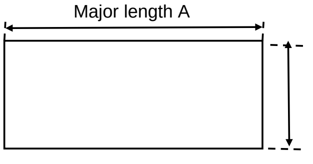
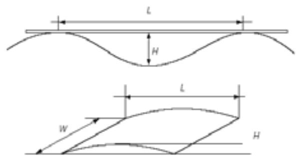
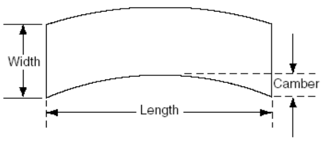
Tolerances for steel supply / manufacture / assembly and erection

B2-WG08-TF2.4

Part A

prepared by David Hughes

MILL TOLERANCES FOR EQUAL AND UNEQUAL ANGLE SECTIONS AND PLATES		**These tolerances refer to the acceptance criteria applied to the raw steel (black) received at the fabrication works from the supplier**					
Definitions	Designation method for angle sections All are nominal dimensions as ordered L = length of section delivered A = Longest flange B = shortest flange t = thickness of flange A and B m = mass per unit length						
Question : Do you apply any of the following tests / checks as supply acceptance criteria?	**Explanation / Sketch**	**Requested data (highlighted yellow)**					
		Applicable to:	Tolerance Limit (millimeters (mm)) Target value	min (-)	max (+)	Comments (& sampling rate)	Reference Standard, if applicable
What **material grades** do you normally employ for the angle sections for transmission line supports?	(note: if different tolerances are applicable to different material grades, please complete a separate sheet for each grade as applicable)	Grade :					
		Grade :					
		Grade :					
		Grade :					
PHYSICAL DIMENSIONAL ACCEPTANCE CRITERIA (state the sampling rate in comments column)							
Do you perform "appearance" Tests?	**Define acceptance / reject criteria**						
Give the min / max tolerances (L') on delivered angle section lengths (L)?		L <=					
		L <=					
		L <=					
		L <=					
		L <=					
		other/define					
Advise the min / max tolerances (t') on delivered angle section thickness (t)?		t <=					
		t <=					
		t <=					
		t <=					
		other/define					
Advise the min / max tolerances (a') on the length of the flanges (A and/or B) of delivered angle sections?		a or b <=					
		a or b <=					
		a or b <=					
		a or b <=					
		other/define					
Advise the min / Max tolerances (s') on the straightness of delivered angle sections (assumed to be function of ordered length L)?	 Please state how "straightness" is measured	L <=					
		L <=					
		L <=					
		L <=					
		other/define					
Advise the min / max tolerances (m' or θ' - state which employed) for "out-of-squareness" for delivered angle sections?		A or B <=					
		A or B <=					
		A or B <=					
		other/define					
		A or B <=					
		A or B <=					
		A or B <=					
		other/define					

Max / Min twist tolerance (δo' or T', state which) for delivered angle section over delivered length (L)		A or B <=					
		A or B <=					
		A or B <=					
		A or B <=					
		A or B <=					
		other					
Advise the min / max tolerances (r2' and Lt') for the "toe" dimensions (r2 and Lt) of delivered angle sections		A, B or t <=				for Lt'	
		A, B or t <=				for Lt'	
		other/define				for Lt'	
		A, B or t <=				For r2'	
		A, B or t <=				For r2'	
		other/define				For r2'	
Advise the min / max tolerances for the "root" dimensions (r1' and Lr') of delivered angle sections		A,B or t <=				for r1'	
		A,B or t <=				for r1'	
		other/define				for r1'	
		A,B or t <=				For Lr'	
		A,B or t <=				For Lr'	
		other/define				For Lr'	
Advise the min / max tolerances (w') on the mass per unit length (w) of delivered angle sections?	Nominal mass per unit length= w Actual mass per unit length = W Difference = w - W per unit length Tolerance w' = (w - W) / w (%)						
		other/define					
Advise the min / max tolerance (As') on the sectional area (As) of the delivered angle sections?	Nominal area = As Actual Area = AS Difference = As - AS Tolerance As' = (As - AS) / As (%)						
		other/define					
Advise the min / max tolerance (W') on the thickness (*W*) of the delivered plate sections?		W <=					
		W <=					
		W <=					
		W <=					
		other/define					
Advise the min / max tolerances (A') on the length (A x B) of the delivered plate sections?		B,A <=					
		B,A <=					
		B,A <=					
		B,A <=					
		other/define					
Advise the min / max tolerance (Sr') on the flatness (steepness ratio Sr) of delivered plate sections? (defined as H/Lx100% with plate resting under own weight)		W, L <=					
		W, L <=					
		W, L <=					
		W, L <=					
		other/define					
Advise the min / max tolerance (Cm') on the camber (Camber/Length in %) of delivered plate sections with nominal thickness/width of w ?		W, L <=					
		W, L <=					
		W, L <=					
		W, L <=					
		other/define					
Advise the min / max tolerance (Os') on the Out-of-square (Os' = *U / W x100%*) of delivered plate sections with nominal thickness/width of w?		w <=					
		w <=					
		w <=					
		w <=					
		other/define					

Do you impose any **other physical tolerance limitations** (e.g. area, surface area, etc.)?	Show / define	define	define				
MECHANICAL ACCEPTANCE CRITERIA. Which of the following mechanical tests do you perform for your factory acceptance tests? Please advise the sampling rate (explanation / sketch column) and acceptance criteria (tolerance limits / comments column)							
Tensile strength							
Minimum Yield strength							
Percentage elongation							
Impact strength (Charpy V-notch)							
Bend test							
Hardness (Brinell)							
Hardness (Rockwell)							
Others (define)							
CHEMICAL ACCEPTANCE CRITERIA. Which of the following chemical tests do you perform for your factory acceptance tests? Please advise the sampling rate (explanation / sketch column) and acceptance criteria (tolerance limits / comments column)							
Carbon Equivalent Value							
Carbon							
Silicon							
Sulphur							
Copper							
Nickel							
Chromium							
Manganese							
Phosphorus							
Molybdenum							
Vanadium							
Other? (state)							
Can you supply actual Quality Records for any of the above tests you have indicated have been performed? If Yes, please provide contact details (Name, email address, etc.) to facilitate the transfer of data, else please attach to your response.		Please advise contact details here or refer to data provided with your response					

Tolerances for steel supply / manufacture / assembly and erection

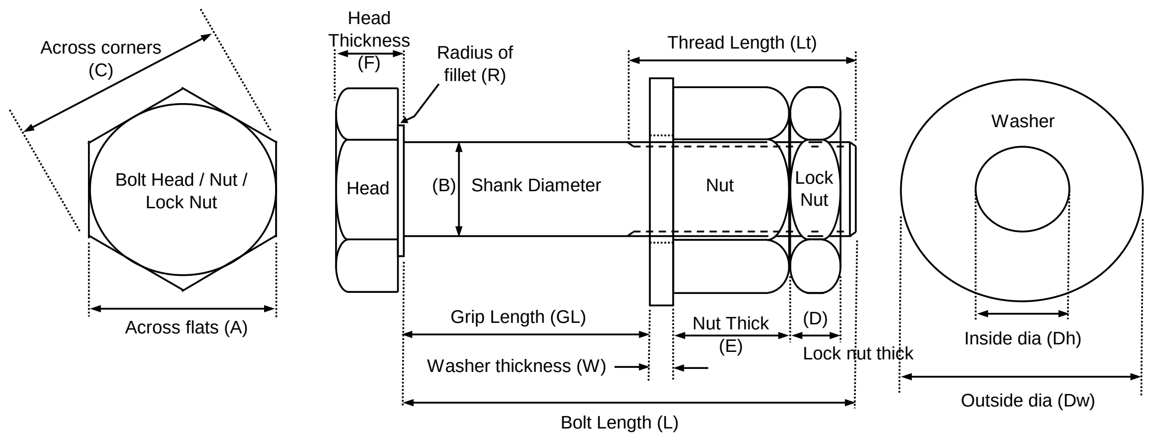
B2-WG08-TF2.4

Part B

prepared by David Hughes

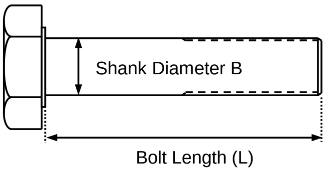
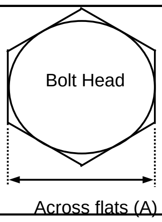
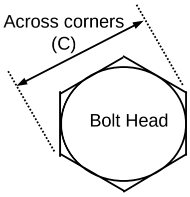
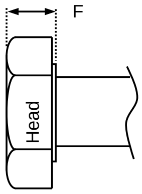
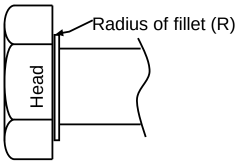
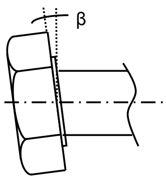
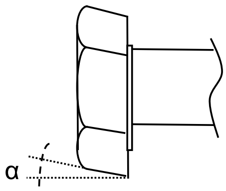
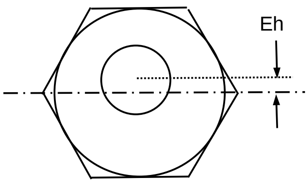
MANUFACTURE TOLERANCES FOR NUTS, BOLTS AND WASHERS

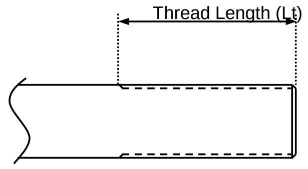
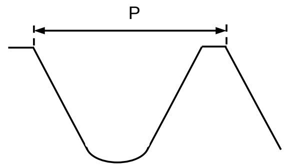
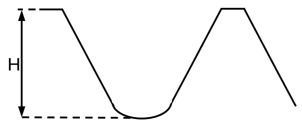
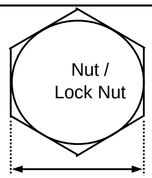
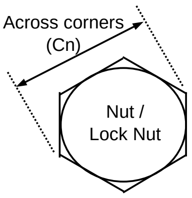
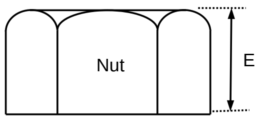
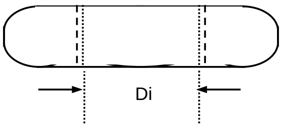
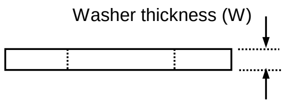
These tolerances refer to the acceptance criteria applied to black bolts, nuts and washers received at the fabrication works from the manufacturer.

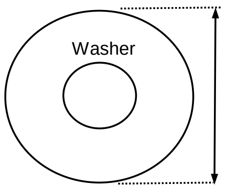
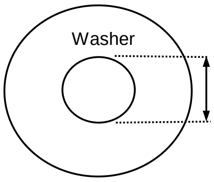
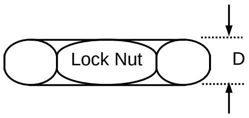


DEFINITION OF PHYSICAL DIMENSIONS EMPLOYED FOR BOLTS, NUTS, WASHERS AND LOCKNUTS

Question: Do you apply any of the following acceptance checks for bolt supply? If yes, advise tolerances used.	**Explanation / Sketch**	**Requested data (highlighted yellow)** Applicable to nominal dia?	Tolerance Limit (millimeters (mm)) Target value	min (-)	max (+)	Comments	Reference Standard, if applicable
Firstly : Please advise what nominal bolt diameters you normally employ for steel lattice transmission supports? State all applicable	Bolt shank diameter (unthreaded portion)	B =					
		B =					
		B =					
		B =					
		B =					
		others?					
2nd. What Bolt Grade(s) do you normaly employ for the above nominal bolt diameters?	(note: if different tolerances are applicable to different bolt grades please copy this worksheet and complete for each bolt grade as applicable)	for M					
		for M					
		for M					
		for M					
		for M					
		others?	State				
3rd. What nut locking method, if any, do you generally employ ? Advise if you use a combination of methods.	Tighten nut to torque ?						
	Split spring washer ?						
	Domed spring washer (Bellville) ?						
	Washers with locking tabs ?						
	Double nuts ?						
	Thread deformation ?						
	Swaged Nuts ?						
	Chemical locking material ?						
	Other ?						
PHYSICAL DIMENSIONAL ACCEPTANCE CRITERIA (state the sampling rate in comments column)							
Do you perform "appearance" Tests?	**Define**						

Advise the tolerances (L') for the nominal bolt length (L)		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
Advise the max / min tolerances (B') for each nominal bolt diameter (B)	See above	for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (A') applied for the **bolt head / nut / lock nut diameter across flats (A)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (C') applied for the **bolt head diameter across corners (C)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (F') applied for the **bolt head thickness (F)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (R') applied for the **radius of the head fillet (R)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (β') applied for the **bolt head taper (inclination of bearing surface)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (α') applied for the incination (α) of the **bolt head side faces**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (Eh') applied for the eccentricity of **bolt head to the shank (Eh)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				

For each nominal bolt diameter (B) advise the max / min tolerances (Lt') applied for the **threaded length on the bolt (Lt)** for use **<u>WITHOUT</u>** lock nuts but with washers		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (Lt'') applied for the **threaded length on the bolt (Lt)** for use **<u>WITH</u>** lock nuts and washers	See above	for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the thread pitch tolerance (P') for the required pitch (P)		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the thread height tolerance (H')		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (An') applied for the **nut / lock nut diameter across flats (An)**	 Across flats (An)	for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (Cn') applied for the **nut / lock nut diameter across corners (Cn)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (E') applied for the **thickness of the nut (E)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (Di') applied for the internal thread diameter **(Di)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
What are the standard washer thicknesses (W) and their respective tolerances (W') you normally employ for lattice steel transmission supports?		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				

For each nominal bolt diameter (B) advise the max / min tolerances (Dw') applied for the **outside diameter of the washer (Dw)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the max / min tolerances (Dh') applied for the **outside diameter of the washer (Dh)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
For each nominal bolt diameter (B) advise the **difference between the washer inside hole diameter and the bolt nominal diameter (Dh-B) together with associated tolerances**	as defined above	for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
Do you use locking devices? (if yes, state type and any tolerance limits applied for their supply)	Define						
		Type?					
For each nominal bolt diameter (B) advise the max / min tolerances (D') applied for the **lock nut thickness (D)**		for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
Advise how you calculate the allowable grip length (GL) for each nominal bolt diameter B (include all allowances, e.g. for galvanising thickness)	**Define**	for M					
		for M					
		for M					
		for M					
		for M					
		others?	Define				
Do you impose any **other physical tolerance checks / tests ?**	Show / define						
<u>MECHANICAL ACCEPTANCE CRITERIA</u>. Which of the following mechanical tests do you perform for your factory acceptance tests? If Yes, please advise the sampling rate (explanation / sketch column) and acceptance criteria (tolerance limits / comments column)							
Tensile test							
Shear test							
Wedge tensile test							
Proof stress test							
Proof load test							
Head percussion test							
Decarborized layer test							
Retempering test							
Surface hardness test							
Hardness test Vickers							
Hardness test Rockwell							
Hardness test Rockwell							
Hardness test Brinell							
Other test?	Define						

CHEMICAL ACCEPTANCE CRITERIA. Which of the following chemical tests do you perform for your factory acceptance tests? Please advise the sampling rate (explanation / sketch column) and acceptance criteria (tolerance limits / comments column)							
Carbon Equivalent Value							
Carbon							
Silicon							
Sulphur							
Copper							
Nickel							
Chromium							
Manganese							
Phosphorus							
Molybdenum							
Vanadium							
Other? (state)	define						
Can you supply actual Quality Records for any of the above tests you have indicated have been performed? If Yes, please provide contact details (Name, email address, etc.) to facilitate the transfer of data, else please attach to your response.		Please advise contact details here or refer to data provided with your response					

Tolerances for steel supply / manufacture / assembly and erection

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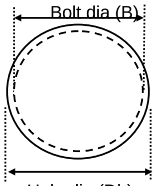
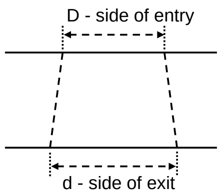
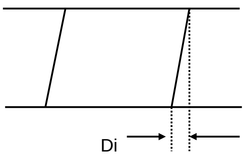
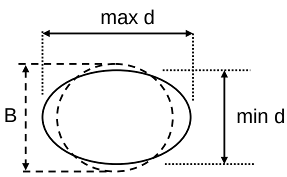
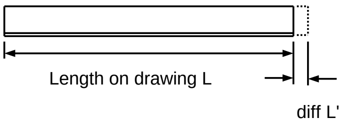
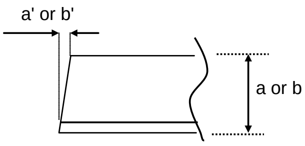
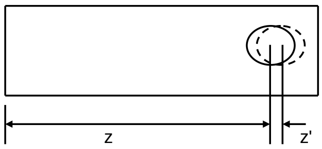
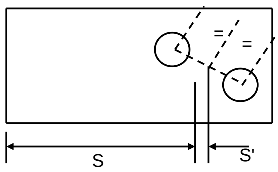
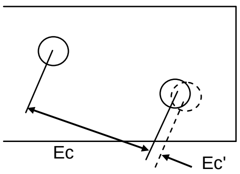
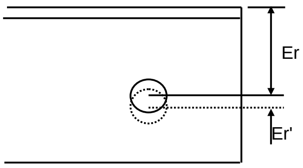
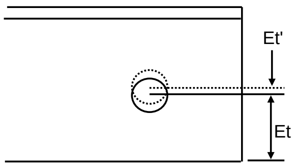
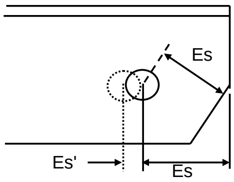
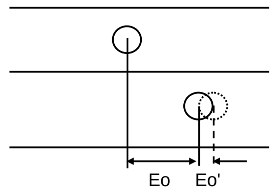
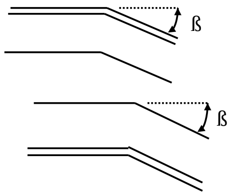
Part C

prepared by David Hughes

TOLERANCES FOR POST-FABRICATION CHECKS FOR EQUAL / UNEQUAL ANGLE & PLATE SECTIONS		**These tolerances refer to the acceptance criteria applied AFTER fabrication (before galvanising) for angle and plate sections**					
DEFINITIONS AS PER PREVIOUS WORKSHEETS							
		Requested data (highlighted yellow)					
			Tolerance Limit (millimeters (mm))				
Question: Do you apply any of the following tests / checks for fabrication acceptance?	Explanations / Sketchs	Applicable to:	Target value	min (-)	max (+)	Comments	Reference Standard, if applicable
HOLES / DIAMETERS							
Nominal bolt diameters previously advised to be employed for steel lattice transmission supports	(see Worksheet "Bolt supply")	-					
		-					
		-					
		-					
		-					
		-					
For each nominal bolt diameter (B) advise the **required hole diameter (Dh) and its tolerance (+/-Dh')**		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
State thickness / steel grade limits for making hole by punching or drilling for each nominal bolt diameter (B)	-	-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		other?	define				
Taper of punched holes, defined as the difference between the hole diameters on either side of the angle or plate section (d' = d-D)		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
Inclined axis of hole perpendicular to face of angle or plate section		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
Non-circularity of hole. For target hole diameter Dh, tolerances are: +dc' = dmax - Dh and -dc' = Dh - dmin		-	-				
		-	-				
		-	-				
		-	-				
		-	-				
		-	-				

Advise tolerances for any other hole / diameter checks performed	Define							
LENGTHS AND DISTANCES								
Overall length of member as per drawing (L) advise max and min tolerance (L') after fabrication		L<=						
		L<=						
		L<=						
		L<=						
		L<=						
		L<=						
Advise tolerance (a' or b') for the squareness of sawn or sheared ends of sections, (measured between the toe and heel of the angle)		a, b<=						
		a, b<=						
		a, b<=						
		a, b<=						
		a, b<=						
		a, b<=						
Advise the tolerance (z') for drawing dimension (z) to required center of hole		z <=						
		z <=						
		z <=						
		z <=						
		z <=						
		z <=						
Tolerance (S') to drawing dimension (S) to the (theoretical) center of a groups of holes		S <=						
		S <=						
		S <=						
		S <=						
		S <=						
		S <=						
Tolerance (Ec') to drawing dimension (Ec) between any two adjacent holes		Ec<=						
		Ec<=						
		Ec<=						
		Ec<=						
		Ec<=						
		Ec<=						
Minimum distance (Er) between a rolled edge (heel) and hole centre for each bolt diameter B and associated tolerance (Er') on actual guage line dimension (Er) as per drawing		-						
		-						
		-						
		-						
		-						
		-						
Minimum distance (Et) between a rolled edge (toe) and hole centre for each bolt diameter B and associated tolerances (Et') on actual guage line dimension (Et) as per drawing		-						
		-						
		-						
		-						
		-						
		-						
Minimum distance (Es) between a seared or cut edge and hole centre for each bolt diameter B and associated tolerances (Es') on actual dimension (Es) as per drawing		-						
		-						
		-						
		-						
		-						
		-						

Tolerance (Eo') of drawing dimension (Eo) between two holes in opposite faces of an angle section		-					
		-					
		-					
		-					
		-					
		-					
Advise tolerances for any other length or distance checks performed	Define						
ANGLES		Limits on achievable bend ß					
		Grade	ß°	a, b	t		
Maximum bend angles (ß°) for open or closed flanges - state angle or plate section limits (thickness (t), flange width (a,b) and or grade)							
Advise tolerances for any other angle checks performed	Define						
Can you supply <u>actual</u> Quality Records for any of the above tests you have indicated have been performed? If Yes, please provide contact details (Name, email address, etc.) to facilitate the transfer of data, else please attach to your response.		Please advise contact details here or refer to data provided with your response					

Tolerances for steel supply / manufacture / assembly and erection

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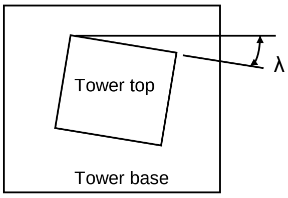
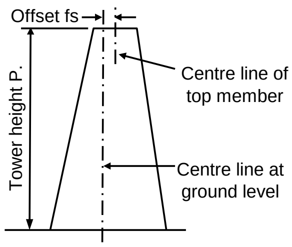
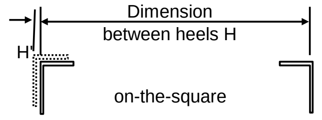
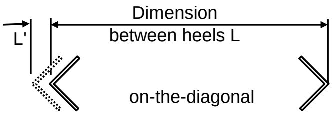
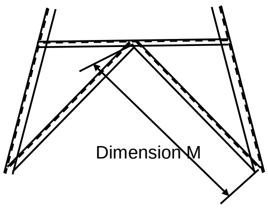
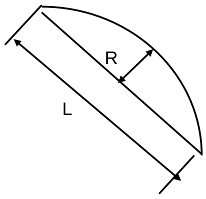
Part D

prepared by David Hughes

TOLERANCES EMPLOYED FOR THE CHECK ASSEMBLY SUPPORTS		This sheet refers to the methods and acceptance criteria employed AFTER fabrication AND galvanising for the test to check detailing / fabrication accuracy					
Question: Do you apply any of the following tests / checks for check assembly acceptance?	Explanation / Sketch	Requested data (highlighted yellow)					
		Applicable to Dimension?	Tolerance Limit			Comments	Reference Standard, if applicable
			Target	min (-)	max (+)		
GENERAL PROCEDURAL QUESTIONS							
Do you perform / require check assembly tests?							
If, yes, do you perform / require check assembly tests in the vertical or horizontal?							
Are the check assembly / trial tests performed with galvanised steel?							
Are the tests performed with the actual bolts (diameters, lengths and grades), washers and nuts to be supplied with the towers?							
What measuring device(s) do you employ to record dimensions? What accuracy is achievable ?							
What measuring device(s) do you employ to record levels ? What accuracy is achievable ?							
Are the above devices calibrated before each test ?							
If steel tapes are employed are allowances made for temperature and tension ?							
Are all bolts included in the assembly / trial test ?							
If all the bolts are not included under what conditions are some bolts not included ?							
Are the bolts tightened during the test ?							
If the bolts are tightened, what method or combination of methods is used at site ?	Maximum manual with no checks ?						
	Manual, with random checks using a calibrated tool ?						
	Calibrated power tool ?						
	Load indicating washer ?						
	Turn of nut method ?						
	Other ?						
If bolts are torqued identify the torque value (q) and its derivation (in comments column) plus the permitted tolerances (q') for each of the nominal bolt diameters and grades you previously identified.		-					
		-					
		-					
		-					
		-					
		-					

For horizontal tests…..							
How many faces do you assemble for horizontal assembly / trial tests ?							
Are adjustable (rigid) supports employed to maintain the tower centre-line as a true horizontal ?							
If supports are employed for horizontal tests, to what accuracy are they set ?							
What precautions are taken to minimise any effects from member or panel self-weight ?							
Are adjustable (rigid) supports employed to maintain the tower centre-line as a true horizontal ?							
If supports are employed, to what accuracy are they set ?							
What precautions are taken to minimise any effects from member or panel self-weight ?							
Advise what limits you suggest would necessitate an assembly / trial test to be conducted in the vertical.							
Twist (λ) between top and bottom of support expressed as a percentage of the support or panel height (P)		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
Tolerance (V') for "Verticality" of tower expressed as a percentage of the offset (fs) to the overall support height (P)		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
What tolerances are employed when setting the support footings?	Levels ?						
	Rake of leg joints to base ?						
	Twist of leg to support face ?						
	Face Heel-heel dimensions?						
	Diagonal Heel-heel dimensions ?						

For horizontal and vertical tests…….							
Identify the tolerance (H') on dimensions measured across tower faces (H -horizontal distance between heels of legs)		H<=					
		H<=					
		H<=					
		H<=					
		H<=					
		H<=					
Tolerance (L') on dimensions measured across tower diagonal (L -horizontal distance between heels of legs)		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
What tolerance (M') is permitted for dimensions (M) between connections as identified in the drawings ?		M<=					
		M<=					
		M<=					
		M<=					
		M<=					
		M<=					
Tolerance of "straightness" R' (expressed as percentage of member / panel length L) when assembled ?		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
Advise any other checks performed and the tolerances adopted for either horizontal or vertical check assembly / trial tests	Define						
Can you supply <u>actual</u> Quality Records for any of the above tests you have indicated have been performed? If Yes, please provide contact details (Name, email address, etc.) to facilitate the transfer of data, else please attach to your response.		Please advise contact details here or refer to data provided with your response					

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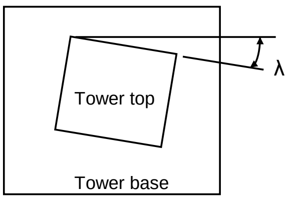
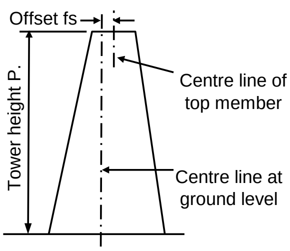
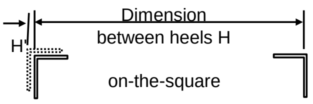
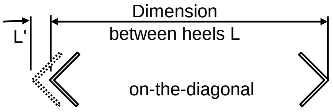
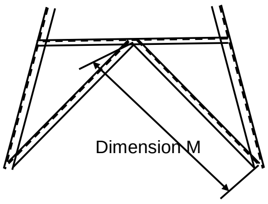
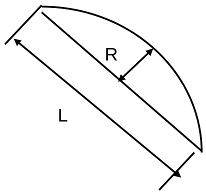
Tolerances for steel supply / manufacture / assembly and erection

Part E

prepared by David Hughes

Question	Explanation / Sketch	Requested data (highlighted yellow)					
ERECTION TOLERANCES FOR SUPPORTS		**These tolerances refer to the acceptance criteria applied PRIOR TO, DURING & AFTER erection of the support**					
DEFINITIONS AS PER PREVIOUS WORKSHEETS							
		Applicable to dimension?	Tolerance Limit Target	min (-)	max (+)	Comments	Reference Standard, if applicable
FOUNDATION STUB SETTING TOLERANCES							
What instrument is employed on site to measure :-	Levels at top of stub ?						
	Rake of leg joints to base ?						
	Twist of leg to support face ?						
	Face Heel-heel dimensions?						
	Diagonal Heel-heel dimensions ?						
What are the acceptance tolerances employed at site for ?	Levels at top of stub ?						
	Rake of leg joints to base ?						
	Twist of leg to support face ?						
	Face Heel-heel dimensions?						
	Diagonal Heel-heel dimensions ?						
TOLERANCES FOR TOWER ERECTION							
Are the checks you identify below made at different stages of support erection ? If yes, please define							
Are any of the following practices to correct mis-fit of holes permitted during erection? If yes, indentify the acceptable limits	Drifting (hammering a tapered probe into the holes to bring them in line) ?						
	Reaming (cutting the mis-fit hole(s) to permit bolt entry) ?						
	Site welding of holes and redrilling ?						
	Other ? Identify						
Twist (λ) between top and bottom of support expressed as a percentage of the support or panel height (P)		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
Tolerance (V') for "Verticality" of tower expressed as a percentage of the offset (fs) to the overall support height (P)		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
		P<=					
Identify the tolerance (H') on dimensions measured across tower faces (H -horizontal distance between heels of legs)		H<=					
		H<=					
		H<=					
		H<=					
		H<=					
		H<=					

Tolerance (L') on dimensions measured across tower diagonal (L -horizontal distance between heels of legs)		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
What tolerance (M') is permitted for dimensions (M) between connections as identified in the drawings ?		M<=					
		M<=					
		M<=					
		M<=					
		M<=					
		M<=					
Tolerance of "straightness" R' (expressed as percentage of member / panel length L) when assembled ?		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
		L<=					
If the bolts are tightened at site, advise what method is used ?	Maximum manual with no checks ?						
	Manual, with random checks using a calibrated tool ?						
	Calibrated power tool ?						
	Load indicating washer ?						
	Turn of nut method ?						
	Other ?						
If bolts are torqued identify the torque value (q) and its derivation (in comments column) plus the permitted tolerances (q') for each of the nominal bolt diameters and grades you previously identified.		-					
		-					
		-					
		-					
		-					
		-					
Advise any other checks performed and the tolerances adopted for either horizontal or vertical check assembly / trial tests	Define						
Can you supply actual Quality Records for any of the above tests you have indicated have been performed? If Yes, please provide contact details (Name, email address, etc.) to facilitate the transfer of data, else please attach to your response.		Please advise contact details here or refer to data provided with your response					