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The effects of local joint flexibility on the reliability of fatigue life estimates and inspection planning

Prepared by **MSL Engineering Ltd**
for the Health and Safety Executive

OFFSHORE TECHNOLOGY REPORT

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The effects of local joint flexibility on the reliability of fatigue life estimates and inspection planning

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HSE BOOKS

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EXECUTIVE SUMMARY

Introduction

MSL Engineering Limited (MSL) has prepared this report for the Offshore Safety Division of the Health & Safety Executive (HSE). The report relates to a study of the effects of linear-elastic local joint flexibility (LJF) on fatigue life predictions for offshore steel jacket structures.

Objectives

The objectives of the study, in addition to evaluating the effects of LJF on fatigue life predictions, include an assessment of their impact on platform inspection planning.

Scope

A conventional, rigid-joint, spectral fatigue analysis has been carried out on Shell's Leman CD Platform. The platform was installed in the Southern North Sea in June 1970, in 34m of water. Conventional fatigue analysis indicates numerous joints with fatigue-lives below 10 years. Results from underwater inspection of 46 joints, however, show that only two joints have crack indications. The fatigue analysis was repeated with local joint flexibility explicitly modelled in the analysis. The resulting fatigue life predictions were then compared with the rigid-joint analysis and with the inspection data.

Summary of Results

The results of the spectral fatigue analysis using the flexible joint structural model are presented Section 4.4. The results show that, in all cases, the fatigue-life predictions have increased compared to the rigid-joint analysis. The factor on life afforded by the implementation of LJF varies depending on the location of the joint within the structure. This factor is a ratio of the life calculated using flexible joint modelling to the life calculated using a rigid-joint model. The average factors on life for each of the framing components considered are as follows:

(i)	Transverse frames (A to F):	19.3 factor on life
(ii)	Longitudinal frames (1 &2):	9.2 factor on life
(iii)	Horizontal framing (-24' elev.):	8.0 factor on life

Impact on Inspection Planning

The impact on platform underwater inspection planning is discussed in Section 5, where two main conclusions are drawn, namely:

(i) The implementation of LJF in the fatigue analysis reduces the requirement for underwater inspection by approximately 75%.

(ii) Two joints have been found to have crack indications during underwater inspections of the Shell Leman platform. Both joints are identified as requiring inspection based on the LJF fatigue analysis.

Conclusions

The following conclusions have been identified from this study;

- The findings of this study support the view held by industry that conventional rigid joint fatigue analysis under-predicts fatigue life.
- It is seen that implementing joint flexibility allows for a more accurate fatigue life prediction and closer agreement with results of underwater inspections.
- The use of LJF can assist in the overall optimisation of inspection planning. This is particularly important for older structures as newer structures would normally be designed to have minimum fatigue lives that were much higher than the intended service life (e.g. 10 times required life).

However, it should be noted that the data set is limited (i.e. one structure) and further correlation with other types of structures to consider the influence of parameters such as platform vintage, design basis and framing configuration which also exhibit fatigue cracking would be required. Also other uncertainties within the fatigue recipe, such as uncertainties in the loading, not considered within the scope of this study may play an important role in the fatigue life predictions.

Furthermore, it should be emphasised that a number of elements are considered within the inspection strategy and that the use of LJF is one element that can be of use in determining this.

CONTENTS

1. INTRODUCTION

The report describes a study of the effects of linear-elastic local joint flexibility (LJF) on fatigue life predictions for an offshore steel jacket structure. The objectives of the study, in addition to evaluating the effects of LJF, include an assessment of their impact on platform inspection planning.

In Section 2 of the report the background to the study describes the present practice for prediction of fatigue lives and discusses the efforts exerted by industry, over the last 20 years, to better understand the fatigue behaviour of structures in the offshore environment. Despite the efforts described in Section 2, it is recognized within the offshore community that fatigue-life predictions for steel jacket structures tend to under-predict the lives of the joints. Comparisons between observed and predicted fatigue cracks[1] indicate that, even using more refined fracture-mechanics based prediction methods, fatigue-lives are being under-predicted by up to 18 times for certain structural components and by a factor of at least 3 for main framing elements of steel jackets.

The objectives of the study have been met by performing both rigid-joint and flexible-joint fatigue analyses on a Platform located in 34m of water in the UK sector of the Southern North Sea. The structure was installed in 1970 and has a service life of 30 years. Based on the results of a spectral fatigue analysis undertaken in 1990[2] the platform has numerous joints with predicted lives of less than 10 years. Section 3 contains a description of the platform, and describes the rigid joint fatigue analysis including a comparison of the predicted fatigue lives with those calculated in the previous analysis, Reference 2. The flexible-joint fatigue analysis is described in Section 4 and the fatigue-life predictions are presented and compared with those from the rigid-joint analysis.

Results from underwater inspections, including magnetic particle inspections (MPI), of forty-six joints, some with repeat inspections, have been evaluated in light of the fatigue-life predictions from the flexible-joint analysis. The impact of the effects of LJF on inspection planning for the platform is discussed in Section 5.

Section 6 summarises the findings from the study and discusses conclusions that may be drawn from the results.

2. BACKGROUND TO THE STUDY

Offshore steel jacket structures consist primarily of tubular members and associated joints, which are formed by the intersection of brace and chord members. The complex geometry at joint intersections results in stress concentrations of varying intensity. Wave loading causes fluctuations in stresses around the intersections, potentially leading to fatigue-induced crack growth and ultimately failure. Fatigue failure is defined as the number of stress cycles, a function of time, taken to reach a pre-defined failure criterion. Fatigue failure analysis is not a rigorous science and the idealisations and approximations inherent in it prevent the calculation of absolute fatigue lives. Nevertheless, the prediction of fatigue lives is essential for the safe life-cycle management of an offshore installation.

The industry-standard approach to fatigue analysis must address four specific issues:

(i) The operational environment of a structure and the relationship between the environment and imposed forces in a structure.

(ii) The internal stresses at a critical point in the structure induced by external forces acting on the structure.

(iii) The time to failure due to the accumulated stress history at the critical point.

(iv) The definition of ‘failure’ used in design.

An examination of the four areas above proves instructive:

(i) The definition of operational environment lies within the domain of metocean investigations, which define wave scatter diagrams, periods, etc. Wide ranges of metocean investigations have been conducted over the past two decades.

(ii) The calculation of external forces acting on the structure requires application of Morison’s equation together with a suitable wave theory that permits conversion of the wave particle velocities and accelerations to externally applied forces. This area, inclusive of definition of drag and inertia coefficients, has received significant attention by hydrodynamicists over the past two decades.

(iii) System FE analysis provides a suitable tool for the derivation of nominal section stresses along component elements within the structural model. The level of accuracy depends on the ability of the model to adequately capture actual behaviour. The nominal section stresses must be amplified by an appropriate factor (SCF) to account for geometric stress concentrations.

(iv) The time to failure and definition of failure has seen an investment by HSE and industry exceeding £30m over the past two decades to establish experimentally derived S-N curves across a range of parameters.

Excluding fabrication defects, a review of available information reveals that the difference between prediction and observation may be due to one or more of the following parameters:

(i) Wave kinematics in the splash zone

(ii) Wave spreading, at least for Southern North Sea (SNS) structures
(iii) Hydrodynamic loads
(iv) Deterministic versus stochastic wave modelling
(v) Pile-soil flexibility
(vi) Stress concentration effects
(vii) Local Joint Flexibility (LJF)

Of the above parameters, discussions with industry reveal that LJF effects are likely to be of most significance.

Extensive test data have demonstrated that all tubular joints possess elastic flexibility, which varies depending on joint type, geometry and loadcase. It is generally recognised that the amount of brace rotation required to shed in-plane and out-of-plane moments at the joint is small and consistent with the imposed rotations from low amplitude waves, which, in the main, dominate fatigue life consumption. The moments, in practice, would therefore be expected to be shed from the joints and be amplified at the brace member mid-span location.

Structural engineering mechanics suggests that, in essence, representing the joints with finite linear elastic flexibility (i.e. an accurate reflection of the way joints behave in practice) instead of no flexibility (i.e. infinitely stiff, typical present-day practice, inaccurate reflection of joint response) would result in a reduction of acting loads at the joints, with a commensurate increase in member loads to maintain equilibrium.

The platform selected was considered suitable for the purpose of this study on the basis that it had been in-service for 30 years and has predicted fatigue lives for many of its joints of less than 10 years. More importantly during this time several inspections have been conducted at certain intervals, including visual and MPI inspections of the same joints, the details of which are given in Appendix A. Of the fifty-three inspections (using MPI) carried out during the service life of the structure, three have given crack-like indications on two joints. One of the cracked joints, identified during the 1987 inspection and confirmed two years later, is located amongst the horizontal conductor guide framing at elevation –24' (joint 5405). The other crack indication was found on longitudinal frame 1 (joint number 5401) at the intersection with transverse frame D, also at -24' elevation. This indication is described in the inspection report as a lack of sidewall fusion and was removed by local grinding to a depth of 4mm. It should be noted however that the indication was not found on earlier inspections of the same joint.

3. RIGID JOINT FATIGUE ANALYSIS

3.1 Platform Description

The Platform is an existing structure located in 34m of water in the UK sector of the Southern North Sea. The structure was identified as a good candidate for the study for a number of reasons, as follows:

(i) The platform was installed in 1970 and has a service life of 30 years.

(ii) Based on the results of a spectral fatigue analysis undertaken in 1990[2] the platform has predicted lives of less than 10 years for numerous joints.

(iii) A total of fifty-three MPI inspection results are available, covering 46 different joints. Therefore, data on repeat inspections are available.

The platform is a wellhead platform. It supports twenty, 26in. diameter, conductors. The platform substructure is a twelve-legged steel jacket in a 6 x 2 array. The jacket is braced with single diagonals between four levels of horizontal framing in the two longitudinal frames and with inverted K-bracing in the six transverse frames. The jacket supports a number of appurtenances including a boat landing, 6 drainpipes, barge bumpers, riser inspection platforms, jacket walkways and sacrificial anodes. The jacket and appurtenances weigh 927 tonnes in air.

The foundation comprises twelve, 36 in. diameter piles, driven through the legs. The wall thickness of each pile increases from 1 in. to 1.25 in. at the mud-line. Total pile weight is 893 tonnes. The piles extend above the jacket to support a module support frame, which, in turn, supports the twin deck topsides structure. The topsides include an accommodation module, helideck and wellhead facilities and has an operating weight is 2276 tonnes including a live load allowance of 512 tonnes.

3.2 Structural Model

In 1990, Shell commissioned Wimpey Offshore to carry out a static spectral fatigue analysis of the platform[2]. In the present fatigue analysis every effort has been made to ensure consistency with the Wimpey structural model to allow verification of the predicted fatigue lives via comparisons with those presented in the Wimpey report. Consistent with this objective, the topsides, jacket, appurtenances and the foundation system were all modelled in the manner described in the Wimpey Report[2].

The SACS computer software suite was used for the present fatigue analysis. A three-dimensional isometric of the SACS[3] model is shown in Figure 3.1. Two-dimensional plots of the jacket frame elevations and horizontal framing plans are included in Appendix B.

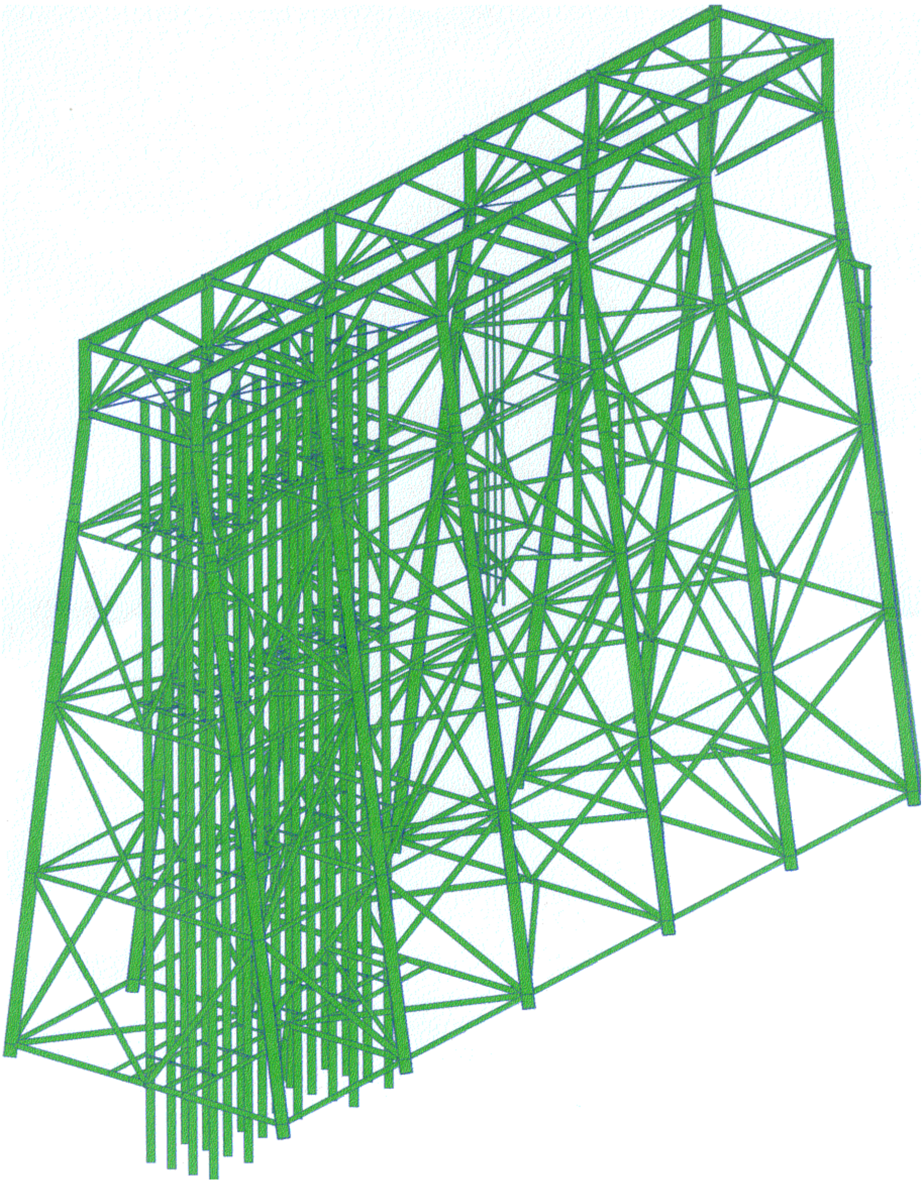

Figure 3.1
3D Isometric of the Structural Model

3.3 Analysis Parameters

As with the structural modelling, the representation of the hydrodynamic loading was selected consistent with that used in the Wimpey analysis. The data used is summarised below.

Water Depth

The water depth used in the analysis was 35.4m. This is made up of the water depth of 34.0 m, to L.A.T, plus an adjustment of 1.4m from L.A.T to M.S.L.

Marine Growth

The marine growth profile used for all members is given in Table 3.1.

Table 3.1
Marine Growth Profile

Elevation level		Marine growth Thickness
From	To	
L.A.T +2.0m	L.A.T -2.0m	125 mm on radius
L.A.T -2.0m	L.A.T -4.0m	100 mm on radius
L.A.T -4.0m	L.A.T -6.0m	75 mm on radius
L.A.T -6.0m	Mud-line	50 mm on radius

Wave Loading

A one-year return period wave was used, consistent with that used in the Wimpey analysis. The wave heights and frequency rosette reference to cardinal platform direction is shown in Figure 3.2

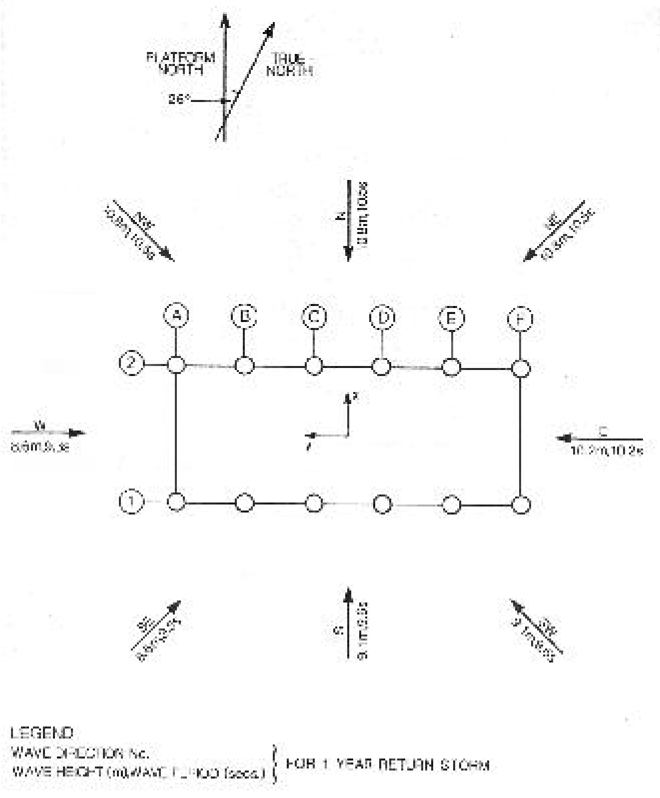

Figure 3.2
Leman CD Platform 1-Year Wave Data

Wave Directionality

The spectral fatigue analysis considers wave attack from the eight directions indicated in Figure 3.2. The probability of occurrence for each wave direction is specified in Table 3.2. These values represent the contribution of each wave direction to the gross fatigue damage.

Table 3.2
Wave Directional Probability

Direction	Probability (%)
From NNE	9.17
From ENE	7.97
From ESE	09.17
From SSE	12.78
From SSW	17.88
From WSW	18.27
From WNW	12.98
From NNW	11.78

The short-crestedness of the sea was specified for each direction based on a $\cos^2$ function, with spreading set to –90, -45, 0, 45 and 90 degrees relative to each of the eight wave directions.

Wave Spectra

The JONSWAP spectrum, representing a non-fully developed storm situation was applied for all sea-states.

Sea-State Probability

The probability of occurrence of significant wave height (H_s) and zero-crossing period (T_z) was taken from the Southern North Sea wave scatter diagram presented in the Wimpey report. Eighty-eight sea states, representing the complete scatter diagram, were derived and implemented in the analysis.

Wave Frequencies Selection

Thirty wave periods, ranging from 2.5 to 20.0 seconds, were selected for use in the determination of transfer functions. A cut-off of 15.1 m wave height i.e. the wave height of the 100-year design event was applied to the data. A wave steepness of 1/23 was used based on the results of a calibration study reported in the Wimpey Report.

Stress Concentration Factors

Hot spot stresses and associated fatigue lives were calculated at eight positions around each tubular joint intersection. In general, SCFs were calculated in accordance with the Efthymiou parametric equations. However, the platform includes a number of joints with geometries outside the range of application of the Efthymiou equations. These joints were typically highly overlapped K and KT joints. In such cases, the SCFs calculated and reported in the Wimpey report were specified directly in the present fatigue analysis.

S-N Curve

The HSE T'-curve was used in the fatigue life estimation and cumulative damage was determined using the Palmgren-Miner criterion.

3.4 Fatigue Analysis Results

Fatigue-life calculations were extracted from the SACS analysis for a selection of twenty-four joints, in order to compare predicted lives with those presented in the Wimpey report. The joints were carefully selected to include a representative sample, all with low predicted lives, distributed amongst the various framing components of the jacket. They included joints from one of the transverse frames (Frame F), both longitudinal frames (Frames 1 & 2) and from the first horizontal framing plan below the waterline.

The predicted fatigue lives from the present MSL analysis and the Wimpey fatigue analysis are shown, for comparison, in Table 3.3. Figures contained in Appendix C indicate the precise locations of the joints identified in the table.

Table 3.3 shows that good agreement was achieved between the results of the two fatigue analyses. In more than 50% of cases, the difference in life is less than 18 months. In general, the lives from the present analysis are slightly higher. Joint 5605, on the horizontal plan bracing (-24' elevation), has two braces with lives approaching 10 times those reported in the Wimpey analysis. It is believed that this is a result of the explicit modelling of the large eccentricities in the MSL analyses. The main reason for the small differences that exist are differences in the modelling of some jacket appurtenances due to a lack of data in the Wimpey Report. As expected, their effect is small as evidenced by the generally high level of agreement in fatigue life calculations.

Table 3.3
Comparison of Fatigue Life Predictions, MSL and Wimpey Analyses

Joint No.	Location	Brace	Calculated Fatigue Life (Years)	
			MSL analysis	Wimpey analysis
5804	Transverse Frame F	5804-7807	1.27	0.50
5804		5804-7801	1.29	0.50
5201	Longitudinal Frame 1	5201-7101	3.09	2.10
5301		5301-7201	3.05	2.40
5601		5601-7401	3.09	2.00
5801		5801-7601	3.37	2.20
5107	Longitudinal Frame 2	5107-7207	9.85	5.50
5207		5207-7307	7.66	4.50
5407		5407-7607	7.95	4.90
5607		5607-7807	7.58	4.60
5806	Horizontal Plan Framing @ -24' Elev.	5806-5908	6.49	13.30
5805		5805-5905	1.18	0.70
5803		5803-5903	1.18	0.70
5802		5802-5901	6.04	10.50
5603		5603-5691	0.30	0.00
5603		5603-5702	1.97	2.80
5603		5603-5502	1.20	3.00
5603		5603-5503	0.18	0.10
5605		5605-5504	1.28	0.00
5605		5605-5506	19.13	2.70
5605		5605-5706	21.66	2.50
5605		5605-5964	2.41	0.00
5706		5706-5607	11.72	11.20
5706		5706-5978	40.17	31.80

4. FLEXIBLE JOINT FATIGUE ANALYSIS

4.1 Implementation of Local Joint Flexibility

There are several methodologies available to account for the effects of local joint flexibility[4 - 10] in offshore structures. The present study has used the equations and implementation philosophy formulated by Buitrago[4]. The methodology has been tailored to accommodate the element modelling capabilities of the SACS analysis software. The method involves inserting a short 'flex-element' at the end of the brace. The flex-element connects the brace to the surface of the chord.

Buitrago[4] gives explicit formulae to determine the local joint flexibilities for various joint types and geometries. These equations are directly employed here to calculate the appropriate local joint flexibility. The result is then used to calculate the necessary area and inertial properties of the flex-element to represent the axial and bending (both in-plane and out-of-plane) stiffness of the joint. Torsional and shear flexibilities are not considered.

The area, A, and the moments of inertia, I, of the flex-element are calculated as follows:

$$I = \frac{L}{E(LJF_m)}$$

$$A = \frac{L}{E(LJF_p)}$$

Where:

L	is the length of the flex-element
LJF_m	is either the in-plane or the out-of-plane bending local joint flexibility
LJF_p	is the axial loading local joint flexibility

4.2 Validation of the LJF Methodology

In order to verify the implementation methodology, a simple model of a T-Joint was created using the SACS software. The T-joint was given the same geometry as a test specimen selected from the Makino[11, 12] database which contains data relating to full-scale failure tests on tubular joints. SACS analyses were carried out both with and without the flex-element. Five axial loading tests, two in-plane bending tests and two out-of-plane bending tests were used for the comparison.

The results of the validation study are presented in Table 4.1, Table 4.2 and Table 4.3 for axial, in-plane bending and out of plane bending respectively. The tables show that, when the flex-element is included in the model, the predicted deformations are in good agreement with the test results. Conversely, the rigid joint model, as expected, shows no correlation with the test results.

Table 4.1
Comparison of Axial loading

Specimen No.	T-Joint Geometry					Axial Load (kN)	Chord Wall Deformation		
	D (mm)	T (mm)	d (mm)	t (mm)	L (mm)		δ_{flex} (mm)	δ_{rigid} (mm)	δ_{test} (mm)
TC-8	165.2	4.24	89.1	3.5	527	45.1	0.703	0.023	0.512
TC-12	318.5	4.5	139.8	4.4	1593	76.5	2.241	0.035	4.141
TC-13	457.2	4.9	89.1	3.0	2286	46.1	2.916	0.069	4.572
TC-76	165.4	4.55	61.0	2.76	495	58.8	1.127	0.056	1.472
TC-92	216.47	4.51	216.33	4.58	696	248	1.426	0.049	0.770

Table 4.2
Comparison of In-Plane Bending (IPB)

Specimen No.	T-Joint Geometry					IPB Moment (kNm)	Chord Wall Deformation		
	D (mm)	T (mm)	d (mm)	t (mm)	L (mm)		θ_{flex} (rad)	θ_{rigid} (rad)	θ_{test} (rad)
TM-39	355.4	15.1	317.4	8.7	1422.4	405	0.0093	0.0038	0.0081
TM-41	456.1	15.4	317.2	8.6	1828.8	341	0.0107	0.0041	0.0108

Table 4.3

Comparison of Out-of-Plane Bending (OPB)

Specimen No.	T-Joint Geometry					OPB Moment (kNm)	Chord Wall Deformation		
	D (mm)	T (mm)	d (mm)	t (mm)	L (mm)		θ_{flex} (rad)	θ_{rigid} (rad)	θ_{test} (rad)
TM-1	216.42	4.5	216.4	4.56	696	18.0	0.0179	0.0006	0.0116
TM-2	216.45	4.5	165.55	4.53	698	6.80	0.0177	0.0007	0.0208

The results of the validation study, presented in the tables above, indicate that the Buitrago formulations and the applied implementation methodology allow the SACS software to effectively represent the local joint flexibility of tubular joints under axial, in-plane bending and out-of-plane bending loads.

4.3 Selection of Joints

Local joint flexibilities were implemented into the SACS fatigue analysis model at eighty brace intersections on sixty-seven separate nodes. The joints were carefully selected to include a representative sample, including those with low predicted lives, distributed amongst the various framing components of the jacket. They include six joints from each of the transverse frames (Frames A to F), ten joints from each of the longitudinal frames (Frames 1 & 2) and twenty-four joints from the first horizontal framing plan below the waterline (-24' elevation).

An important consideration in joint selection was to ensure symmetry of the flexible joints around the structure to prevent the introduction of artificial secondary forces caused by asymmetrical structural stiffness. At the time of the analysis, inspection data were not available and, therefore, engineering judgment was applied to predict which nodes were likely to have been included in the platform periodic underwater inspections, and to include LJF for those nodes. The selection was based upon rigid-joint fatigue-life predictions and areas of known susceptibility to fatigue cracking. In Tables 4.4, 4.5 and 4.6, which summarise the results of the fatigue analyses, bold typeface is used to indicate those joints for which inspection data were subsequently received. It turned out that LJF was implemented into approximately 95% of all inspected joints.

4.4 Fatigue Analysis Results

The results of the spectral fatigue analysis with LJF implemented are presented in Table 4.4, Table 4.5 and Table 4.6 for the transverse frames, the longitudinal frames and the horizontal framing plan at –24' elevation, respectively. The tables show that, in all cases, the fatigue life predictions have increased. The factor on life afforded by the implementation of LJF is also shown in the tables for each joint. This factor is a ratio of the life calculated using flexible joint modeling to the life calculated using a rigid joint model. The average factors on life for each of the framing components considered are as follows:

Transverse frames (A to F): 19.3 factor on life
Longitudinal frames (1 & 2): 9.2 factor on life
Horizontal framing (-24' elev.): 8.0 factor on life

For a very small number of joints as shown in Table 4.6 the revised fatigue lives with LJF were still low (eg between 0.6 and 5.7 years) for Node 5603. The reasons for this are not known but may be due to uncertainties such as in the wave loading or LJF prediction for this joint type.

The comparison of the predicted lives using the rigid-joint and the flexible-joint analyses are illustrated in the figures contained in Appendix C.

Table 4.4
Comparison of Predicted Fatigue Lives – Transverse Frames

Frame	Node	Element	Fatigue Lives		Factor on Life	Average Factor on Life
			Rigid	Flexible		
A	7107	7107-5104	279.9	2021.9	7.22	24.7
	7101	7101-5104	272.0	2146.6	7.89	
	5104	**5104-7107**	**11.6**	**381.2**	**32.86**	
	5104	**5104-7101**	**14.1**	**424.4**	**30.10**	
	5107	5107-5104	1076.1	48981.0	45.52	
	5101	5101-5104	3269.7	80218.0	24.53	
B	7207	7207-5204	277.7	3008.5	10.83	13.8
	7201	7201-5204	271.7	2049.0	7.54	
	5204	**5204-7207**	**10.9**	**52.7**	**4.83**	
	5204	**5204-7201**	**13.5**	**350.4**	**25.96**	
	5207	5207-5204	3375.5	77365.0	22.92	
	5207	5201-5204	6178.4	66934.0	10.83	
C	7307	7307-5304	254.6	1556.4	6.11	23.4
	7301	7301-5304	255.4	1702.0	6.66	
	5304	**5304-7307**	**8.6**	**334.8**	**38.93**	
	5304	**5304-7301**	**8.6**	**493.4**	**57.37**	
	5307	**5307-5304**	**13.8**	**6462.0**	***Ignored***	
	5307	5301-5304	4251.8	32759.0	7.70	
D	**7407**	**7407-5404**	**49.2**	**248.5**	**5.05**	26.0
	7401	**7401-5404**	**45.0**	**251.6**	**5.59**	
	5404	**5404-7407**	**1.1**	**43.6**	**39.64**	
	5404	**5404-7401**	**1.2**	**33.8**	**28.17**	
	5407	5407-5404	1334.3	12457.0	9.34	
	5401	5401-5404	244.1	16653.0	68.22	
E	7607	7607-5604	432.0	2341.5	5.42	11.1
	7601	7601-5604	414.0	1812.6	4.38	
	5604	**5604-7607**	**4.1**	**35.3**	**8.61**	
	5604	**5604-7601**	**4.5**	**179.0**	**39.78**	
	5607	5607-5604	3900.0	19606.0	5.03	
	5601	5601-5604	2043.3	6856.5	3.36	
F	**7807**	**7807-5804**	**47.4**	**233.8**	**4.93**	17.6
	7801	**7801-5804**	**45.4**	**235.9**	**5.20**	
	5804	**5804-7807**	**1.3**	**31.2**	**24.57**	
	5804	**5804-7801**	**1.3**	**31.5**	**24.42**	
	5807	5807-5804	741.0	16216.0	21.88	
	5801	5801-5804	836.0	20747.0	24.82	

Bold typeface indicates joints that have been inspected

Table 4.5
Comparison of Predicted Fatigue Lives – Longitudinal Frames

Frame	Node	Element	Fatigue Lives		Factor on Life	Average Factor on Life
			Rigid	Flexible		
1	7101	7101-5201	365.0	1984.9	5.44	9.0
	7201	7201-5301	330.0	1941.8	5.88	
	7301	7301-5401	109.0	632.7	5.80	
	7401	7401-5601	292.4	1888.4	6.46	
	7601	7601-5801	321.6	1777.4	5.53	
	5201	**5201-7101**	**3.1**	**34.0**	**11.00**	
	5301	**5301-7201**	**3.1**	**34.0**	**11.15**	
	5401*	**5401-7301**	**1.5**	**25.7**	**16.91**	
	5601	**5601-7401**	**3.1**	**34.8**	**11.26**	
	5801	**5801-7601**	**3.4**	**35.5**	**10.53**	
2	7207	7207-5107	567.0	3194.0	5.63	9.4
	7307	7307-5207	615.0	3692.5	6.00	
	7407	7407-5307	221.7	1179.4	5.32	
	7607	7607-5407	647.0	3374.2	5.22	
	7807	7807-5607	744.0	3754.3	5.05	
	5107	**5107-7207**	**9.9**	**117.2**	**11.90**	
	5207	**5207-7307**	**7.7**	**114.3**	**14.92**	
	5307	**5307-7407**	**3.6**	**32.7**	**9.08**	
	5407	**5407-7607**	**8.0**	**118.2**	**14.87**	
	5607	**5607-7807**	**7.6**	**120.3**	**15.87**	

Bold typeface indicates joints that have been inspected

*Underwater inspection shows crack indication

Table 4.6
Comparison of Predicted Fatigue Lives - CGF @ -24 ft. Elevation

Plan Elevation	Node	Element	Fatigue Lives		Factor on Life	Average Factor on Life
			Rigid	Flexible		
-24 ft.	5807	5807-5706	89.3	160.9	1.80	8.1
	5806	**5806-5908**	**6.5**	**71.3**	**10.97**	
	5805	**5805-5905**	**1.2**	**31.8**	**26.50**	
	5803	5803-5903	1.2	32.4	27.00	
	5802	**5802-5901**	**6.0**	**57.5**	**9.58**	
	5801	**5801-5702**	**44.1**	**71.6**	**1.62**	
	5706	5706-5978	40.2	3300.0	*ignored*	
	5706	5706-5607	11.7	12.8	1.09	
	5702	5702-5971	81.7	156.7	1.92	
	5607	5607-5706	116.1	603.9	5.20	
	5607	5607-5506	104.4	198.3	1.90	
	5605	**5605-5964**	**2.4**	**8.5**	**3.54**	
	5605	**5605-5706**	**21.7**	**52.8**	**2.43**	
	5605	**5605-5506**	**19.1**	**311.2**	**16.29**	
	5605	**5605-5504**	**1.3**	**5.7**	**4.38**	
	5603	**5603-5961**	**0.3**	**0.7**	**2.33**	
	5603	**5603-5702**	**2.0**	**5.0**	**2.50**	
	5603	**5603-5502**	**1.2**	**3.7**	**3.08**	
	5603	**5603-5503**	**0.2**	**0.6**	**3.00**	
	5407	**5407-5506**	**24.8**	**56.6**	**2.28**	
	5406	5406-5426	5.9	82.7	14.02	
	5403	5403-5423	0.9	27.6	30.67	
	5402	5402-5422	3.7	40.8	11.03	
	5401	**5401-5502**	**10.6**	**21.0**	**1.98**	

Bold typeface indicates joints that have been inspected

5. IMPACT ON INSPECTION PLANNING

5.1 Inspection Categories

The categories identified below have been generated to group the inspected joints in order of predicted fatigue lives. The categories have been selected solely for purposes of assessing the impact of LJF on what might be considered a rational inspection prioritisation.

Category 1: Highest Priority, predicted fatigue lives of less than 10 years
Category 2: High Priority, predicted fatigue lives between 10 and 30 years
Category 3: Medium Priority, predicted fatigue lives of 30 to 60 years.
Category 4: Inspection not justified on the basis of fatigue assessment

The platform has been in place for thirty years; assuming a reasonable level of reliability in the fatigue life predictions, some of the Category 1 joints should have developed crack indications. A smaller proportion of the Category 2 joints may also have some visible indications.

5.2 Inspection Results

Of the fifty-three inspections (using MPI) carried out during the service life of the structure, three have given crack-like indications on two joints. One of the cracked joints, identified during the 1987 inspection and confirmed two years later, is located amongst the horizontal conductor guide framing at elevation –24' (joint 5405). The other crack indication was found on longitudinal frame 1 (joint number 5401) at the intersection with transverse frame D, also at -24' elevation. This indication is described in the inspection report as a lack of sidewall fusion and was removed by local grinding to a depth of 4mm. It should be noted however that the indication was not found on earlier inspections of the same joint.

5.3 Impact of LJF on Inspection Planning

Figure 5.1 shows the eighty joints included in the LJF study categorised in accordance with the criteria defined above. The figure shows that the number of Category 1 joints reduces from 31 to 6 when LJF is implemented into the fatigue analysis. The total number of Category 1 and Category 2 joints, which would be expected to be the focus of underwater inspections, reduce from 41 to 10 joints.

> It may also be noted that the histogram for the LJF analysis is more reasonable in that it reflects the tail end of the distribution that can be expected from a fatigue analysis. The rigid joint analysis, on the other hand, seems to suggest a local peak in the tail end.

The locations of the Category 1 and Category 2 joints are shown in Figure 5.2. It can be seen that nine of the ten joints are located amongst the conductor guide framing at the -24' elevation. The joint with the crack indication (5405) was modelled, consistent with the Wimpey analysis, as rigid since a grouted repair clamp has been installed. Nevertheless the identical adjacent brace connection (5403) has a similar rigid joint fatigue life prediction and hence it can be deduced that the LJF fatigue life of joint (5405) would also be similar to that of joint (5403) and hence identified as a Category 2 joint. The only Category 1 or Category 2 joint, from the flexible joint analysis, not amongst the conductor guide framing is joint 5401 on longitudinal frame 1 at the intersection with transverse frame D, also at -24' elevation. This joint was also found to have a crack indication during underwater inspection.

In summary:

A. Assuming that Category 1 and Category 2 joints are included in the periodic inspections, the implementation of LJF in the fatigue analysis reduces the requirement for underwater inspection by approximately 75%.

B. Two joints have been found to have crack indications during underwater inspections. Both joints are identified as Category 1 or Category 2 in the LJF fatigue analysis.

C. For both joints cracks were observed (see Appendix A) during inspections undertaken in 1987 for joint (5401) and in 1989 for joint (5405) corresponding to 17 years and 19 years. The corresponding lives predicted using LJF were 26 years approximately. Therefore it can be deduced that since the cracks detected have depths which are much less than the joint wall thickness they would be detected before through wall cracking occurred using LJF.

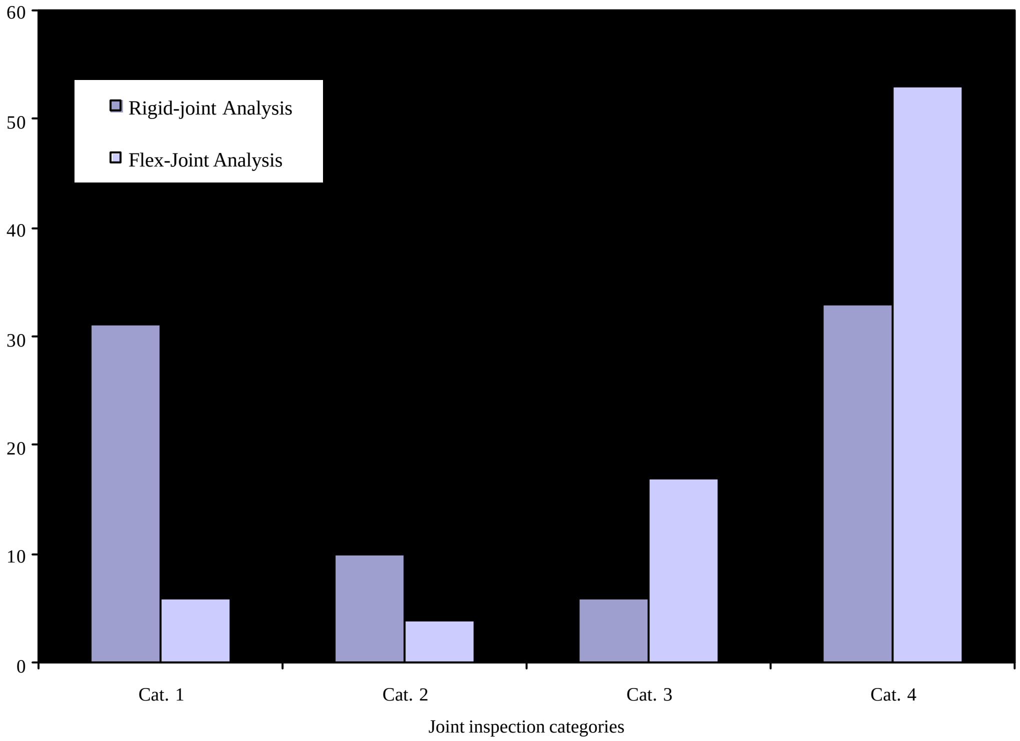

Figure 5.1:
Comparison of Rigid and Flexible Joint Categorization

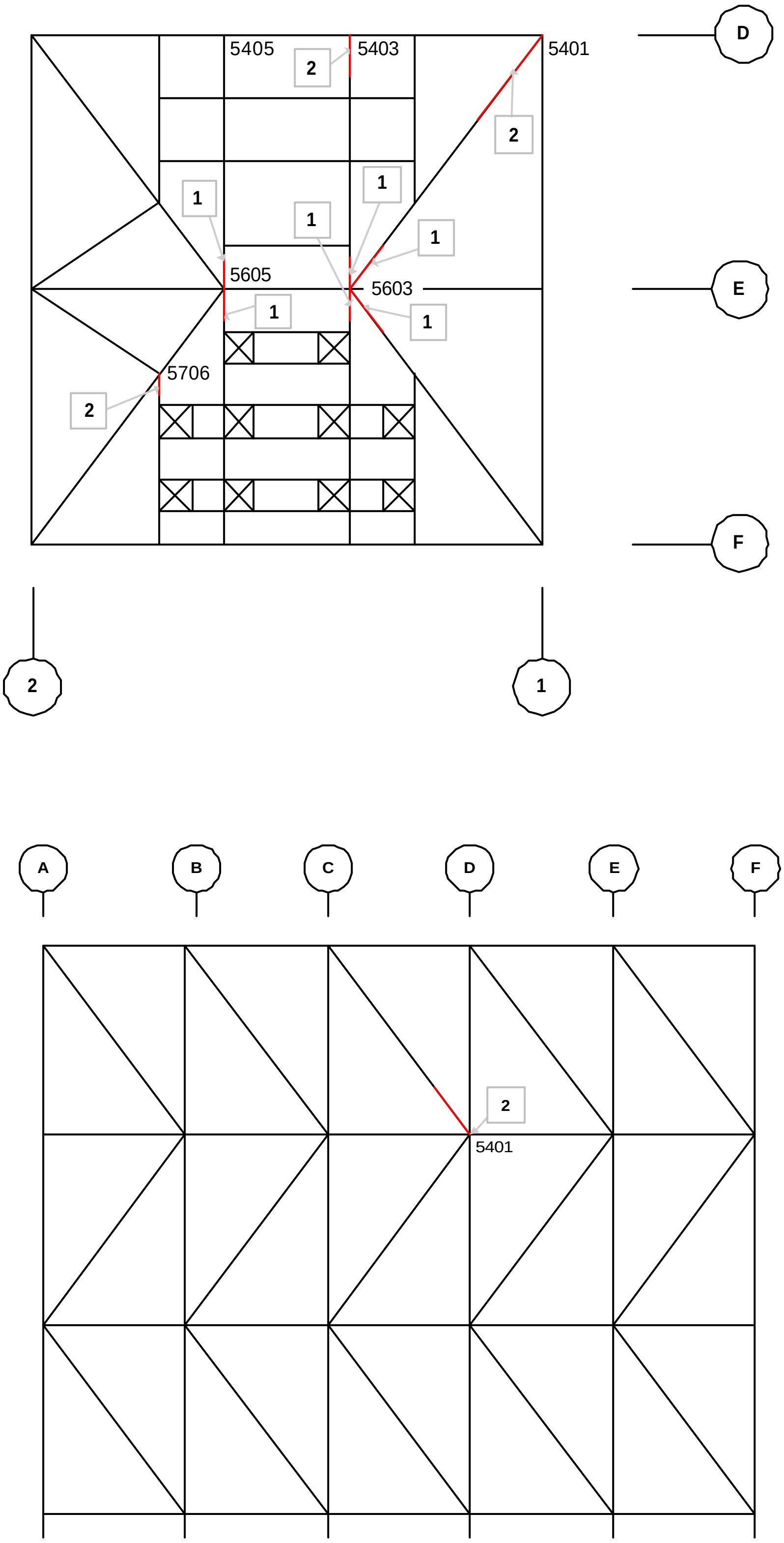

Figure 5.2
Location of Category 1 and 2 Joints on CGF (top) and Frame 1 (bottom)

6. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the structure analysed herein, the following observations can be made:

I. The average increase in predicted fatigue life when local joint flexibility is included in the structural analysis was found to be 19, 9 and 8 for transverse frames, longitudinal frames and the horizontal frame nearest the water line, respectively.

II. The inclusion of LJFs into the analysis reduce the number of joints having lives less than 30 years from 41 (obtained using rigid joint assumptions) to 10.

The two joints that were found to have crack-like indications during actual inspections were still captured within the 10 most susceptible joints identified with the LJF analysis.

The following conclusions have therefore been identified from this study;

- The findings of this study support the view held by industry that conventional rigid joint fatigue analysis under-predicts fatigue life.

- It is seen that implementing of joint flexibility allows for a more accurate fatigue life prediction and closer agreement with results from underwater inspections.

- The use of LJF can therefore assist in the overall optimisation of inspection planning. This is particularly important for older structures as newer structures would normally be designed to have minimum fatigue lives that were much higher than the intended service life (e.g. 10 times required life).

However, it should be noted that the data set is limited (i.e. one structure) and further correlation with other types of structures to consider the influence of parameters such as platform vintage, design basis and framing configuration and which also exhibit fatigue cracking would be required. Also other uncertainties within the fatigue recipe, such as uncertainties in the loading, not considered within the scope of this study may play an important role in the fatigue life predictions.

Furthermore, it should be emphasise that a number of elements are considered within the inspection strategy and that the use of LJF is one element that can be of use in determining this.

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APPENDIX A

Inspection Data

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Frame 1	-7.3	B1	5201	3611	KDT	91	91	No significant defects or cracklike indications found. Pitting 2 mm max depth :- Weld cap 1 - 3 % Chord 9 - 12 % 60 % cover Brace 9 - 12 % 15 % cover Brace 2 - 3 % 20 % cover
Frame 1	-7.3	C1	5301	3531	KDT	87	87	Pitting corrosion in can side of HAZ. General corrosion with pitting corrosion brace side HAZ. Max pitting 2.5mm. General 1mm. MPI : No cracklike defects detected.
Frame 1	-7.3	C1	5301	3621	KDT	93	93	**CD/93/13** No significant defects or cracklike indications found
Frame 1	-7.3	D1	5401	3541	KDT	77		No visible defects at time of inspection.
Frame 1	-7.3	D1	5401	3431	KDT	77		No visible defects at time of inspection.
Frame 1	-7.3	D1	5401	3531	KDT	77		No visible defects at time of inspection.
Frame 1	-7.3	D1	5401	3631	KDT	77		No visible defects at time of inspection.

Location	**Elevtn (m) Ref. to LAT**	**Node Ref. Leg**	**Node Number**	**Member Number**	**Joint Type**	**Visual Inspection Date**	**MPI (EC) Inspection Date**	**COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '**
						89	89	A STRONG INTERMITTENT INDICATION, having the appearance of LACK OF SIDEWALL FUSION, in the chord toe of the weld from 10 o'clock through 12 o'clock to 3 o'clock (and extending 60mm. onto the chord toe of the adjacent weld) was noted. 90% of indications were removed by remedial grinding to a depth of 2mm. with respect to the chord parent metal. All remaining indications (around 10 o'clock) were removed by grinding to a max. depth of 4mm. with respect to the chord parent metal. Ground areas were lightly dressed to remove acute angles, before profile measurements were taken.
Frame 1	-7.3	E1	5601	3441	KDT	81		Isolated pit 0.06", pitting & surface wastage max 0.06", cathodic protection readings taken. Large area of surface wastage max depth 0.04".
Frame 1	-7.3	E1	5601	3541	KDT	81		Node condition good.
Frame 1	-7.3	E1	5601	3561	KDT	81		Pitting & surface wastage max 0.055" extending completely around leg & brace side, cathodic protection readings taken. Pitting max 0.04".
Frame 1	-7.3	E1	5601	3641	KDT	81		Areas of discolouration appeared after cleaning, cathodic protection readings taken, isolated pit max 0.055", surface wastage. Pitting max 0.05".

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
						91	91	No significant defects or crackike indications found. Moderate corrosion pitting on chord 9-12-3 O/C 50 % cover, 2 mm max depth.
Frame 1	-7.3	F1	5801	3461	KT	77		No visible defects.
Frame 1	-7.3	F1	5801	3561	KT	77		No visible defects.
						89	89	No significant defects or cracklike indications found.
Frame 1	-7.3	F1	5801	3661	KT	77		No visible defects.
						93	93	**CD/93/12** No cracklike indications or significant defects found
Frame 2	-7.3	B2	5207	3627	KDT	91	91	No significant defects or cracklike indications found
Frame 2	-7.3	C2	5307	3437	KDT	83		Pitting max 0.04", surface wastage max 0.05".
						89	89	No cracklike indications or significant defects were found. Slight corrosion of entire weld cap, 100% cover, estimated metal loss 1mm.
Frame 2	-7.3	C2	5307	3527	KDT	83		Pitting max 0.04", pit 5" length .125" wide 0.04" depth at 12 o'clock.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	**COMMENTS** **Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '**
Frame 2	-7.3	C2	5307	3537	KDT	83		Pitting & surface wastage max 0.03".
Frame 2	-7.3	C2	5307	3637	KDT	83		Pitting max 0.05", surface wastage max 0.03".
						91	91	No significant defects or cracklike indications found.
Frame 2	-7.3	D2	5407	3447	KDT	79		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common.
						81		Node condition good.
Frame 2	-7.3	D2	5407	3537	KDT	79		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common.
						81		Node condition good.
Frame 2	-7.3	D2	5407	3647	KDT	79		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common.
						81		Node condition good.
						95	95	**CD/95/15** No cracklike indications or significant defects found
Frame 2	-7.3	E2	5607	3467	KDT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.0mm.
						81		Light pitting max 0.03", some surface wastage.
Frame 2	-7.3	E2	5607	3547	KDT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.00mm.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
						81		Light surface pitting max pit 0.05".
Frame 2	-7.3	E2	5607	3567	KDT	81		Light surface wastage, max pit 0.04".
Frame 2	-7.3	E2	5607	3667	KDT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.0mm.
						81		Light pitting max pit 0.05".
						95	95	**CD/95/14** No cracklike indications or significant defects found.
Frame A	-7.3	MID	5104	2611	K	79		Areas of general wastage to max 1mm, general pitting to 1mm, max pitting 2mm, no defects of any consequence.
						81		No defects found.
						95	95	**CD/95/02** No cracklike indications or significant defects found.
Frame A	-7.3	MID	5104	2617	K	79		Areas of general wastage to max 1mm, general pitting to 1mm, max pitting 2mm, no defects of any consequence.
						81		No defects found.
						95	95	**CD/95/01** No cracklike indications or significant defects found.
Frame B	-7.3	MID B1.B2	5204	2627	K	93	93	**CD/93/04** No cracklike indications or significant details found

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	**COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '**
Frame B	-7.3	MID B1.B2	5204	2621	K	93	93	**CD/93/03** No cracklike indications or significant details found
Frame B	-20.7	B2	3207	2425	KT	87	87	CVI : General corrosion & corrosion pitting in both HAZs, max 1.5mm. Light pitting in weld cap. Max pit in toe 2.5mm. MPI : no cracklike or significant defects detected.
Frame C	-7.3	MID C1.C2	5304	2631	K	95	95	**CD/95/05** No cracklike indications or significant details found
Frame C	-7.3	C2	5307	2437	YT	83		Pitting max 0.03", areas of surface wastage.
Frame C	-7.3	MID C1.C2	5304	2637	K	95	95	**CD/95/06** No cracklike indications or significant details found
Frame C	-7.3	C2	5307	2537	YT	83		Pitting max 0.03", areas of surface wastage.
						95	95	**CD/95/07** No cracklike indications or significant details found
Frame D	+ 6.1	D1	7401	2641	YT	93	(93)	**CD/93/34** No cracklike indications or significant defects found
							(94)	**CD/94/34** No cracklike indications or significant defects found

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Frame D	+ 6.1	D2	7407	2647	YT	93	(93)	**CD/93/35** No cracklike indications or significant defects found
							(94)	**CD/94/35** No cracklike indications or significant defects found
Frame D	-7.3	D1	5401	2441	YT	77		No visible defects at time of inspection.
Frame D	-7.3	D1	5401	2541	YT	77		No visible defects at time of inspection.
Frame D	-7.3	D2	5407	2447	YT	79 81		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common. Node condition good.
Frame D	-7.3	D2	5407	2547	YT	79 81		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common. Node condition good.
Frame D	-7.3	MID D1 - D2	5404	2641	K	91	91	No significant defects or crackilke indications found. Localised pitting on chord and brace 3-6-9 O/C, 20 % cover, 2 mm max. depth
Frame D	-7.3	MID D1 - D2	5404	2647	K	93	93	**CD/93/08** No cracklike indications or significant defects found

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Frame E	-7.3	E1	5601	2461	YT	75		Cathodic protection readings taken.
						81		Light pitting max 0.04", some surface wastage, cathodic protection readings taken.
						83		Pitting max 0.02", surface wastage max 0.04".
Frame E	-7.3	E1	5601	2561	YT	75		
						81		Pitting max 0.03", cathodic protection readings taken.
						83		Pitting max 0.04", surface wastage areas.
Frame E	-7.3	E2	5607	2467	YT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.0mm.
						81		Light isolated pitting max pit 0.05".
Frame E	-7.3	E2	5607	2567	YT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.00mm.
						81		Slight undercut, light pitting max pit 0.05".
Frame E	-7.3	MID E1.E2	5604	2666	K	93	93	**CD/93/10** No cracklike indications or significant defects found
Frame E	-7.3	MID E1.E2	5604	2662	K	93	93	**CD/93/09** No cracklike indications or significant defects found. A pit (possibly
Frame F	-7.3	F1	5801	2481	YT	75		No significant defects.
						77		No visible defects.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	**COMMENTS** **Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '**
Frame F	+ 6.1	F1	7807	2687	YT	94	(94)	**CD/94/33** No cracklike indications or significant defects found
Frame F	-7.3	F1	5801	2581	YT	75 77		No significant defects. No visible defects.
Frame F	-7.3	F2	5807	2587	YT	89	89	No cracklike indications or significant defects were found.
Frame F	-7.3	F2	5807	2487	YT	89	89	No cracklike indications or significant defects were found.
Frame F	+ 6.1	F1	7801	2681	YT	94	(94)	**CD/94/32** No cracklike indications or significant defects found
Frame F	-7.3	MID F1 - F2	5804	2687	K	91	91	No significant defects or cracklike indications found. Preferential corrosion on brace over a length of 950 mm 25 - 35 mm from weld toe, 1.5 mm depth.
Frame F	-7.3	MID F1 - F2	5804	2681	K	93	93	**CD/93/11** No cracklike indications or significant defects found.
Horizontal	-7.3	MID	5104	4517	K	79 81		Areas of general wastage to max 1mm, general pitting to 1mm, max pitting 2mm, no defects of any consequence. No defects found.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	**COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '**
Horizontal Frame -7.3	-7.3	BTWN E1.E2	5605	4557	Y	95	95	**CD/95/23** No cracklike indications or significant defects found.
Horizontal Frame -7.3	-7.3	MID A1.A2	5104	4511	K	79		Areas of general wastage to max 1mm, general pitting to 1mm, max pitting 2mm, no defects of any consequence.
						81		No defects found.
Horizontal Frame -7.3	-7.3	BTWN E1.E2	5603	4561	KT	95	95	**CD/95/24** No cracklike indications or significant defects found.
Horizontal Frame -7.3	-7.3	MID B1.B2	5204	4527	K	83	83	Weld partially obstructed by an anode.
Horizontal Frame -7.3	-7.3	MID B1.B2	5204	4521	K	83	83	VISIBLE DISCONTINUITY at 4 o'clock on horizontal brace side, grinding carried out. MPI revealed an indication perpendicular to the weld running from the edge of the visible defect to weld cap. Metal peeling away from brace. Further MPI carried out at 4o'clock position - no defects found. Weld partially obstructed by an anode.
Horizontal Frame -7.3	-7.3	BTWN E1.E2	5603	4551	YT	95	95	**CD/95/25** No cracklike indications or significant defects found.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Horizontal Frame -7.3	-7.3	C2	5307	4527	YT	83		Pitting max 0.02", surface wastage max 0.05".
Horizontal Frame -7.3	-7.3	C2	5307	4539	KT	83		Pitting max 0.03", areas of surface wastage.
Horizontal Frame -7.3	-7.3	MID C1.C2	5304	4534	K	75		No significant defects.
						84	84	No defects found.
						87	87	4 pits in toe max 1.5mm. MPI no cracklike indications detected.
Horizontal Frame -7.3	-7.3	MID	5304	4531	K	75		No significant defects.
		C1.C2				87	87	Isolated pit max 1mm. MPI : No cracklike indications detected.
Horizontal Frame -7.3	-7.3	D1	5401	4531	KT	77	77	No defects found.
							78	No defects of any consequence.
							79	No defects found.
							80	No defects of any consequence.
							81	No defects of any consequence.
							82	No defects of any consequence.
							83	No defects noted.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Horizontal Frame -7.3	-7.3	D1	5401	4541	KT	77		No visible defects at time of inspection.
Horizontal Frame -7.3	-7.3	D2	5407	4537	KT	79 81		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common. Node condition good.
Horizontal Frame -7.3	-7.3	D2	5407	4547	KT	79 81		Areas of general surface wastage evident max 1mm, areas of general pitting to depth 3.00mm common. Node condition good.
Horizontal Frame -7.3	-7.3	MID D1.D2	5405	5542	T	87	87	SEVERE CORROSION PITTING in the HAZs both sides of weld. Max dia. 10mm. Max depth 1.5mm. Pits in weld toes & HAZs. Area of corrosion pitting in weld cap. MPI : No cracklike/significant indications present. No remedial action required.
Horizontal Frame -7.3	-7.3	MID D1.D2	5405	5534	T	87	87	CRACKLIKE DEFECT on horizontal brace side of weld, within a groove, 85mm long, max depth 1.5mm. MPI: CRACKLIKE INDICATIONS on horizontal brace side weld within groove in weld toe, 200mm long in same location as 85mm cracklike defect. No remedial action required.
						89	89	A 195mm. long CRACKLIKE INDICATION was found

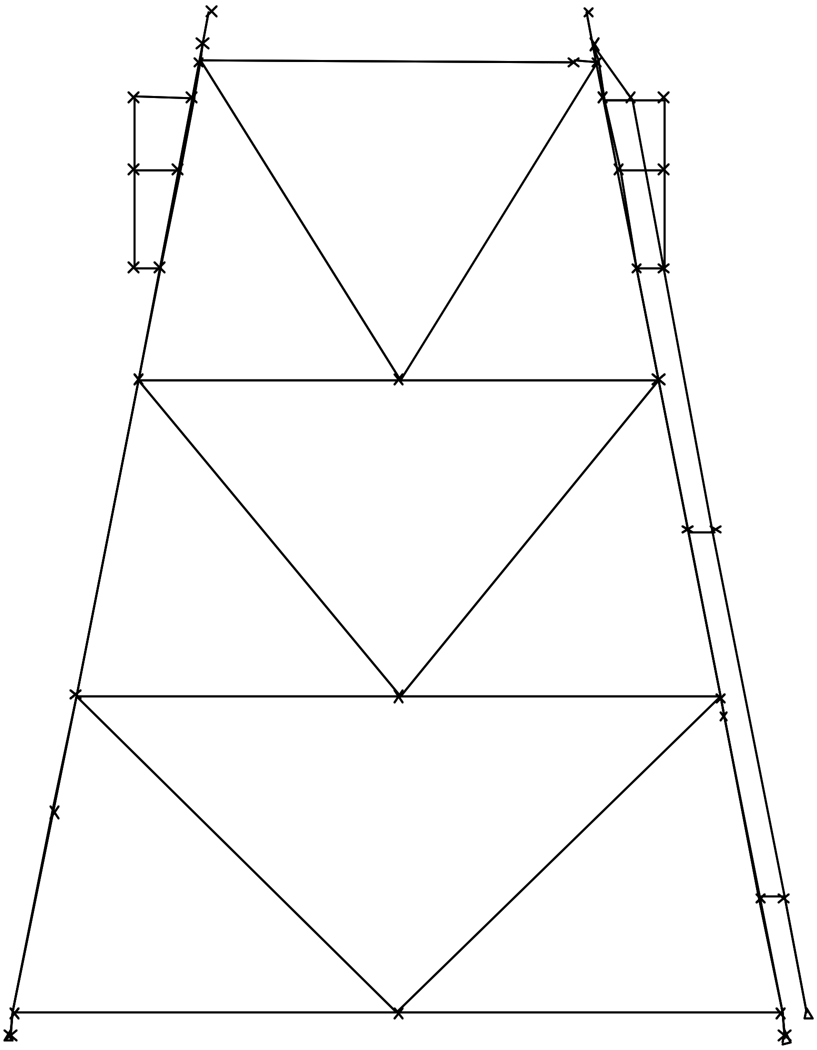
Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
								in the chord toe of the weld from 11 o'clock thro'12 to 1 o'clock. The indication was continuous for approx. 165mm. and intermittent for 30mm.Remedial grinding was carried out in 1mm.increments. When ground to 6.5mm. maximum depth the indication was 155mm. long and mainly continuous. The ground area was lightly profiled and detailed dimensions taken. An FMT showed no indication of flooding in either the brace or the chord.Grouted clamp fitted.
Horizontal Frame -7.3	-7.3	E2	5607	4556	KT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.0mm.
						81		Light surface pitting, slight undercutting on gusset plate.
Horizontal Frame -7.3	-7.3	E2	5607	4566	KT	79		Areas of pitting max 3.00mm common, areas of general surface wastage evident to max 1.0mm.
						81		Light surface wastage.
Horizontal Frame -7.3	-7.3	F1	5801	4571	YT	77		No visible defects.
Horizontal Frame -7.3	-7.3	BTWN F1.F2	5806	6697	T	75		No significant defects.
						87	87	CVI : 5mm dia. x 2mm pit in weld cap. General corrosion & light pitting both sides HAZ. 3 areas of deeper corrosion pitting can side of HAZ, max 3mm. General 1mm. MPI : No cracklike/significant indications detected.

Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location, Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '
Horizontal Frame -7.3	-7.3	BTWN F1.F2	5605	6683	KDT	91	91	No significant defects or cracklike indications found
Horizontal Frame -7.3	-7.3	BTWN F1.F2	5605	4567	KDT	91	91	No significant defects or cracklike indications found
Horizontal Frame -7.3	-7.3	BTWN F1.F2	5805	6689	T	75		No significant defects.
Horizontal Frame -7.3	-7.3	BTWN F1.F2	5802	6667	T	75		No significant defects.
Horizontal Frame -7.3	-7.3	BTWN F1.F2	3722	5368	T	75		No significant defects.
						77		No visible defects.
Horizontal Frame -20.7	-20.7	on CF	3762	5376	T	85	85	No cracklike indications. CF = Conductor Frame
Horizontal Frame -20.7	-20.7	on CF	3722	5368	T	85	85	No cracklike indications. CF = Conductor Frame

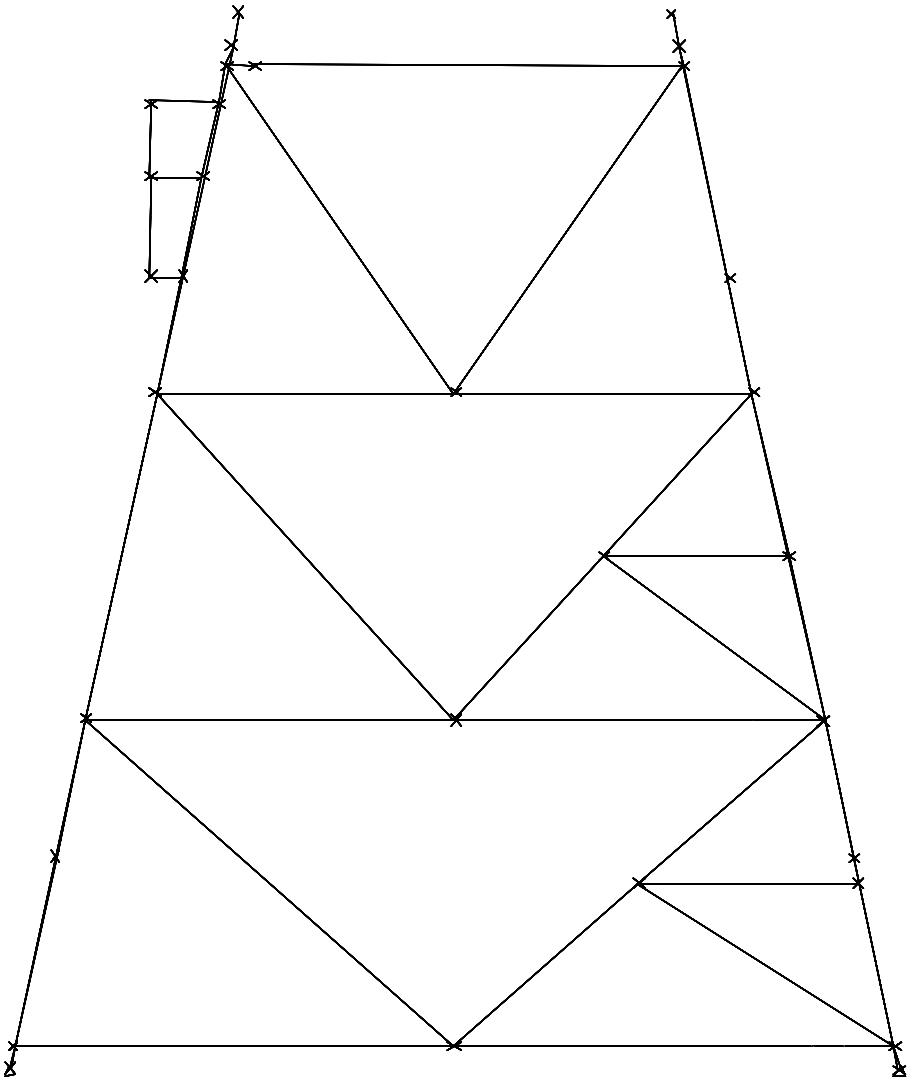
Location	Elevtn (m) Ref. to LAT	Node Ref. Leg	Node Number	Member Number	Joint Type	Visual Inspection Date	MPI (EC) Inspection Date	COMMENTS Location,Elevation, Node Ref and Joint Ref data from Sesam Database Spectral Fatigue Analysis, July 1990, Wimpey Offshore. Joint data from UEG ' Design of Tubular Joints '.
Frame 1	-7.3	D1	5401	3631	KDT	77		No visible defects at time of inspection.
						89	89	A STRONG INTERMITTENT INDICATION, having the appearance of LACK OF SIDEWALL FUSION, in the chord toe of the weld from 10 o'clock through 12 o'clock 12 o'clock (and extending 60mm onto the chord toe of the adjacent weld) was noted. 90% of the indications were removed by remedial grinding to a depth of 2mm with respect to the chord parent metal. All remaining indications (around 10 o'clock) were removed by grinding to a max. depth of 4mm. with respect to the chord parent metal. Ground areas were lightly dressed to remove acute angles, before profile measurements were taken.
Horizontal	-7.3	MID	5405	5534	T	87	87	CVI: CRACKLIKE DEFECT 85 mm long on horizontal brace chord side of weld, within a of weld, within a groove, max depth 1.5mm. MPI: A 200mm long cracklike indication (150mm continuous and 50mm intermittent) in same location as the above visual cracklike defect. No remedial action requested.
						89	89	A 195mm. long CRACKLIKE INDICATION was found in the chord toe of the weld from 11 o'clock thro'12 to 1 o'clock. The indication was continuous for approx. 165mm and intermittent for 30mm. Remedial grinding was carried out in 1mm. increments. When ground to 6.5mm. maximum depth the indication was 155 mm long and mainly continuous. The ground area was lightly profiled and detailed dimensions taken. A Flooded Member Test showed no indication of flooding in either the brace or the chord. Grouted clamp fitted.

APPENDIX B

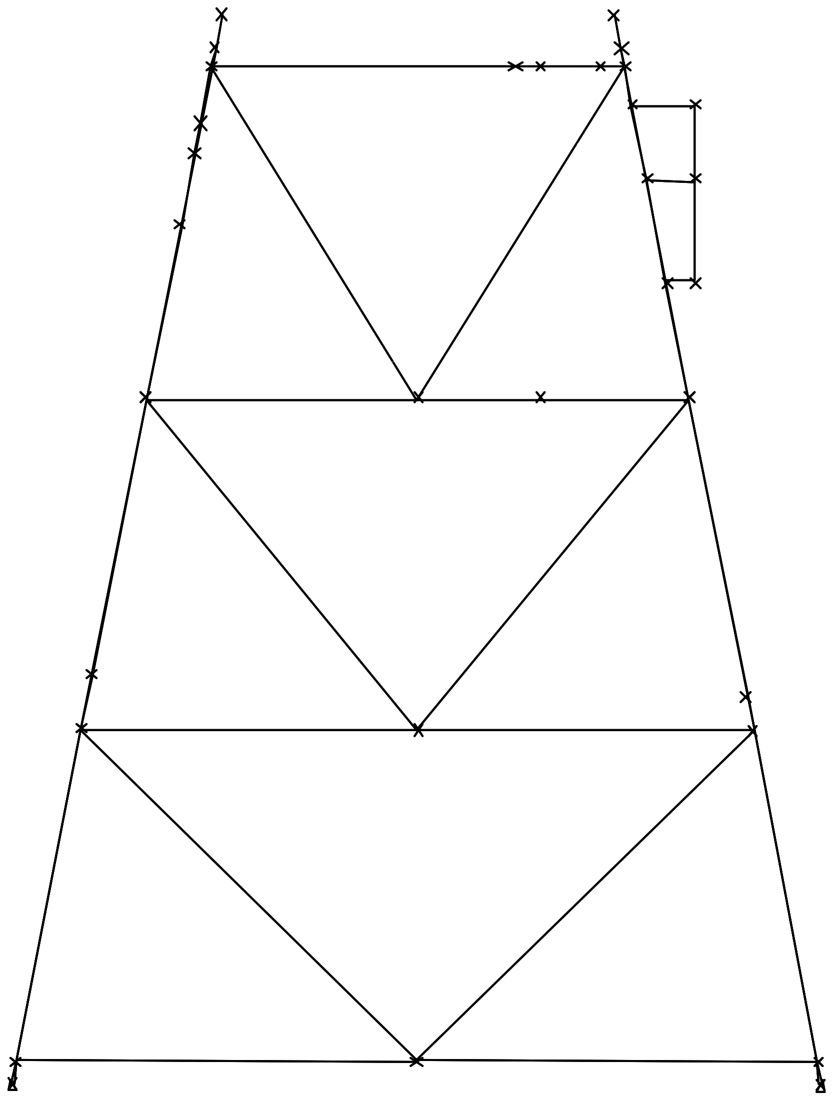
Geometry Plots from the SACS Model



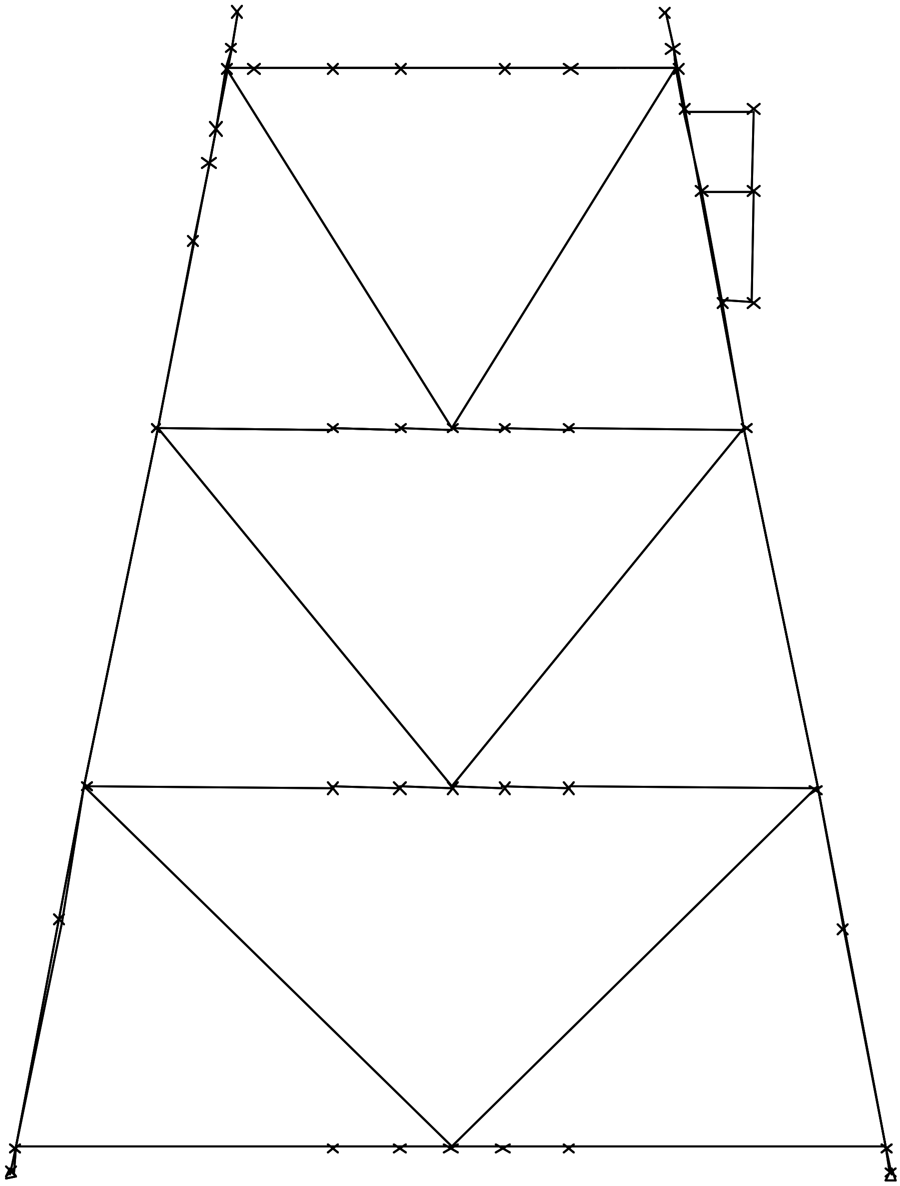
Elevation Frame A



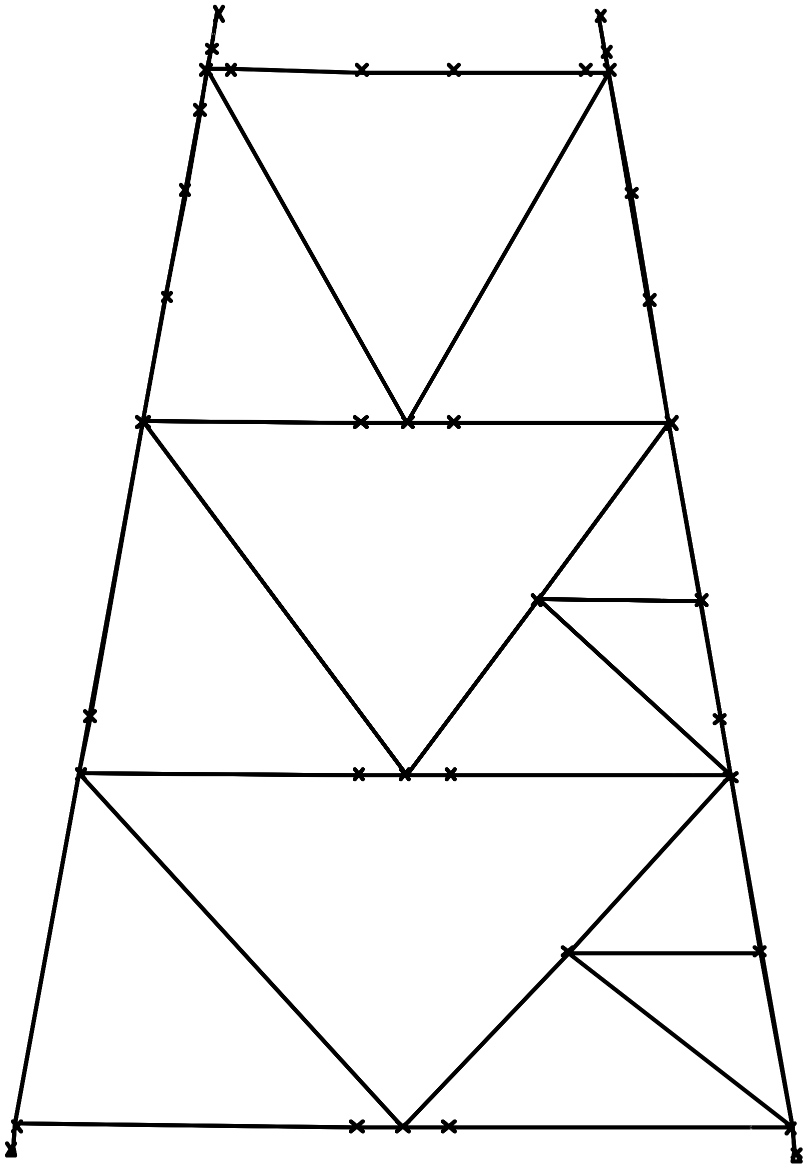
Elevation Frame B



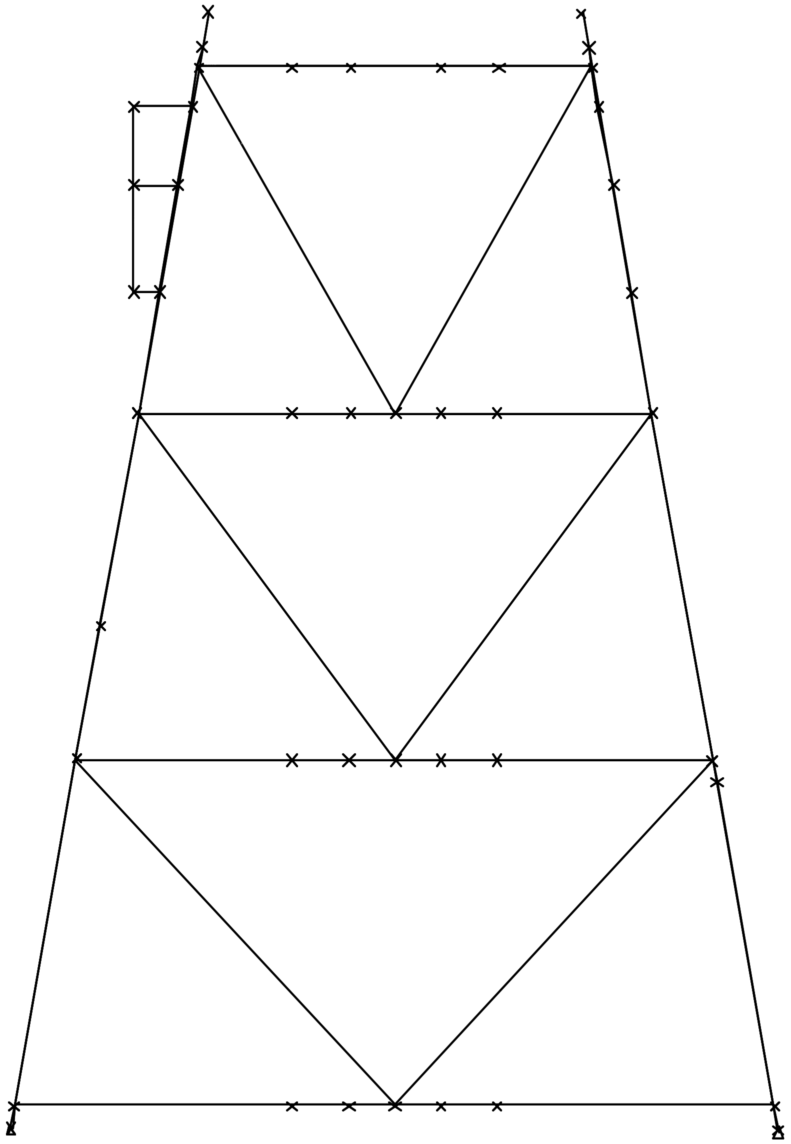
Elevation Frame C



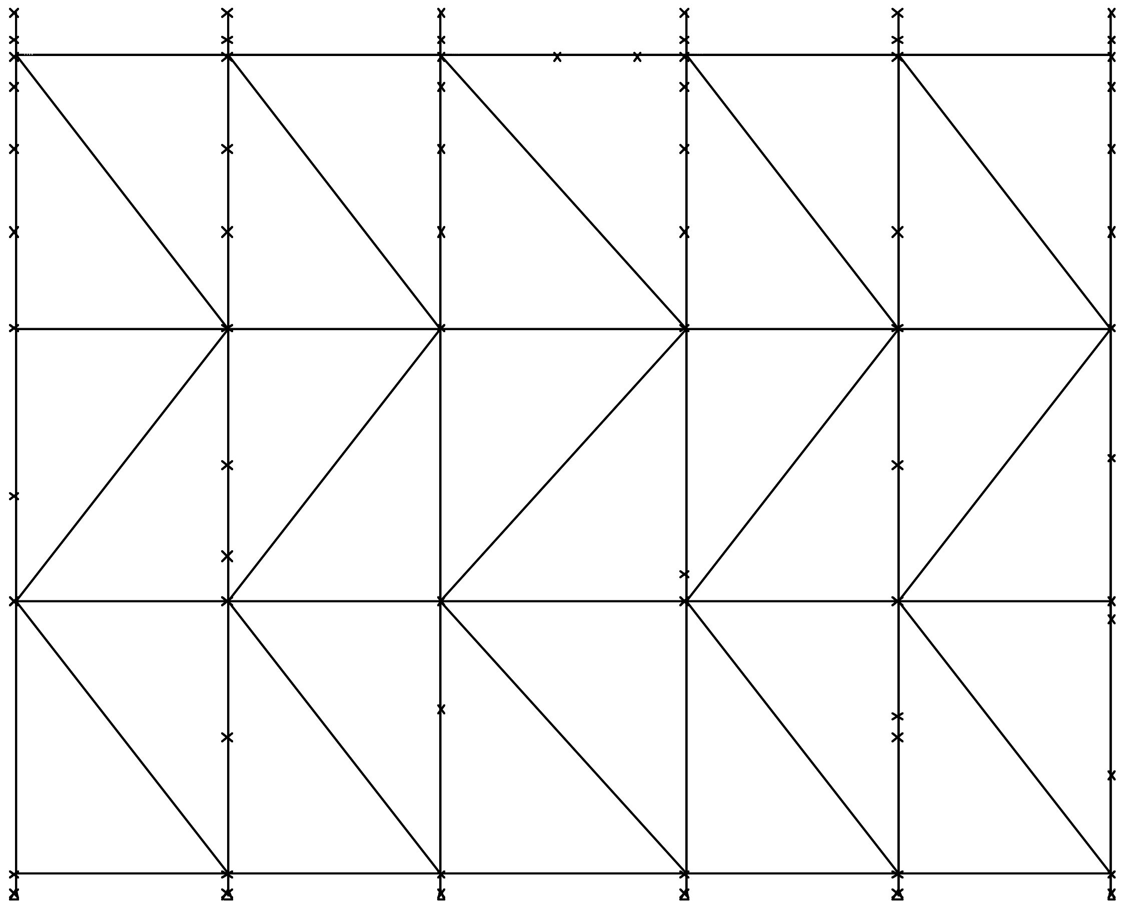
Elevation Frame D



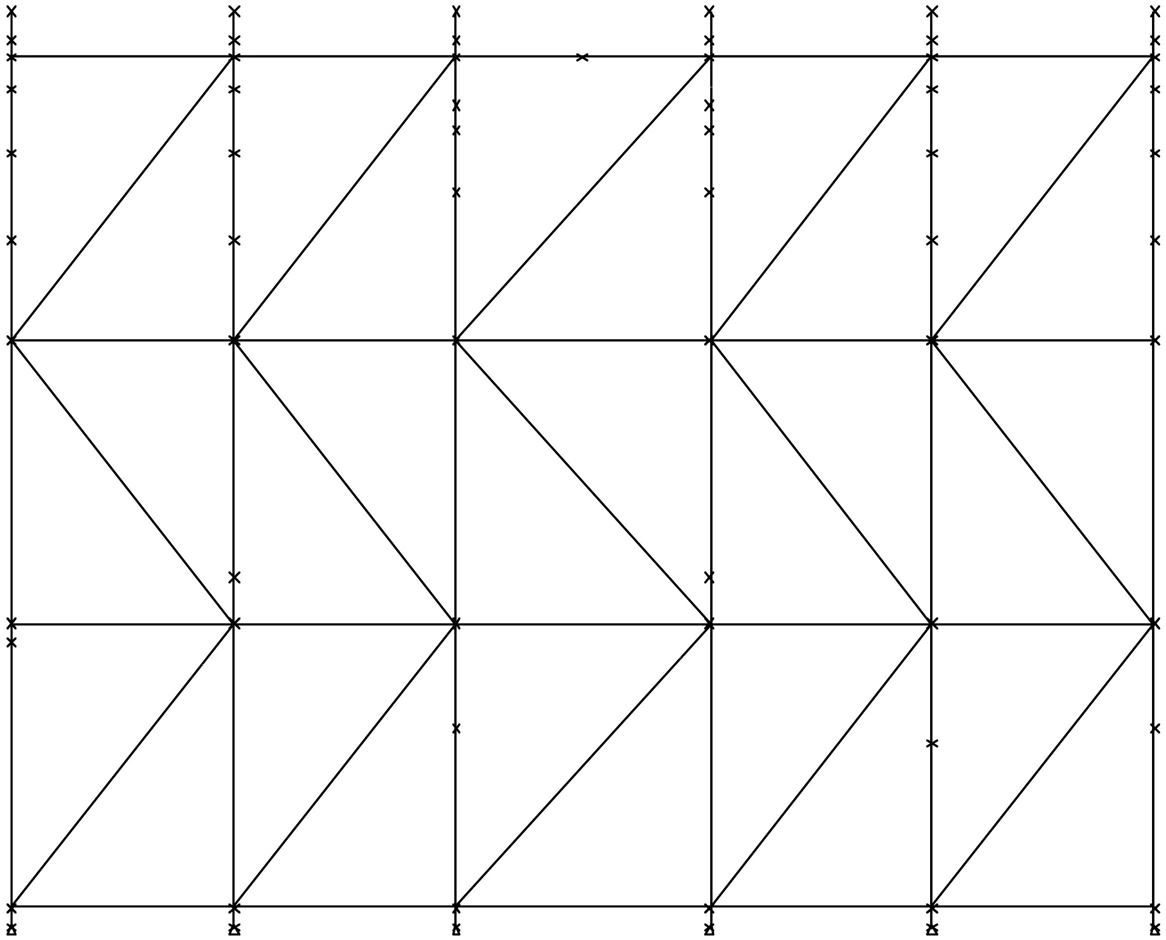
Elevation Frame E



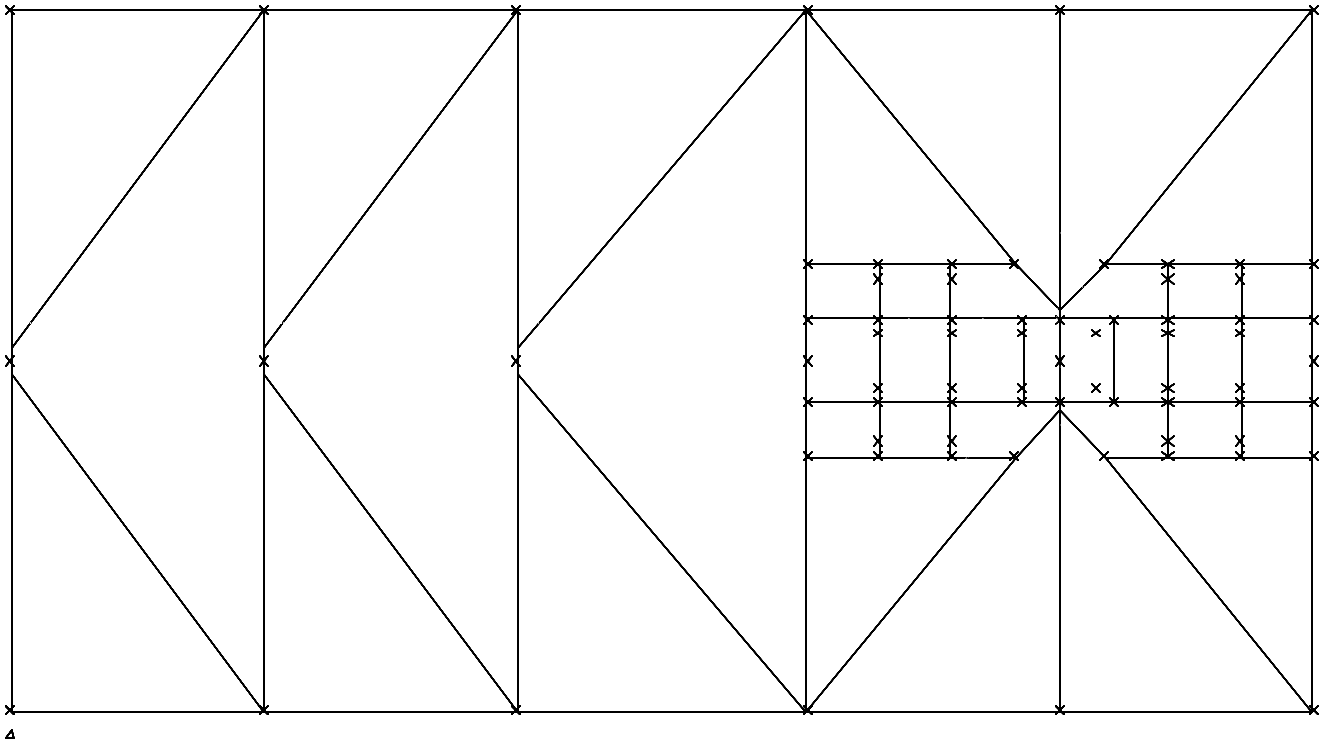
Elevation Frame F



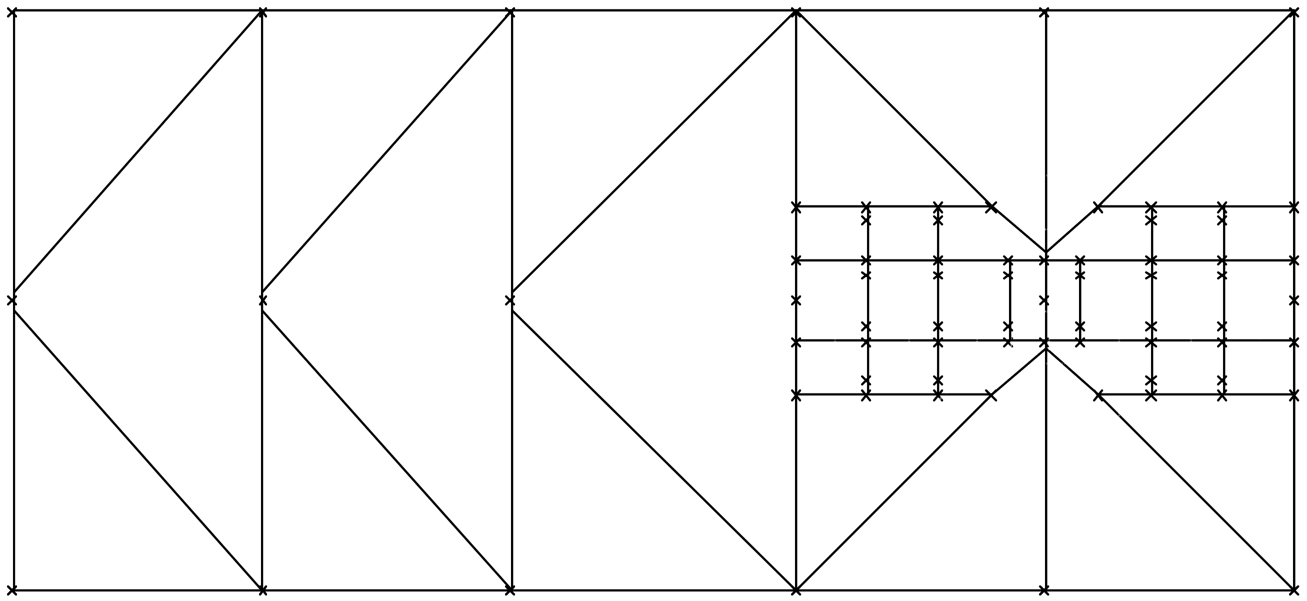
Elevation Frame 1



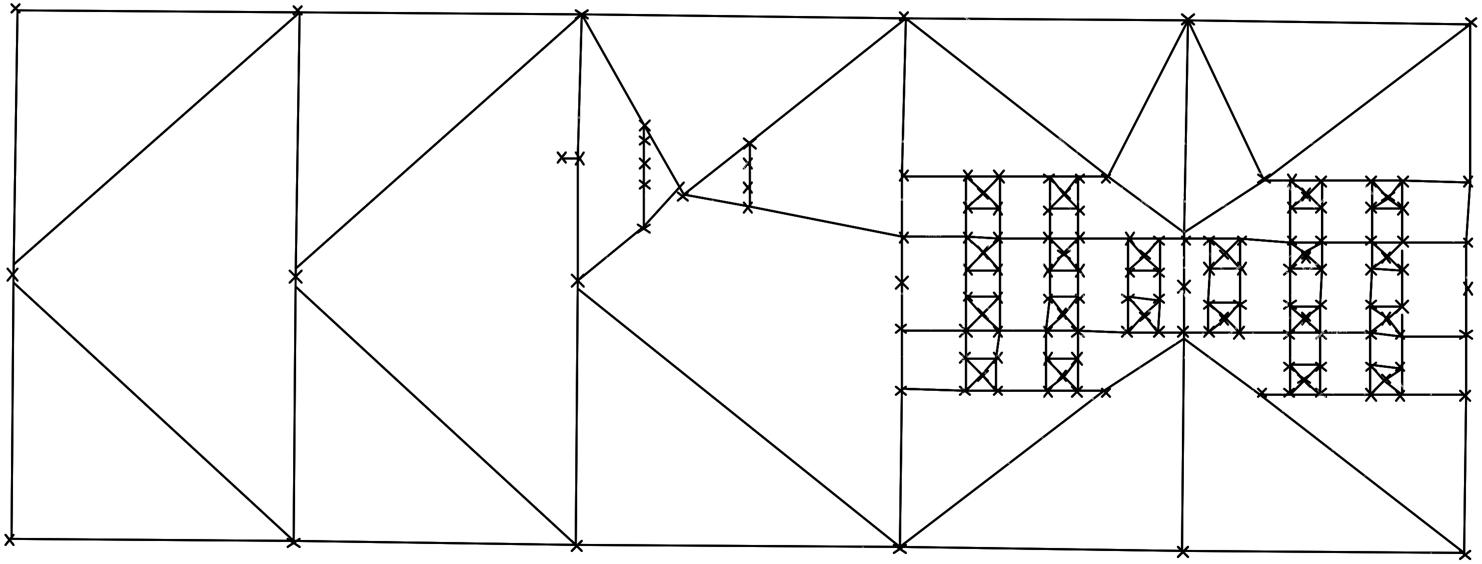
Elevation Frame 2



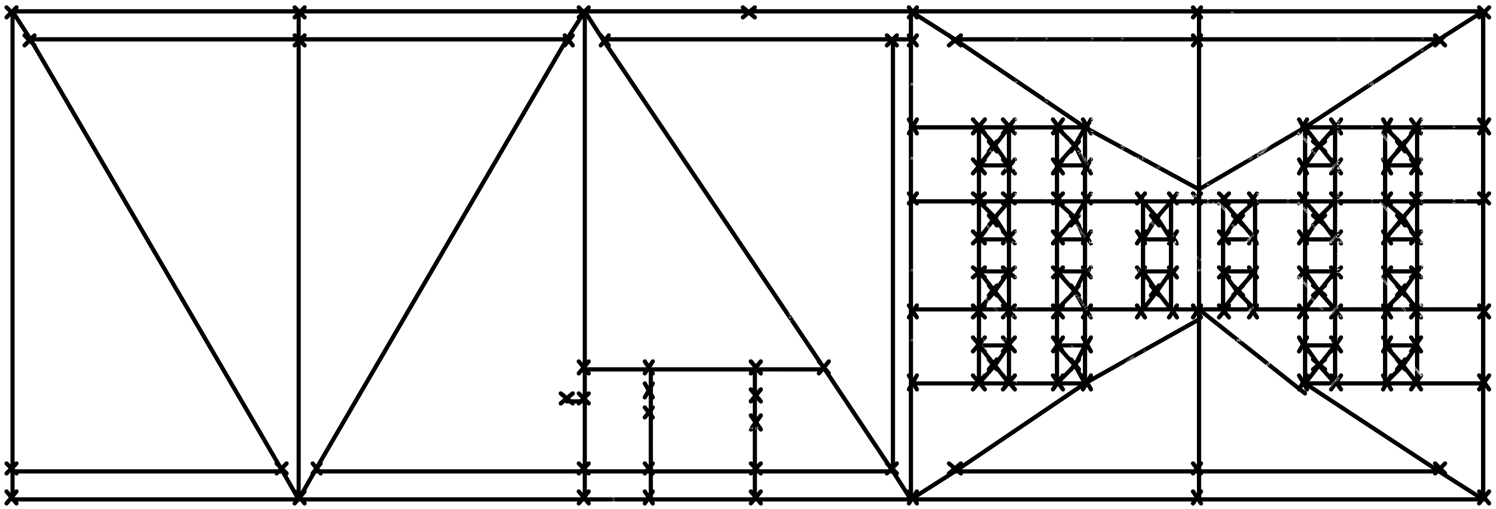
Horizontal Framing Plan @ Elevation –36.1m



Horizontal Framing Plan @ Elevation –20.7m



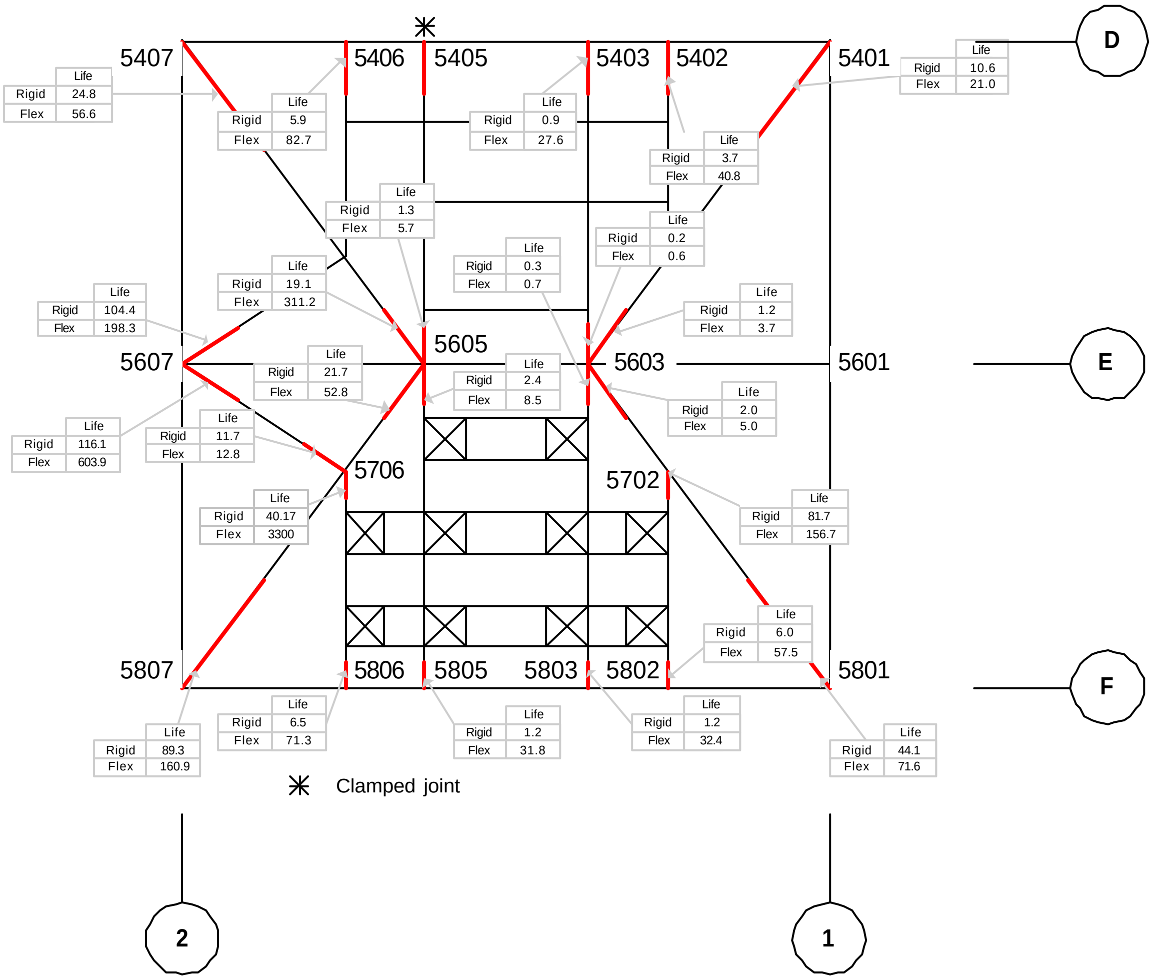
Horizontal Framing Plan @ Elevation –7.3m



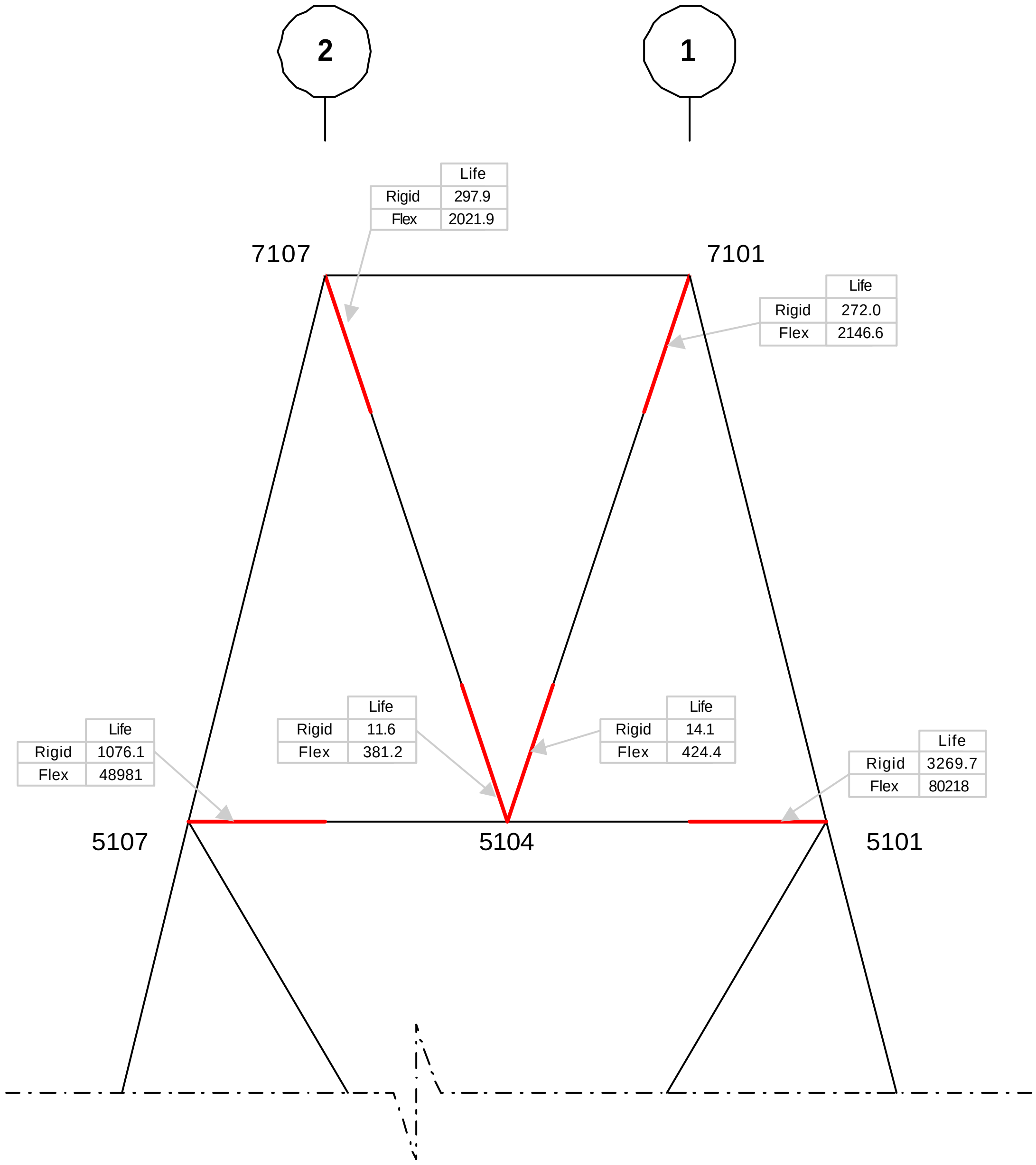
Horizontal Framing Plan @ Elevation +6.1m

APPENDIX C

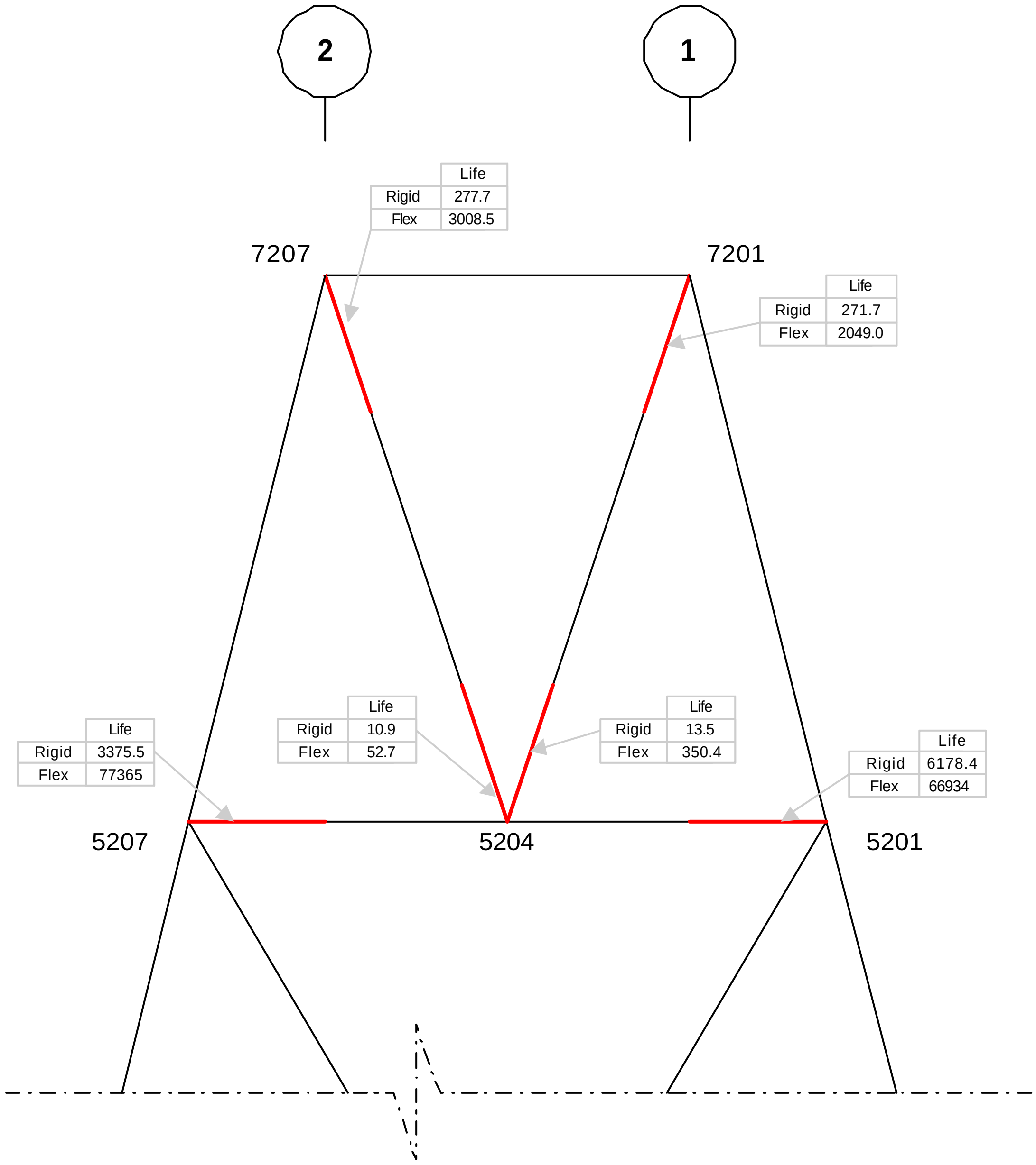
Comparison of Rigid and Flexible Fatigue-life Predictions



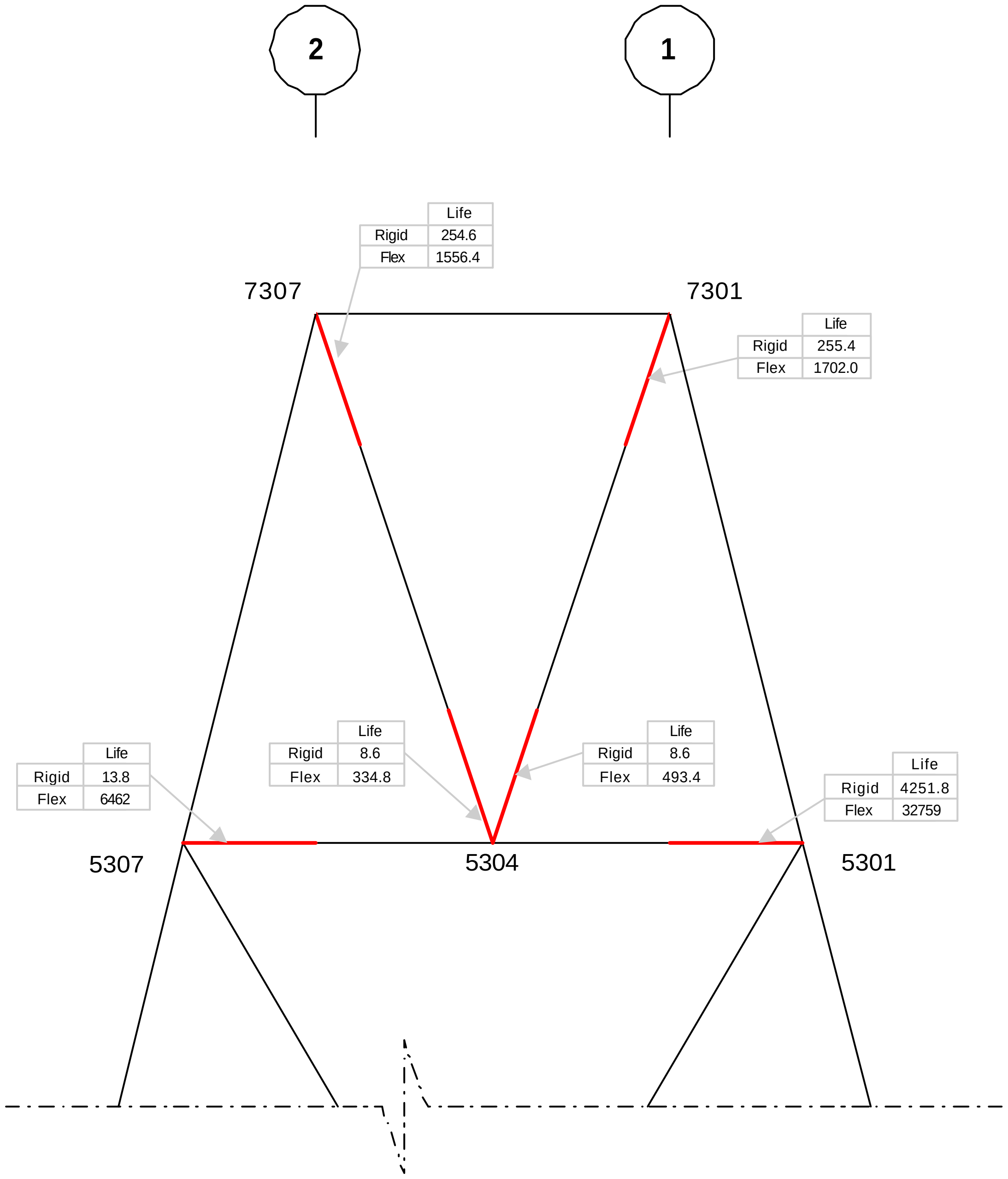
Conductor Guide Framing at Elevation –24 ft



Transverse Frame A



Transverse Frame B



	Life
Rigid	254.6
Flex	1556.4

	Life
Rigid	255.4
Flex	1702.0

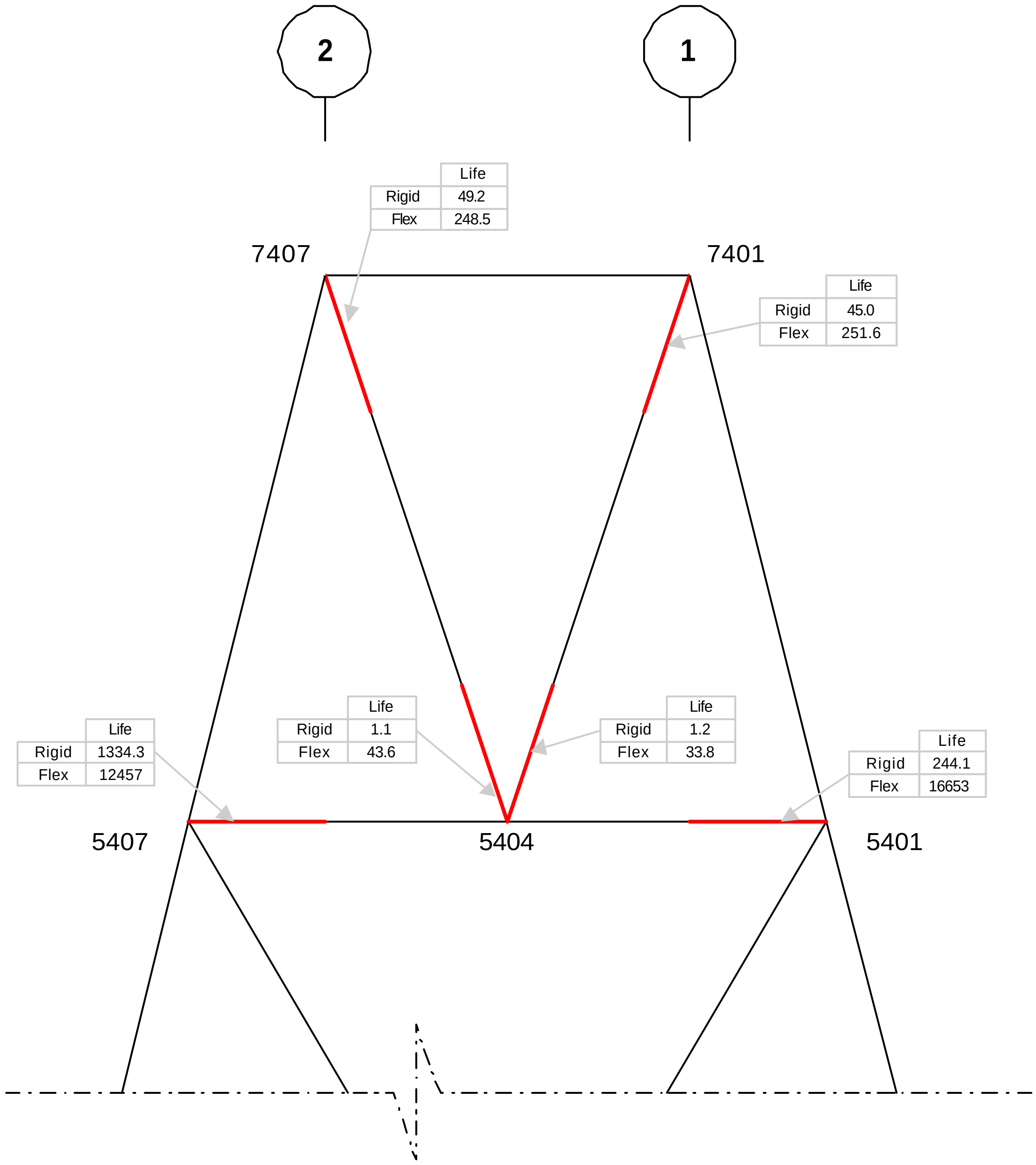
	Life
Rigid	13.8
Flex	6462

	Life
Rigid	8.6
Flex	334.8

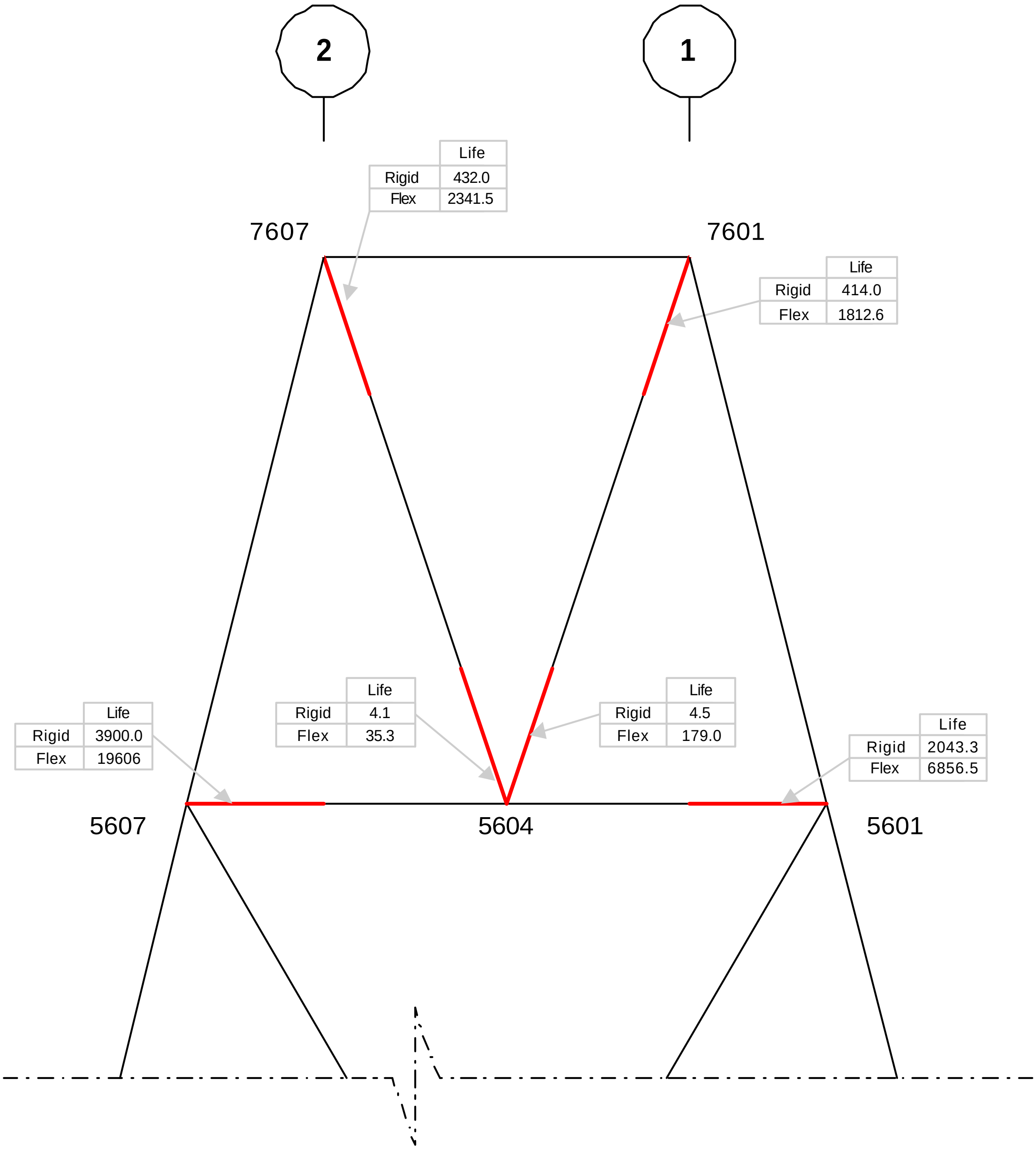
	Life
Rigid	8.6
Flex	493.4

	Life
Rigid	4251.8
Flex	32759

Transverse Frame C



Transverse Frame D



	Life
Rigid	432.0
Flex	2341.5

	Life
Rigid	414.0
Flex	1812.6

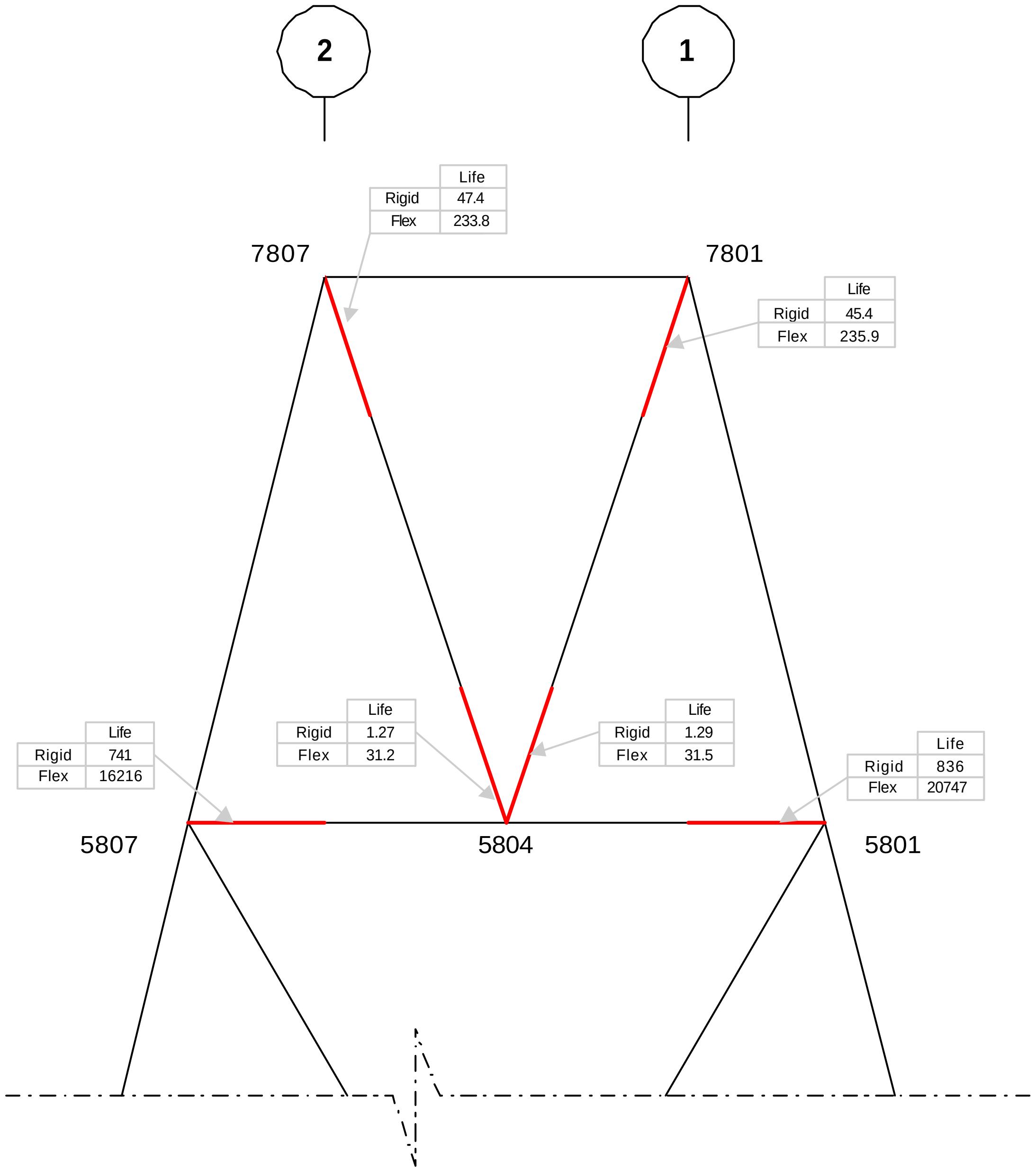
	Life
Rigid	3900.0
Flex	19606

	Life
Rigid	4.1
Flex	35.3

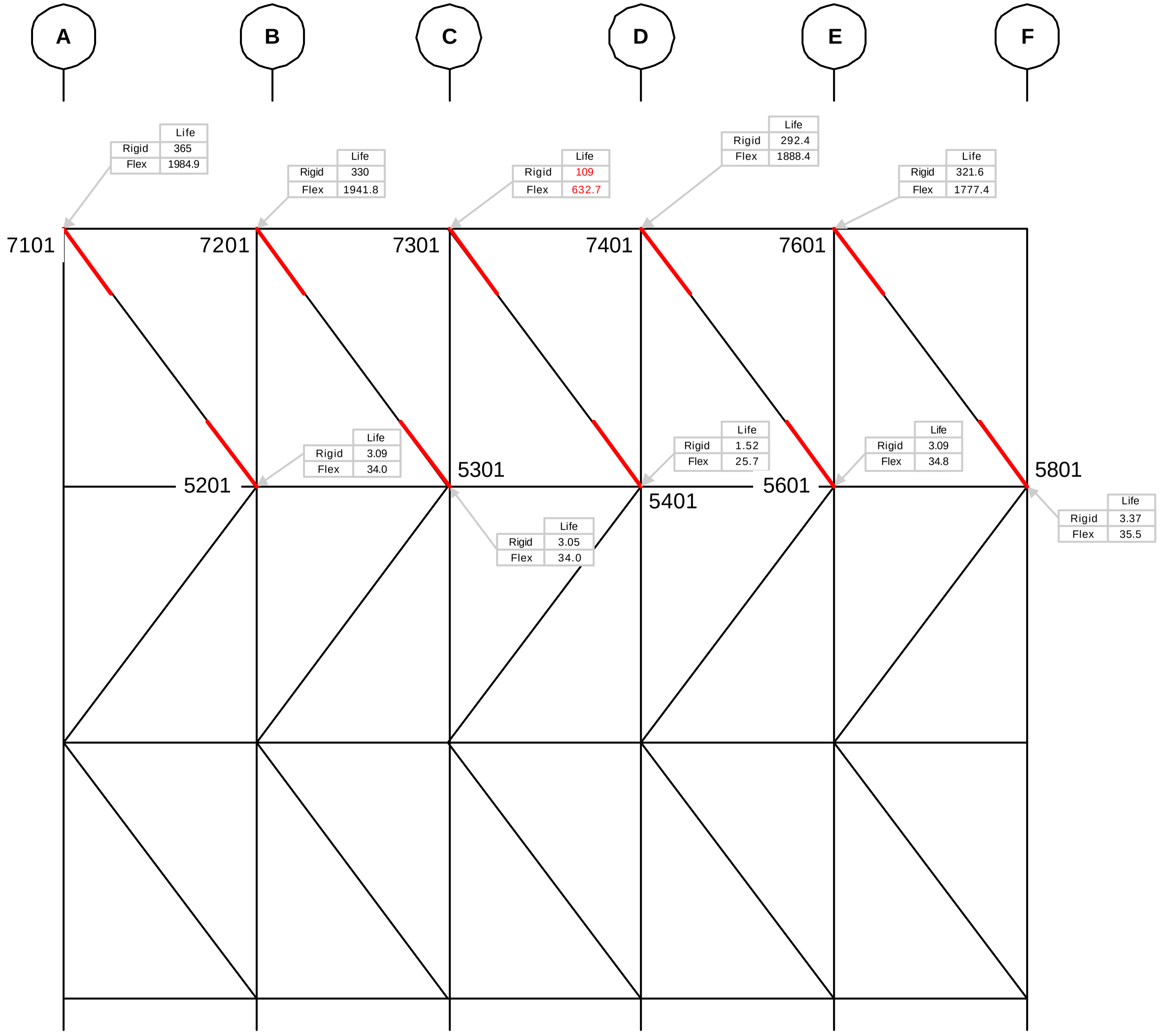
	Life
Rigid	4.5
Flex	179.0

	Life
Rigid	2043.3
Flex	6856.5

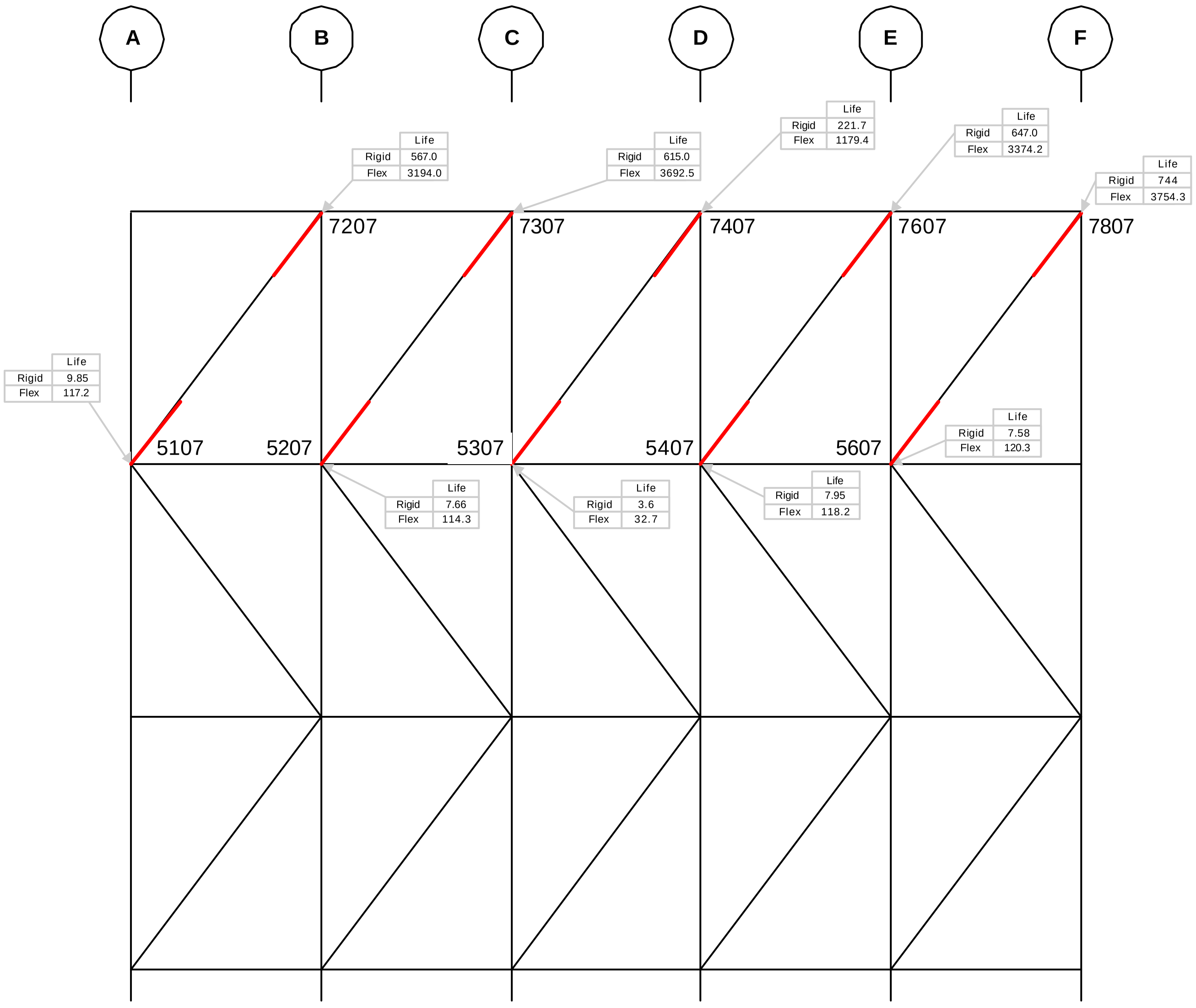
Transverse Frame E



Transverse Frame F



Longitudinal Frame 1



Longitudinal Frame 2

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