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DP&T-SRGE	TITLE: FIRE-STRUCTURE ANALYSES FOR PASSIVE FIRE PROTECTION DESIGN		NP-1 / ESUP

INDEX OF REVISIONS

REV	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	ADDED PROVISIONS TO ACCOUNT FOR THE STRUCTURE IMPAIRMENT
B	GENERAL REVISION
C	REVISED WHERE INDICATED

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	10/28/2016	05/11/2018	07/24/2020	04/22/2021					
DESIGN	ESUP	ESUP	ESUP	ESUP					
EXECUTION	CYMQ	CYMQ	CYMQ	CYMQ					
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APPROVAL	CMR9	SG04	BX65	CMYR					

INDEX

1. INTRODUCTION

This document presents the methodology for the fire-structure analysis used in design of the passive fire protection of structural members of offshore platforms. The presented methodology is based on a combination of the following methods commonly used for the passive fire protection design:

- Screening analysis;
- Strength-level analysis;
- Ductility-level analysis.

The methods above are in order of complexity. For a specific fire scenario, the structural design of the passive fire protection of an offshore platform should start with the screening analysis. If the requirements of the screening analysis are met, the fire scenario is found to be not relevant for the PFP design. If the structure fails to meet the requirements, then a more complex method should be used, to classify the fire scenario as not relevant or to design the PFP. A strength-level analysis might as well be used to classify fire scenarios as not relevant for the PFP design. A ductility-level analysis shall be performed to evaluate the needs of PFP on structural members for the relevant fire scenarios.

The analyses presented in this technical specification addresses the behavior of the structure during accidental limit states. Post-fire assessment shall be performed in order to evaluate the possibility of reuse of the structure after a fire event, considering changes in the material mechanical properties as well as in its metallurgical structure expected after cooling down. Post-fire assessment methodology is not within the scope of this document.

The content indicated hereafter does not exclude the provisions by the Classification Society (CS), also to be complied with. Any unfavorable deviation between the information provided by this document and the Classification Society rules must be reported to PETROBRAS.

2. REFERENCES

This section presents the documents that will be necessary as references for the fire-structure analyses.

2.1. DESIGN DOCUMENTS

[1] STRUCTURAL REQUIREMENTS;
[2] PRIMARY STRUCTURES DRAWINGS;
[3] SECONDARY STRUCTURES DRAWINGS;
[4] GENERAL NOTES FOR STRUCTURES;
[5] WEIGHT CONTROL REPORT;
[6] GENERAL ARRANGEMENT;
[7] METOCEAN DATA;

2.2. RULES, CODES AND STANDARDS

[8] EN1993-1-2 – Eurocode 3 – Design of Steel Structures – Part 1-2: General Rules – Structural Fire Design – 2005;
[9] API RP 2FB – Recommended Practice for the Design of Offshore Facilities Against Fire and Blast Loading – 1st Ed. – 2006;
[10] EN1993-1-1 – Eurocode 3 – Design of Steel Structures – Part 1-1: General Rules and Rules for Buildings – 2005;
[11] DNV RP C208 – Determination of Structural Capacity by Non-linear FE analysis Methods – 2013;
[12] DNV OS C101 – Design of Offshore Steel Structures, General (LRFD Method) –2011;
[13] ABS Guidance Notes on Accidental Load Analysis and Design for Offshore Structures – 2013;
[14] DR-ENGP-M-I-1.3 – Safety Engineering Guideline;
[15] I-ET-3000.00-5400-98G-P4X-003 – Fire Propagation and Smoke Dispersion Study;
[16] DNVGL RP C204 – Design against accidental loads –2017.

3. UNITS

The International System of Units (SI) shall be adopted for the analyses presented in this document. Decimals multiples and fractions of the following units are used:

- Length: meter (m)
- Mass: kilogram (kg)
- Force: Newton (N)
- Stress: Pascal (1 Pa = 1 N/m^2)
- Time: second (s)
- Angle: degree (^{o})
- Temperature: degree Celsius (^{o}C)

4. FIRE-STRUCTURE ASSESSMENT INPUT

The fire assessment consists of five primary inputs:

i. Fire scenario definition;
ii. Structural configuration;
iii. Material properties;
iv. Applied loading;
v. Critical structural items.

4.1. FIRE SCENARIO DEFINITION

The fire scenarios, defined according to [15], shall be considered as input for the steel heat-up analyses.

4.2. STRUCTURAL CONFIGURATION

The structural geometry considers the unit general arrangement and individual member configurations. The structural layout identifies the position of equipment and structural members relative to the release locations considered. This will influence the development of key factors pertinent to the acceptance criteria (proximity to critical safety elements, personnel evacuation routes/muster areas, and degree to which structural damage can be tolerated). Individual structural member geometry definition is required to develop the individual structural member temperature profiles and the overall structural assessment. Utilizing the fire event definition, with the individual member geometry (shape and critical cross-sectional dimensions) and relative position to the fire, it is possible to develop the temperature profile for all affected members during the event.

4.3. MATERIAL PROPERTIES

The primary structural impact of a fire is on the strength and stiffness of the structural members. As the structure is assessed, it is critical that the analysis include the degradation in strength and stiffness with respect to the fire. The changes in properties of structural materials at elevated temperatures including strength, stiffness, and stress-strain behavior are considered, for the scope of this document, to follow the Eurocode 3 [8] approach.

The materials are modelled with their properties at a reference temperature of 20 ºC, with the minimum yield strength presented at [1] and [10], according to the member and steel type (Rolled Profile, Welded Profile, Pipes, Plates). Some of the properties, at reference temperature of 20 ºC, are presented below:

- Young's Modulus: E = 210000 MPa
- Poisson's Ratio: $\nu = 0.3$
- Density: $\rho = 7\,850$ kg/m^3
- Coefficient of thermal expansion: $\alpha = 1.2 \times 10^{-5}$ / ºC

In the Eurocode 3 [8] approach, the stress-strain relationship of steel at elevated temperatures are defined by three temperature-dependent material properties. The changes in stiffness, effective yield strength and proportional limit are presented in Table 1 and illustrated in Figure 1. For intermediate temperature values, linear interpolation may be used. The reduction factors for the material properties are defined as follows:

- effective yield strength, relative to yield strength at 20ºC: $k_{y,\theta} = f_{y,\theta}/f_y$;
- proportional limit, relative to yield strength at 20ºC: $k_{p,\theta} = f_{p,\theta}/f_y$;
- slope of linear elastic range, relative to slope at 20ºC: $k_{E,\theta} = E_{a,\theta}/E_a$.

Table 1 - Reduction factors for stress-strain relationship of carbon steel at elevated temperatures [8]

Steel Temperature θ_a	Reduction factors at temperature θ_a relative to the value of f_y or E_a at 20 ºC $k_{y,\theta} = f_{y,\theta}/f_y$	$k_{p,\theta} = f_{p,\theta}/f_y$	$k_{E,\theta} = E_{a,\theta}/E_a$
20 ºC	1.000	1.000	1.000
100 ºC	1.000	1.000	1.000
200 ºC	1.000	0.807	0.900
300 ºC	1.000	0.613	0.800
400 ºC	1.000	0.420	0.700
500 ºC	0.780	0.360	0.600
600 ºC	0.470	0.180	0.310
700 ºC	0.230	0.075	0.130
800 ºC	0.110	0.050	0.090
900 ºC	0.060	0.0375	0.0675
1000 ºC	0.040	0.025	0.045
1100 ºC	0.020	0.0125	0.0225
1200 ºC	0.000	0.000	0.000

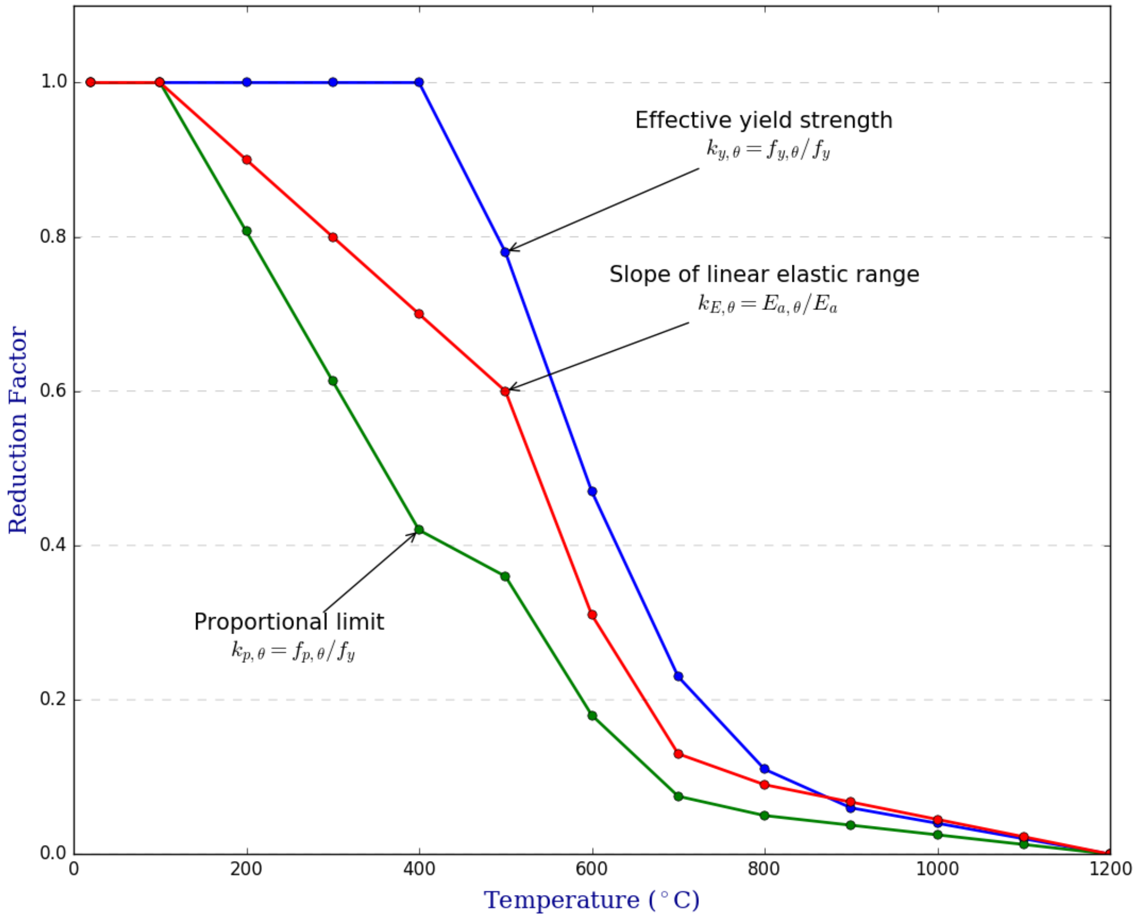

Figure 1 - Reduction factors for the stress-strain relationship of carbon steel at elevated temperatures [8]

The yield stress is taken as the stress at 2 % strain (ε = 0.02) and is termed the effective yield stress. An ellipse is fit between the proportional limit and the effective yield stress and beyond a strain of 2 %, the stress-strain relationship is flat up to a strain of 15 % (ε = 0.15). The temperature-dependence of each parameter is normalized to an ambient temperature value of E = 210000 MPa for E_T and f_y at 20 ºC determined from the 0.2 % strain (ε = 0.002) offset yield strength. The stress f at strain ε may be determined from the expressions given in Table 2.

Table 2 – Stress-strain expressions

Strain range	Stress σ			
$\varepsilon \leq \varepsilon_{p,\theta}$	$\varepsilon E_{a,\theta}$			
$\varepsilon_{p,\theta} < \varepsilon < \varepsilon_{y,\theta}$	$f_{p,\theta} - c + \left(\frac{b}{a}\right)\left[a^2 - \left(\varepsilon_{y,\theta} - \varepsilon\right)^2\right]^{0.5}$			
$\varepsilon_{y,\theta} < \varepsilon < \varepsilon_{t,\theta}$	$f_{y,\theta}$			
$\varepsilon_{t,\theta} < \varepsilon < \varepsilon_{u,\theta}$	$f_{y,\theta}\left[1 - \frac{\left(\varepsilon - \varepsilon_{t,\theta}\right)}{\left(\varepsilon_{u,\theta} - \varepsilon_{t,\theta}\right)}\right]$			
$\varepsilon = \varepsilon_{u,\theta}$	0			
Parameters	$\varepsilon_{p,\theta} = \frac{f_{p,\theta}}{E_{a,\theta}}$	$\varepsilon_{y,\theta} = 0.02$	$\varepsilon_{t,\theta} = 0.15$	$\varepsilon_{u,\theta} = 0.20$
Functions	$a^2 = \left(\varepsilon_{y,\theta} - \varepsilon_{p,\theta}\right)\left(\varepsilon_{y,\theta} - \varepsilon_{p,\theta} + \frac{c}{E_{a,\theta}}\right)$ $b^2 = c\left(\varepsilon_{y,\theta} - \varepsilon_{p,\theta}\right)E_{a,\theta} + c^2$ $c = \frac{\left(f_{y,\theta} - f_{p,\theta}\right)^2}{\left(\varepsilon_{y,\theta} - \varepsilon_{p,\theta}\right)E_{a,\theta} - 2\left(f_{y,\theta} - f_{p,\theta}\right)}$			
Naming Conventions	$f_{y,\theta}$ effective yield strength $f_{p,\theta}$ proportional limit $E_{a,\theta}$ slope of the linear elastic range $\varepsilon_{p,\theta}$ strain at the proportional limit $\varepsilon_{y,\theta}$ yield strain $\varepsilon_{t,\theta}$ limiting strain for yield strength $\varepsilon_{u,\theta}$ ultimate strain			

Based on the expressions given in Table 2, the stress-strain curve, for the reference temperature of 20 ºC, evaluated for the S355 steel with the material properties (f_y = 355 MPa, E = 210000 MPa) according to Eurocode 3 [10] is presented in Figure 2. Stress-strain curves, for temperatures from 20ºC to 1100ºC, are shown in Figure 3.

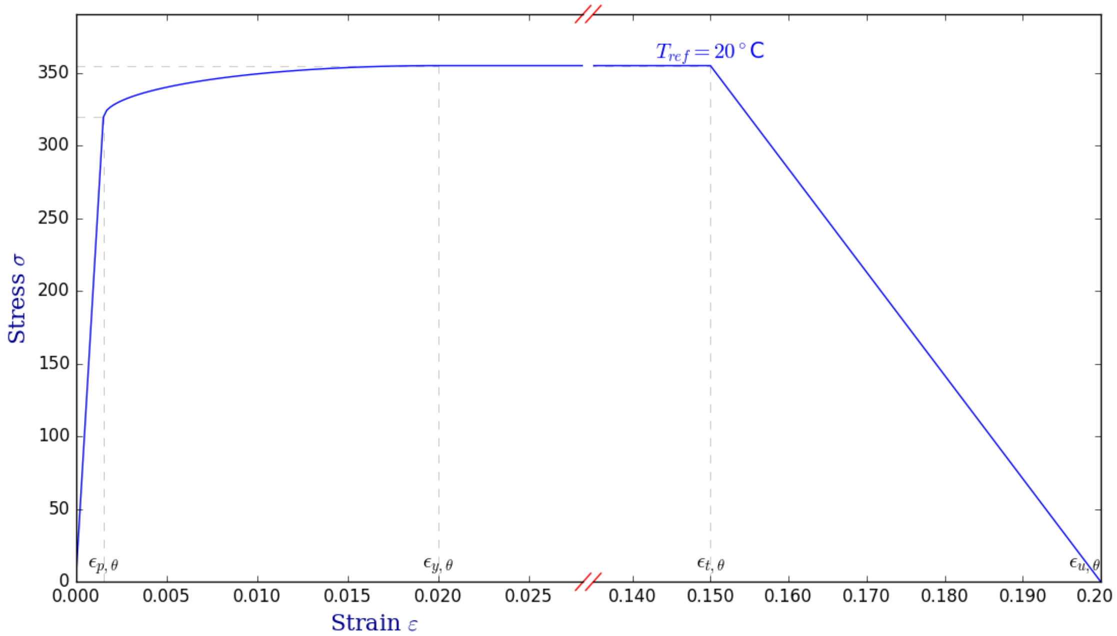

Figure 2 – Stress-strain curve for S355 steel at reference temperature

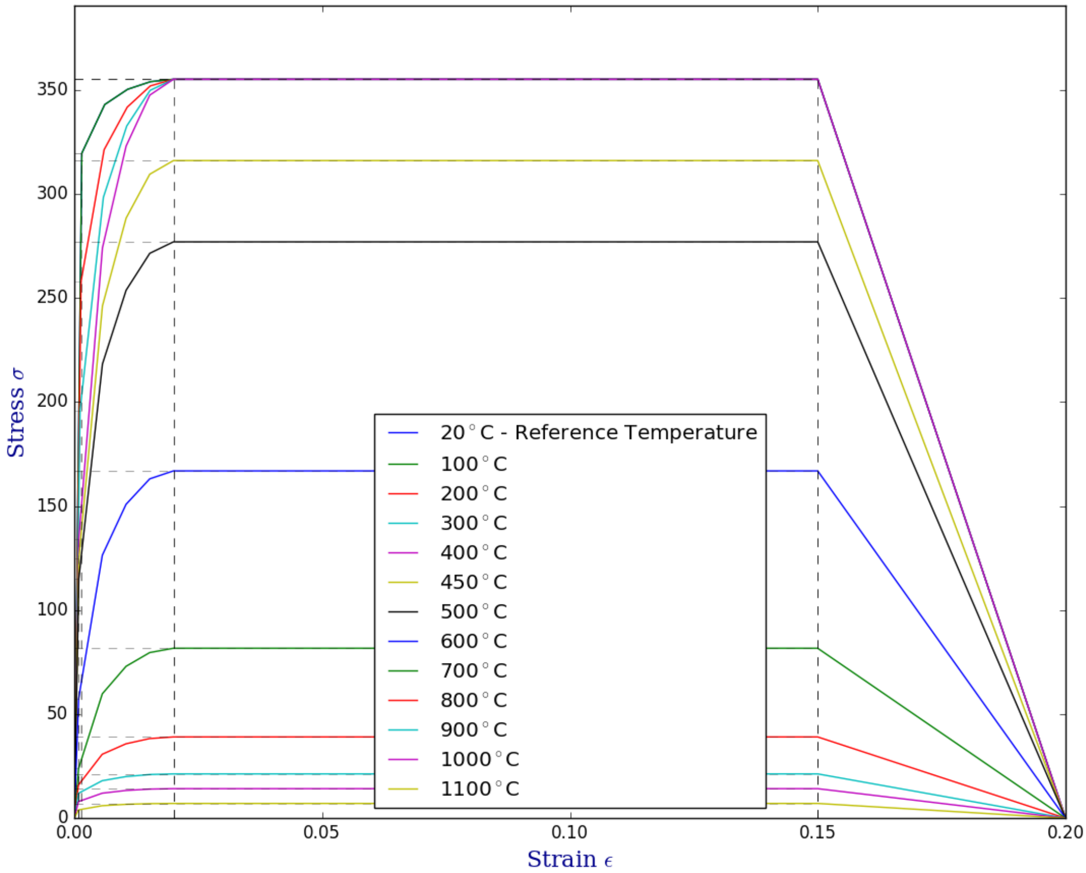

Figure 3 – Stress-strain curves for S355 steel

For temperatures below 400ºC, the stress–strain relationships may be extended by the strain hardening option, provided local instability is prevented and the ratio f_u/f_y is limited to 1.25. The stress-strain curves considering strain hardening for temperatures below 400ºC [8] are shown in Figure 4.

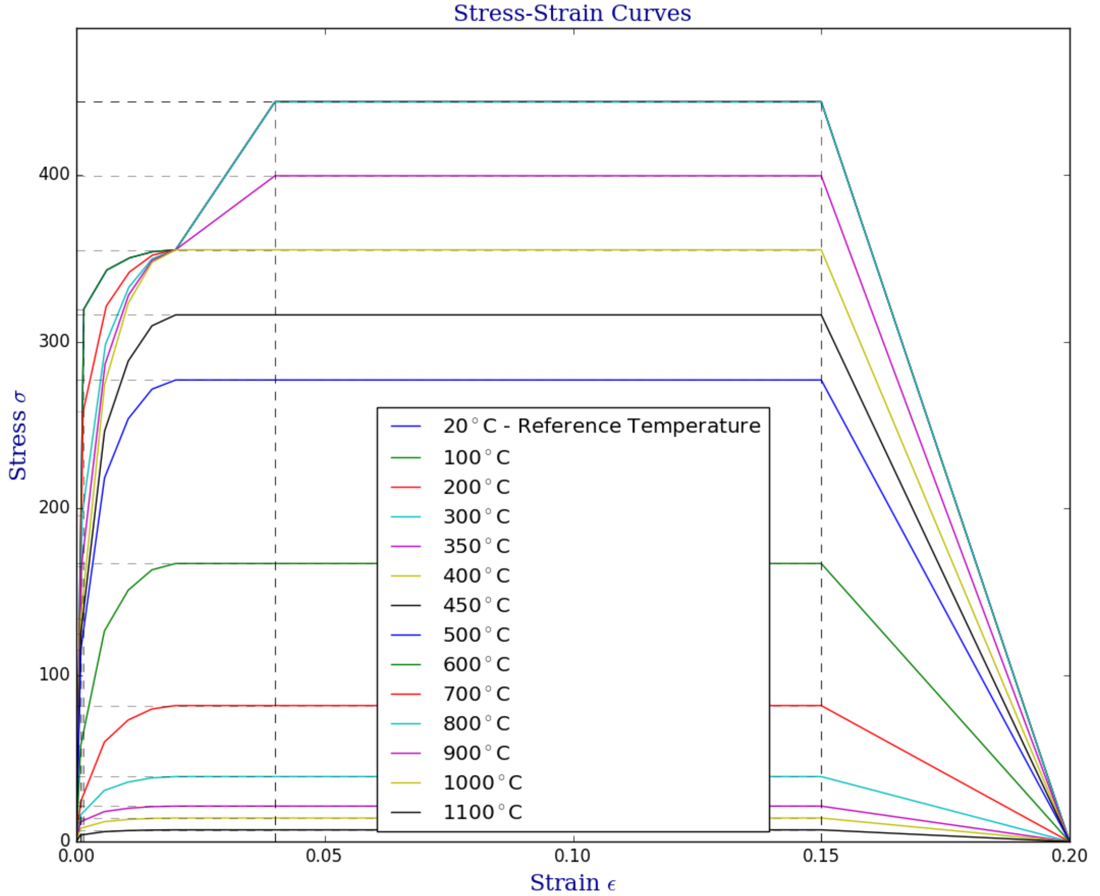

Figure 4 – Stress-strain curves for S355 steel with hardening

4.4. APPLIED LOADING

Loads are separated into two categories for the fire events:

i. Thermal loads;
ii. Structural loads.

Thermal loads are used to predict the individual member thermal histories given the fire scenario definition, the member's geometry, and the presence of any fire protection system (such as PFP) that may limit the heat flux into the structure. The thermal time histories for each exposed member are calculated based on:

- Fire intensity (incident radiant/convective heat fluxes, radiant/convective/conductive heat fluxes away from member);
- Proximity of member to flame (engulfed/non-engulfed member);
- Structure geometry (shape and dimensions).

A steel heat-up analysis will produce temperature profiles that may vary across the sections and along the lengths of components. This information needs to be converted to input for structural analyses software in accordance with the structural model adopted. The starting reference temperature shall be taken as the air temperature characteristic monthly mean value from the metocean data [7] used in the structural design.

Structural loads to be considered in the models can be separated into several broad categories:

- Dead loads consist of structural members self-weight, non-modeled structural weights, miscellaneous items (such as electrical, instrumentation, safety, telecom), operating piping and operating equipment weights;

- Live loads (only at laydown and storage areas). Other live loads as well as environmental loads are not to be considered;
- Functional loads such as helideck and crane loads may be considered but typically only if pertinent to the fire scenario identified.
- Jet fire momentum loads;
- Hull deflections at static condition.

4.5. CRITICAL STRUCTURAL ITEMS

Among the inputs for the fire-structure analyses is the definition of critical structural elements to receive passive fire protection:

- Primary structure (according to design documents);
- Secondary structural elements considered important;
- Secondary structure supporting important equipment;
- Secondary structure supporting piping (escalation);

The definition of the important equipment, secondary structure and piping support structures, as well as the structural performance criteria to be adopted for those elements supporting equipment and piping, shall be defined in a specific meeting with PETROBRAS and Designer's representatives of the following disciplines: structures, process, safety, piping and equipment.

Item 4.3.2.1, from safety engineering guideline [14], shall be considered in the critical equipment/structure definition.

5. FIRE-STRUCTURE DESIGN METHODOLOGY

The fire-structure design methodology presented in this document is based on the Recommended Practice API RP 2FB [9]. There are typically three different assessment methods utilized:

i. Screening analysis (zone method);
ii. Strength-level analysis (linear elastic method);
iii. Ductility-level analysis (nonlinear, elastic plastic method);

The three methods represent an increasing level of sophistication. The fire-structure design will typically progress through each method so as to eliminate a given fire scenario from further consideration due to structural safety and environmental performance, being deemed acceptable with the least computational effort required. This procedure results in a decreasing number of analyses being performed as the method complexity increases.

In order to start the fire-structure assessment, the fire scenarios shall be addressed and steel heat-up analyses shall be performed. With the temperatures in the structural members, the fire-structure assessment is performed with a combination of the three methods:

i. Alternative 1 (screening, followed by linear and nonlinear analyses);
ii. Alternative 2 (screening, followed by nonlinear analyses)

The screening analysis will filter the relevant cases for more complex and in-depth analyses. If the scenario is considered relevant in the screening analysis, according to structural criteria described in the respective section, a strength analysis might be performed. From a strength analysis, a ductility analysis for some fire scenarios might be avoided. Alternatively, a ductility analysis might be performed in order to evaluate the need for passive fire protection at the structural members. The fire-structure design workflow, as considered in this document, is presented in Figure 5.

It should be noted that the decision for mitigation with passive fire protection (PFP) of structural elements is carried out after a ductility analysis.

When PFP is specified, after having considered also criteria defined in Section 9, its effects on structural member temperatures shall be incorporated in the model and the results validated, by including these effects on a steel heat-up analysis, and performing the structural assessment.

Regardless of structural analysis method selected, the facility needs to be verified to meet the acceptance criteria defined in the respective sections of this document.

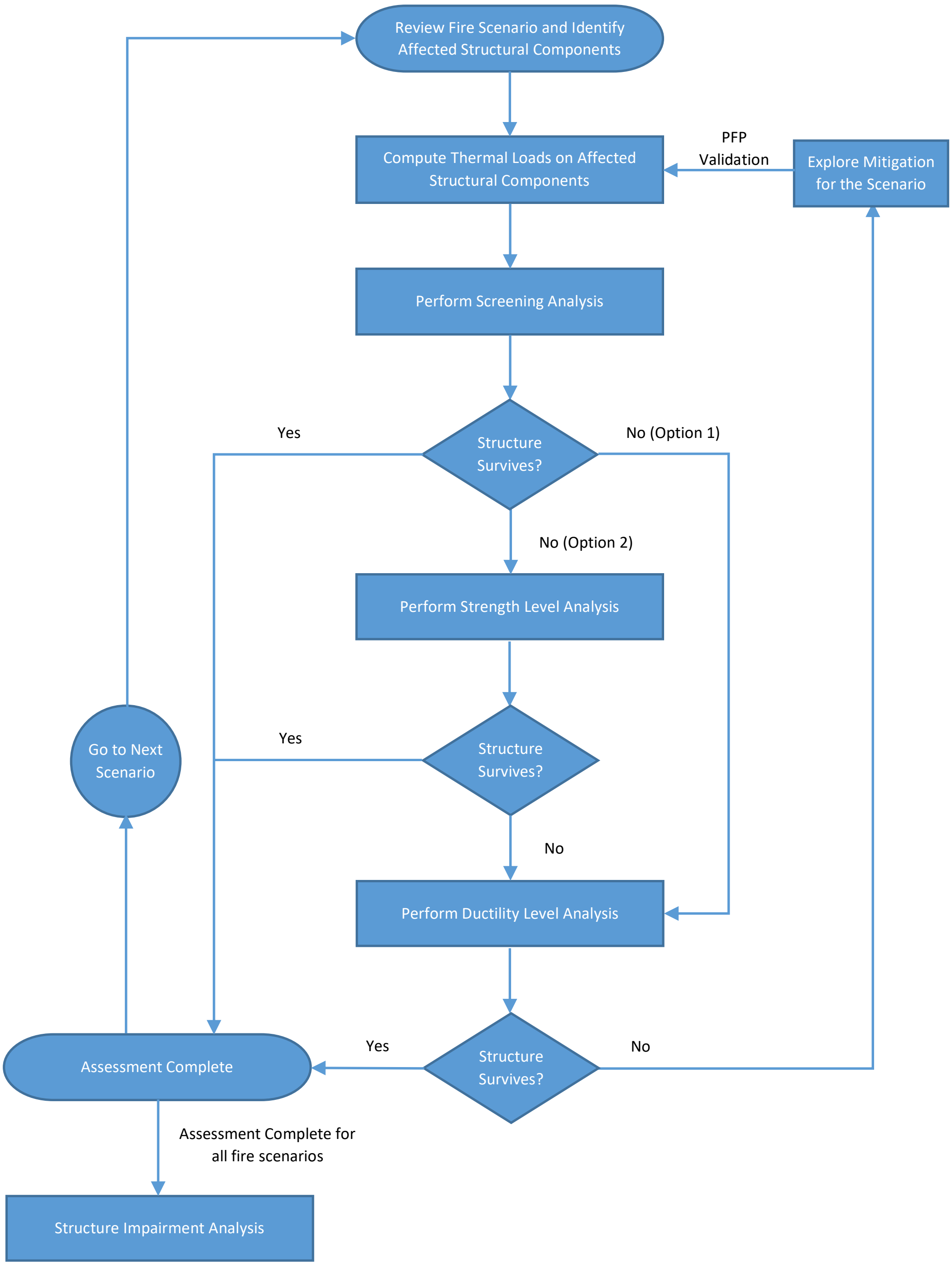

Figure 5 – Fire-structure design workflow

6. SCREENING ANALYSIS

6.1. INTRODUCTION

The screening analysis is the simplest approach. The underlying premise to the screening analysis is that the structure is permitted to experience stresses up to yield during an event such as a fire. As the structural temperature increases, the yield strength will reduce. It is possible to relate the loss in strength to the elastic design utilizations so that acceptance is governed only by the maximum temperature for an individual member.
The main premise of this method is that a member utilization ratio obtained with allowable stress (0.6 F_y) will remain the same for the fire load condition if the utilization ration is increased to 1.0, while the yield stress itself is subject to a reduction factor of 0.6.

6.2. ANALYSIS INPUTS

The inputs for the screening analysis consists of the maximum temperatures at the individual structural members, for each fire scenario. The temperatures at the structural members are obtained directly from the steel heat-up analyses.

6.3. ANALYSIS OUTPUTS

The output from the screening analysis identifies structural members that would exceed the threshold temperature defined at 6.4, therefore, structural elements exceeding the elastic limit for a member that was fully utilized prior to the fire event.

The results provide two alternatives: consider the respective fire scenario as not relevant or perform more refined analyses as presented in 7 or 8.

6.4. DESIGN CRITERIA

All structural members must remain below 450°C during the fire scenario.

7. STRENGTH-LEVEL ANALYSIS

7.1. INTRODUCTION

A linear-elastic analysis is a strength level analysis to evaluate the structural performance considering both temperature profile and member utilization. The scenarios include those fire events with elements that failed to pass the screening method. Depending on the maximum temperature profile attained by individual structural members for the duration of the fire, the reduced stiffness and yield strength of the member should be used in the structural analysis.

The assessment of a given fire scenario will determine the temperature of members affected by the fire and the degradation of the material properties. The structure is checked at the accidental limit state with appropriate load and resistance factors (LRFD) or allowable stress (WSD) corresponding to the accidental limit state design. Thermal induced loads should be considered in the accidental load case and the response of the structure for the accidental load case considering loads according to 4.4 should be compared to the criteria, defined in 7.4.

7.2. ANALYSIS INPUTS

There are two primary inputs for the strength-level, method:

i. Structural member maximum temperature profile for the given fire scenario;
ii. Structural loads as defined at 4.4.

7.3. ANALYSIS OUTPUTS

The outputs from the strength-level analysis are the utilization factors of the structural members for the accidental load case. If the structure does not pass the linear check, then the structure shall be reassessed for the fire event using more advanced (less conservative) nonlinear elastoplastic method.

7.4. DESIGN CRITERIA

The maximum acceptable member utilization for the accidental condition should be adopted as 1.0.

8. DUCTILITY LEVEL ANALYSIS

8.1. INTRODUCTION

The nonlinear, elastoplastic method (ductility-level analysis) is the most refined analysis considered in this document. It is a progressive collapse analysis method that allows for load redistribution as individual members fail due to the applied fire and structural loads. The load redistribution utilizes alternative load paths to compensate for the lost strength in the failed or severely degraded member.

The ductility level analysis is performed in the time domain. The time history analysis traces the entire fire event from its initiation to its termination. During the event, affected structural members experience both the applied structural static loads as well as the time varying thermal loads that degrade both strength and stiffness. The sequence of member failure and load redistribution shall be captured in the analysis. The primary focus of the elastoplastic analysis is to assess the structural system's maximum strength with minimum conservatism. As such, significant plastic (up to 15% strain) deformations and damage associated with the fire event are acceptable for secondary elements that were not defined as critical according to 4.5, provided the damage does not cause the global failure and escalate the consequences of the event.

The model for mechanical response shall take account of [8][16]:

- the combined effects of mechanical actions, geometrical imperfections and thermal actions;
- the temperature dependent mechanical properties of the material, as in 4.3;
- geometrical non-linear effects;
- the effects of non-linear material properties, including the unfavorable effects of loading and unloading on the structural stiffness;
- the effects of thermally induced strains and stresses both due to temperature rise and due to temperature differentials.

The effects of transient thermal creep need not be given explicit consideration when the stress-strain relationships presented in 4.3 are adopted in the model [8].

The fire resistance of a bolted or a welded joint may be assumed to be sufficient provided that the thermal resistance of the joint's fire protection should be equal to or greater than the minimum value of thermal resistance of fire protection applied to any of the joined members [8].

8.2. ANALYSIS INPUTS

The nonlinear structural analysis performed considers the following inputs:

- Structural loads as defined at 4.4;
- Structural member temperature time histories during the fire scenario duration, as defined in 4.4;
- Temperature dependent stress-strain curves and Young Modulus, as defined in 4.3;

The structural member temperatures are obtained from a steel heat-up analysis considering the effects due to the presence of passive fire protection, when specified.

8.3. ANALYSIS OUTPUTS

The results of the ductility analyses are the equivalent stresses as well as total and plastic strains at the structural members. Based on this information, passive fire protection shall be specified, when necessary.

8.4. DESIGN CRITERIA

In the structural evaluation of a defined fire event, the structure should be designed to meet specific performance criteria. These criteria should be selected to ensure that the consequence of the event is consistent with the risk level assigned in the risk assessment for that event. The performance criteria defined in this document shall be taken into account together with the criteria defined in the safety engineering guideline document.

The structural criteria to be used in the ductility analyses are the following:

- Any blast walls and fire walls shall remain in place without rupture or discontinuation of their supports; deformation of the wall shall be limited to avoid escalation.
- Safety critical elements (SCEs) that are designed to mitigate the effects of a major accident, such as those necessary for (a) the safe shut down of the installation, (b) personnel protection and escape, (c) fire protection, suppression and control, (d) communications, and (e) hydrocarbon containment including transport and storage; shall remain intact.
- Structural elements classified as primary structure shall not be subject to total strain above 2%.
- Global structure stability shall be preserved at the end of temperature history ensuring that there is no sudden or progressive collapse of the overall topside structure.
- Local buckling shall be prevented or considered accordingly.
- Critical deformation of secondary structure to avoid damage to critical equipment and piping supports, as defined according to 4.5.
- The design shall take into account the ultimate limit state beyond which the calculated deformations of the structure would cause failure due to the loss of adequate support to one of the members [8].

8.5. VALIDATION STEP

A validation step shall be performed including the effects of the PFP in the structure in order to assure that the structural behavior of the protected structure is as intended. The effects of the PFP in the protected structural element might be included on a steel heat-up analysis in order to perform the structural assessment for the validation step. Alternatively, in a simplified way, the PFP effects on the structure temperatures might be considered as a limiting maximum temperature that the element will be subject to, according to the PFP manufacturer data.

9. STRUCTURE IMPAIRMENT ANALYSIS

After the workflow presented in Figure 5 is complete for every fire scenario, a structure impairment analysis shall be performed in order to ensure that the impairment criteria is met.

The structure impairment analysis step accounts for the occurrence of failure of any structural member of the platform and is performed to assess the risk of structural failure due to fire events. The expression structural failure is used here to indicate that the structure failed to comply with the design criteria adopted in 8.4, and does not mean real structural collapse.

When it is identified, during the structural analysis step, that the structure needs mitigation by PFP to perform within the allowable structural limits for a specific fire scenario (8.4), a failure is accounted with the frequency of occurrence of the fire scenario in study. The total impairment of the structure due to fire events should be lower than the limit value specified in [15]. If the total impairment of the structure is greater than the limit, PFP shall be applied to reduce the impairment of the structure to the limit value.

In order to choose the fire scenarios that will receive PFP, the fire scenarios shall be ordered as presented in [15] and PFP shall be applied to the fire scenarios that are increasing the impairment of the structure, at the locations and quantities designed in the structural step.

10. PASSIVE FIRE PROTECTION DESIGN

The PFP requirements for the structure should be determined after the analyses shown at workflow presented in Figure 5 were performed. According to the characteristics (jet fire or pool fire) and duration of the fire scenario a compatible type of PFP shall be specified should the structural members fail to meet the structural criteria.

The final report with the results from the fire-structure analyses shall present the temperature profiles, highlighting the maximum steel temperatures for each time step for the relevant scenarios. An example of a temperature plot for a specific fire scenario and a specific time of the analysis is shown in Figure 6

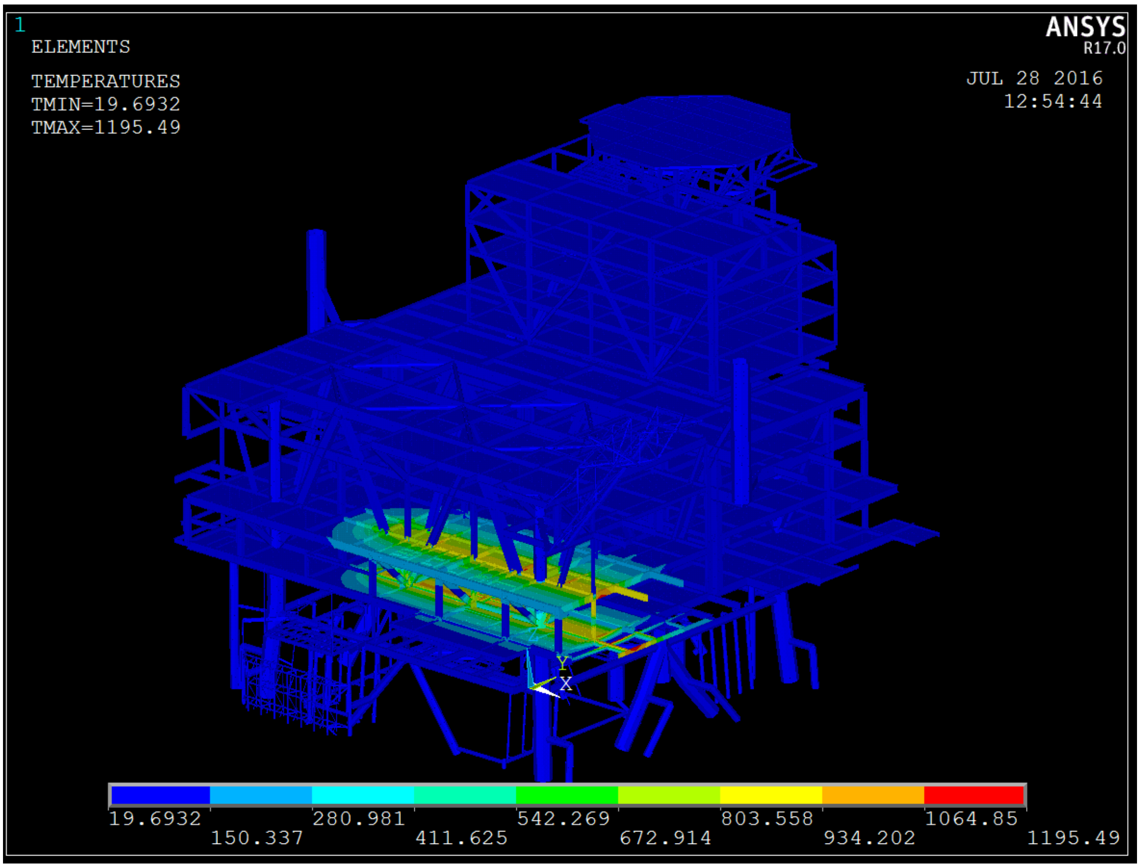

Figure 6 – Temperatures (ºC) in t=1140s, without PFP

Stresses, plastic/total strains as well as the structural criteria that was used to design the PFP shall be presented at the report for each fire scenario were the ductility analysis was performed. Utilization factor of the structure for the accidental limit state shall be presented for the fire scenarios where the linear analyses was performed. An example of a structural criteria plot based on total mechanical strain is shown in Figure 7, after a validation step where the effects of the PFP on the structure temperature were taken into account in the structural analyses.

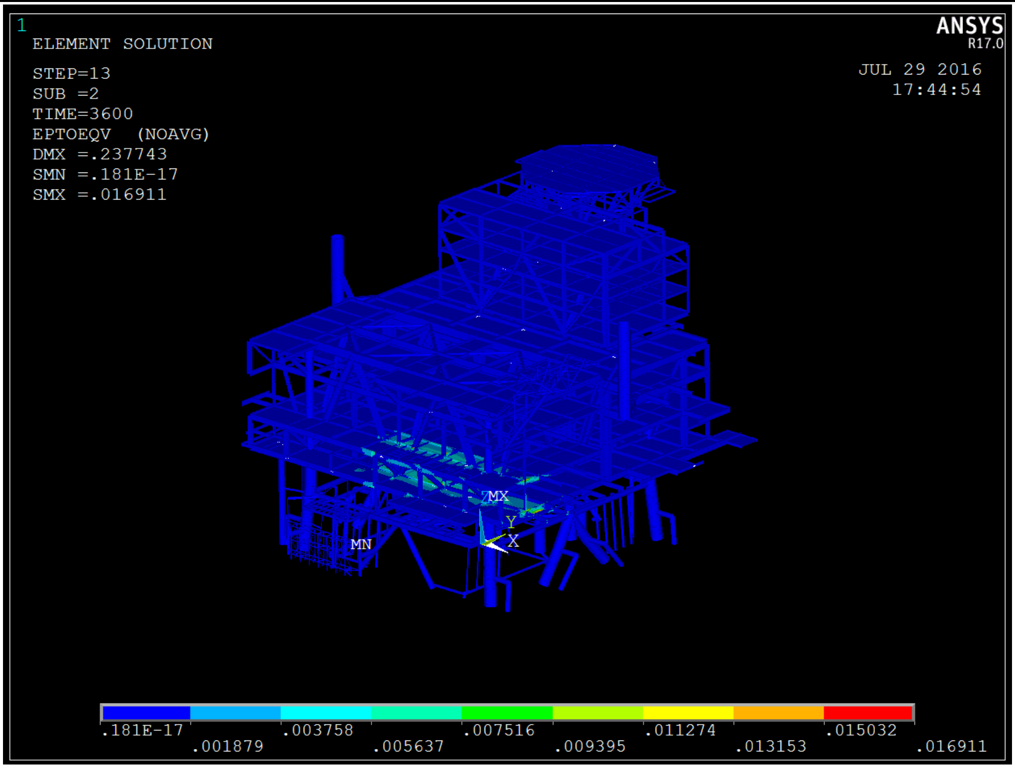

Figure 7 – Equivalent Total Strain in t=3600s, with PFP

The simulated fire scenarios shall be presented at the report, as well as the phase of the workflow, presented at Figure 5, at which each fire scenario was considered in accordance to the structural criteria.

For the fire scenarios, that required passive fire protection, the structural drawings indicating the passive fire protection location on the primary structure, secondary structure as well as PFP specification and quantitative (total area) shall be presented at the structural report. PFP quantitative for a specific scenario is presented in Table 3 for reference.

Examples of the indication of PFP requirements for each structural member are presented from Figure 8 to Figure 10. PFP requirements on primary structure are shown in Figure 8, while the PFP requirements on secondary structures considered critical for the performance of the unit during a fire event are presented in Figure 9. Additional structural drawings might be required to present the PFP as the one presented in Figure 10. A 3D view of the structural model highlighting the structural members that required PFP should be presented as in Figure 11.

Passive fire protection coat-back length recommendation shall also be included in the report. In lieu of a specific analysis for coat-back length optimization, coat-back length of 450 mm shall be used.

Table 3 – Structural members to be protected for a fire scenario

Structural Member	**Member Length** [m]	**Section Perimeter** [m]	**PFP Area** [m²]
X035-X140	8.14	3.18	25.85
X048-X161	6.00	2.88	17.28
X104-X155	1.50	2.38	3.58
X132-X173	6.56	4.77	31.28
X135-X082	2.51	2.18	5.49
X136-X135	0.97	2.78	2.70

Structural Member	**Member Length** [m]	**Section Perimeter** [m]	**PFP Area** [m²]
X137-X136	1.90	2.78	5.28
X139-X137	1.90	2.78	5.28
X142-X086	2.51	4.57	11.48
X142-X139	1.89	2.78	5.26
X143-X142	1.78	2.78	4.94
X146-X145	1.60	2.78	4.45
X148-X071	3.50	2.78	9.74
X148-X146	1.32	2.78	3.68
X157-X151	6.25	3.28	20.47
X161-X159	5.50	2.08	11.46
X161-X179	3.57	2.88	10.28
X177-X151	6.56	4.76	31.21
X179-X178	5.03	2.78	14.02
X179-X180	5.00	2.78	13.92
X179-X241	6.06	2.88	17.44
		Total PFP Area [m²]	255.09

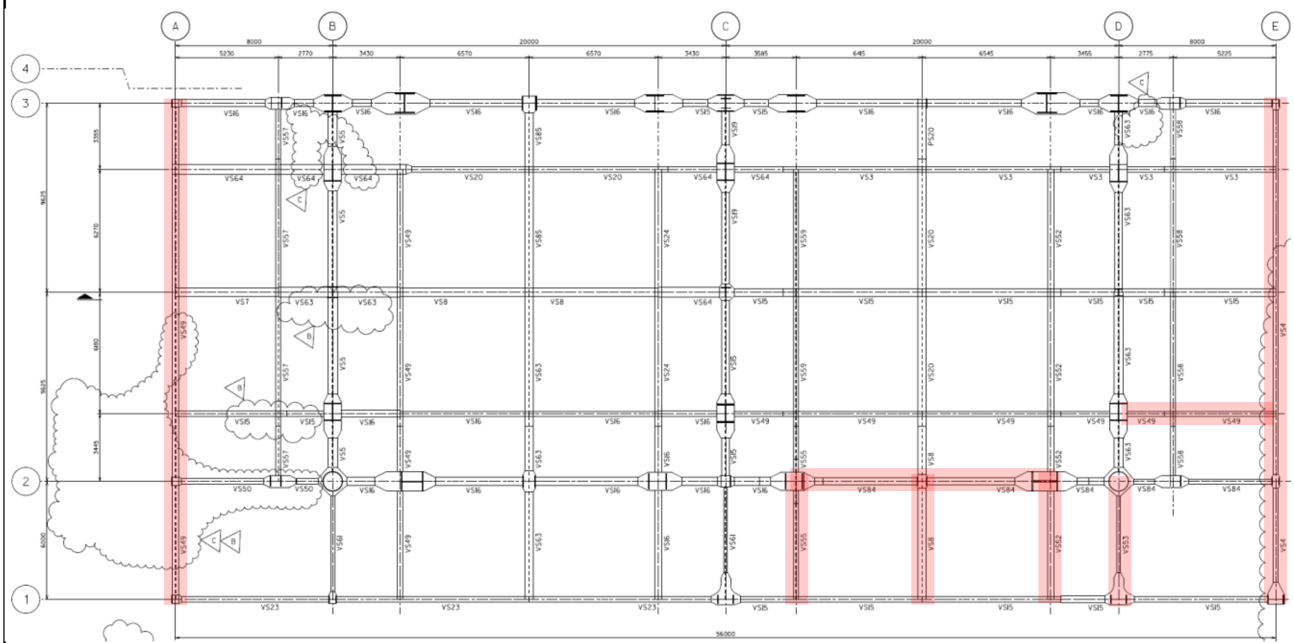

Figure 8 – PFP at primary structure

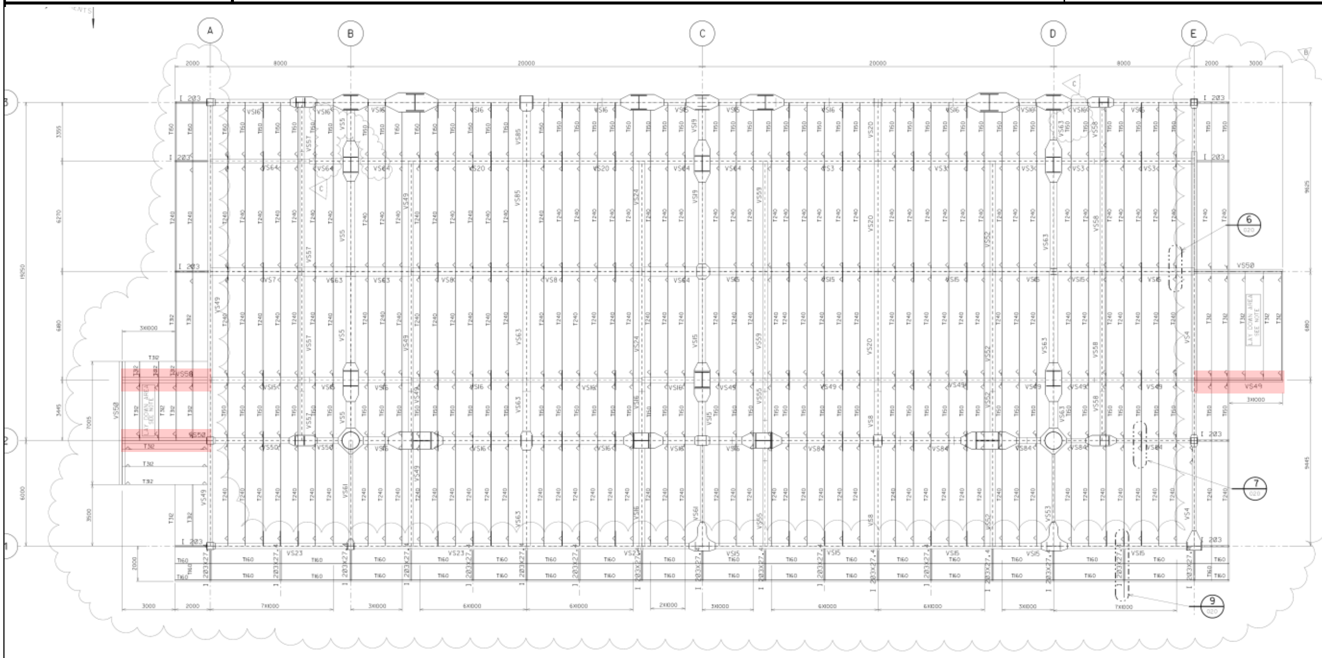

Figure 9 – PFP at secondary structure

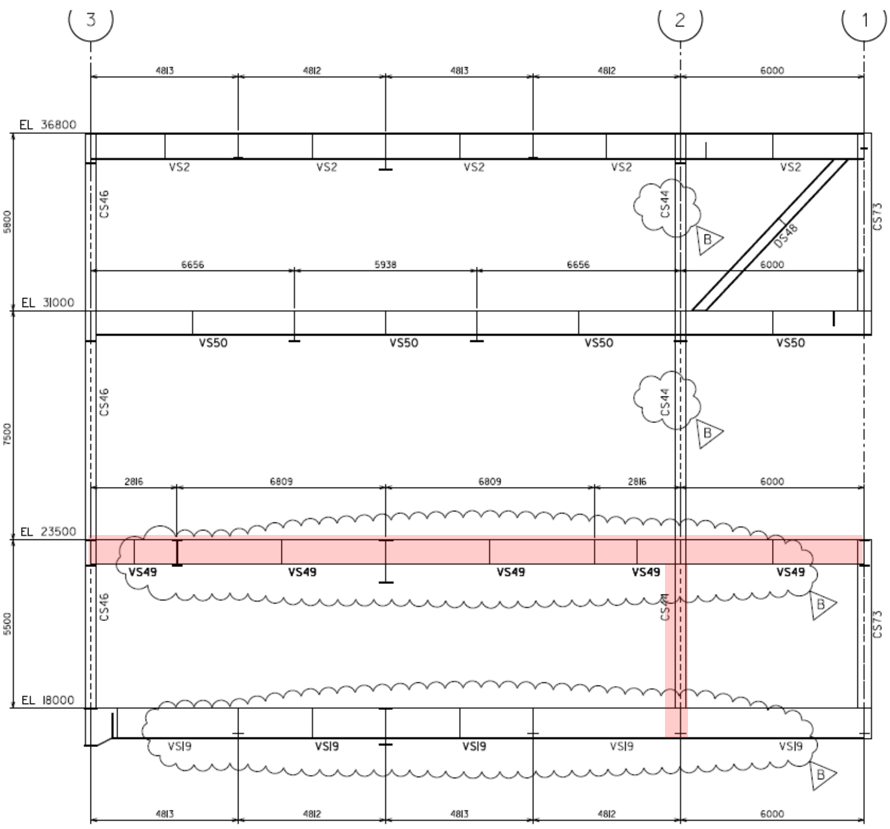

Figure 10 – PFP at elevation A

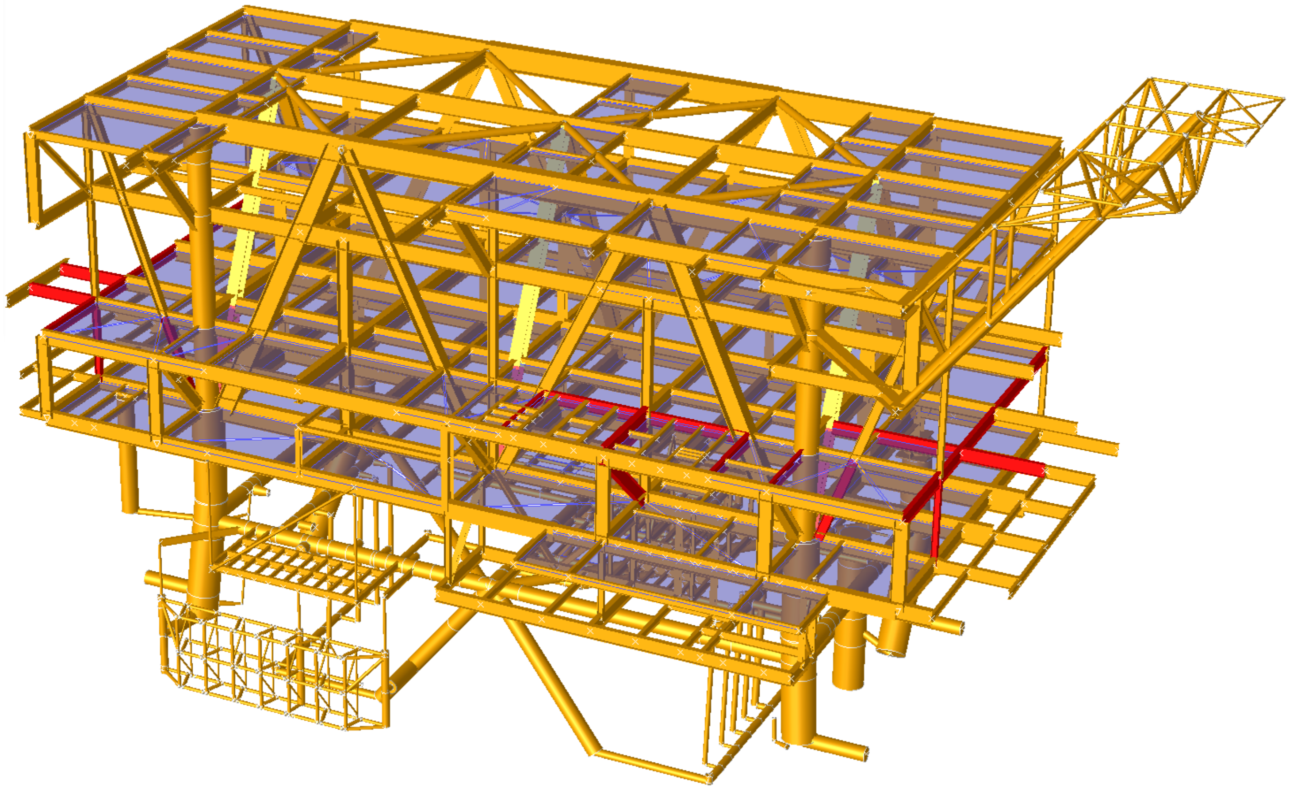

Figure 11 – 3D view of the structural model with PFP highlighted

11. DELIVERABLES

The final report with the results from the fire-structure analyses shall be delivered with the contents as shown in 10.

Digital files of data output containing the heat flux, resulting from the CFD analyses and used to generate the steel temperature history that will be input for the fire-structure analyses, shall also be delivered. All heat flux files and steel temperature history files for all simulated fire scenarios shall be among the deliverables.

An example of such type of file, for the specific case where the KFX-FAHTS-USFOS package is used for the analyses is the file with “.k2f” extension, exported from KFX to be used in FAHTS. Together with the “.k2f” file, the FAHTS configuration file and the structural model used to perform the temperature interpolation shall be delivered.

For the case where the CFD analyses were not performed in KFX, besides the output files containing the heat flux, digital files of data output with the results of thermal simulations (steel heat-up) shall be delivered for all fire scenarios, in a format compatible with the structural model, in order to allow the use of the temperature history as a load in the structural model. This data should contain the steel average temperature and temperature gradients along the beam cross-section, evaluated at the nodes of every finite element from the structural model, with mesh characteristic size no larger than 0.5 m, for the time steps as follows: results after 2 and 5 minutes from the start of the fire as well as for regular intervals at every 5 minutes up to the end of the fire or 60 minutes, whichever is lower. The structural model containing the mesh used for temperature interpolation shall be within the deliverables.

A spreadsheet associating each output file to the fire scenarios simulated shall be delivered. With this spreadsheet, it should be possible to identify the complete fire scenario, including location of the leak point (module, identification of the component origin of the leak), segment inventory, duration of the fire, depressurization condition (with or without depressurization), direction of the leak, flow rate and occurrence frequency of the fire scenario.

A spreadsheet with the results of the impairment frequency analysis described in 9 shall be delivered. This spreadsheet should contain data of all fire scenarios analyzed, its occurrence frequency as well as the impairment frequency before and after the PFP recommendation. With this spreadsheet it should be possible to identify which fire scenario lead to the impairment of the structure after the elastoplastic analyses as well as which fire scenarios lead to passive fire protection.