

GENERAL SPECIFICATION

STRUCTURAL

GS EP STR 108

Requirements for evaluation of finite elements analysis and results

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1. Scope

This document defines the general procedures and minimum requirements to be applied for the Finite Element Analysis (FEA) and pertaining to design of steel structures. It is applicable to all kind of steel structures such as but not limited to: offshore platforms, subsea structures, onshore structures where a FEA is conducted.

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published at the effective date of this document.

The Company recognizes these documents as a source of sound recommendations on good practice. However, in some cases the requirements of these International Standards do not comply with the requirements of the Company's General Specifications. Furthermore, there exists within these International Standards the requirement for the owner or operator to define certain parameters which may override suggested default values.

Any other proposal based on the content of these International Standards shall be subject to Company approval.

Reference	Title
Basu, R.I. & Al	Guidelines For Evaluation of Finite Elements and Results - SSC-387, Ship Structures Committee 1996
Cook, R.D. & Al	Concept and Applications of Finite Element Analysis - Fourth Edition, 2002, John Wiley & Sons
DNV-RP-C208	Determination of Structural Capacity by Non-linear FE analysis Methods
Felippa, C.A.	Department of Aerospace Engineering Sciences University of Colorado Master level course: Introduction to Finite Element Methods (ASEN 5007)
Fung, Y.C., Tong, P.	Classical and Computational Solid Mechanics - World Scientific Publishing, Singapore, 2001
Hartmann, F., Katz, C.	Structural Analysis with Finite Elements - 2 nd edition, Springer, 2007
Morris, A.	A Practical Guide to Reliable Finite Element Modelling - John Wiley & Sons, 2008
Smith, J.M.	Quality Management in Engineering Simulation: A Primer for NAFEMS QSS, 2008

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published.

The provisions of this document shall be applied in the light of the supplementary documents supplied by the Owner, including:

- Country specificity appendices
- Job specification
- Data sheets
- Articles and conditions; list of tasks
- Quality assurance provisions.

Reference	Title
GS EP STR 101	Design of offshore jacket and subsea structures
GS EP STR 102	Design of offshore topside structure
GS EP STR 201	Materials for offshore steel structures
GS EP STR 202	Cast materials for steel structures
GS EP STR 203	Forged materials for steel structures
GS EP STR 204	Subsea structures: Carbon Steel Material and Fabrication
GS EP STR 401	Loadout, seafastening, transportation and installation of offshore structures
GS EP STR 652	F(P)SO - Steel hull design requirements

3. Terms and definitions

Actions: External load applied to the structure (direct action) or an imposed deformation or acceleration (indirect action). An imposed deformation can be caused by fabrication tolerances, settlement, temperature change or moisture variation. An earthquake typically generates imposed accelerations.

Action effects: effect of actions on structural components (example: internal forces, moments, stresses, strains, motions and deformations).

Analyst: is a person directly responsible for the formulation of the problem, the preparation of data, the design, development and processing of the simulation, and the specification of solution requirements. A single FEA may require several analysts each according to their qualifications and experience.

Basic Variable: One of a set of specified set of variables representing physical quantities which characterize actions, environmental influence, geometrical quantities, or material properties including soil properties.

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Boundary Conditions: restraint placed on a structural component by its surrounding structure or its environment.

Characteristic Value: Value assigned to a basic variable or action or resistance model which has a prescribed probability of not being violated by unfavourable values during some reference period.

Design Criteria: Quantitative formulations that describe the conditions to be fulfilled for each limit state.

Design Service Life: assumed period for which a structure or structural component is to be used for its intended purpose, including anticipated maintenance if practicable but without substantial repair being necessary.

Design Value: value of a basic variable or action or strength model derived from a representative value for use in a design verification procedure.

Engineering Simulation: Establishes the behavioural characteristics of an engineered object or system in order to predict its response to specified actions.

Finite Element Analysis (FEA): The process of performing computer simulations to predict the response of a structure or structural component to specified actions using a numerical model made of Finite Elements in order to assess its fitness for purpose.

Fit-for-Purpose: Meeting the intent of an International Standard although not meeting some specific provisions of the standard in local areas such that failure in these areas will not cause unacceptable risk to life-safety or the environment.

Limit State: Condition beyond which a structure or structural component no longer fulfils design criteria.

Multi-Physics: Combining different physical models of reality for simulation of their interaction in a single (coupled) analysis.

Multi-Scale Analysis: Combining different levels of mathematical idealisation in a single analysis.

Primary Structure: comprises all structural components that provide strength and stiffness to the considered structure. The part of the structure for which, local or global failure would entail some loss in the intended purpose.

Reference Period: period of time used as a basis for determining values of a basic variable.

Representative Value: value assigned to a basic variable or action or strength model for verification of a limit state.

Resistance: Capacity of a component, or a cross-section of a component to withstand action effects without failure.

Return Period: average period between occurrences of an event or of a particular value being exceeded. The return period is equal to the reciprocal value of the probability of exceedance of the event in the unit of time chosen as reference period.

Simulation: Performing calculations according to some engineering simulation process.

Secondary Structure: The part of the structure which does not contribute significantly to the overall strength and stiffness of the structure but which supports individual items of equipment transferring the actions thereon onto the primary structure.

Structure: An engineered object performing a mechanical role that should be assessed according to the theory of solid mechanics. A structure may be composed of structures (or substructures) and be itself part of a larger structure (a structural system).

Structural Component: Physically distinguishable part or subset of a structure or structural system that participates of the intended purpose.

Structural Model: Idealization of the structural system for design or assessment purposes.

Structural System: a set or combination of structures that operate together for an intended purpose.

Validation: The process of determining the degree to which a model is an accurate representation of the real world structure from the perspective of the intended uses of the structure.

Verification: The process of determining that a computational model accurately represents the underlying mathematical model and its solution.

4. General requirements

Finite Element Analysis (FEA) should be performed and reported following the requirements in the present Specification.

The FEA should be clearly established as necessary in demonstrating the analysed structure or structural component and/or system is fit for its intended purpose within the expected quality and reliability levels, in place, in addition or in application of established Standards, Codes of Practice, Rules and Company specifications that are or would normally be applicable to such structure or structural component.

The general requirements defined in this section are further detailed and elaborated upon in later sections of the Specifications and in the Appendix 1.

4.1 Standards, Codes of Practice, Rules, State of the Art

Appropriate references should be given to relevant Standards, Codes of Practice and Rules in performing and interpreting the Finite Element Analysis. State of the Art for FEA may be taken from other Standards, Codes of Practice and/or Rules as well as from books and guides from recognized authors or organizations and papers published in peer reviewed journals and conference proceedings.

State of the Art only expressed in conference papers is subject to approval by Company.

4.2 The FEA process in Structural Analysis

Three phases could be identified in the FEA process. They may be part of an iterative cycle, particularly in system design, for nonlinear FEA and for sensitivity studies.

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Summary of the FEA process	
Preparatory Phase	The scope and objectives of the analysis are discussed or revised. The problem is diagnosed and a modelling approach is planned.
Modelling Phase	Engineering assumptions are made and the problem is idealised as a conceptual mathematical model. A discretised numerical approximation of the idealised model is created in software and solved computationally to an acceptable level of numerical accuracy.
Assessment Phase	The results are interpreted, and the validity of the simulation is assessed and established through Analysis Verification and Validation. The results are analysed and compared in the context of the problem assessment criteria, conclusions are drawn and a FEA report is produced.

FEA submitted to Company should exhibit the steps taken through the above process.

4.3 Personnel - Qualification and Experience

The FEA analysis should be performed by qualified personnel with relevant experience. Qualifications and experience of performing Analysts and Supervisors, in relation to the type and scope of the analysis, should be provided to Company. The following defines the expected competence:

- The analyst should be qualified to an appropriate academic standard in engineering, physics or a mathematically based science. If the academic or professional qualification is not in the relevant engineering field, at least one year's relevant experience is required.
- The analyst should possess adequate experience level for the FEA at hand. Experience levels are defined from [Smith, J.M.](#) - NAFEMS according to the criticality of the simulation.
- Both these requirements should be met by the performing analyst, either singly or as a team, including a consultant whenever necessary.

The Analyst must be familiar with the design requirements, codes of practice, analysis and design standards relating to the structure at hand. The Supervisor must have, and the Analyst should preferably have, experience with analyses of comparable size and complexity as the analysis being performed.

4.4 Analysis Definition and Scope

The expected outcome of the FEA in relation to limit state strength and fitness for purpose of the considered structural component, within the expected quality and reliability levels, should be defined and clearly stated. To this end, a discussion of the structural component functions and responses should be provided, including in particular:

- Functional redundancies, built-in or implied from higher level assembly
- Relationship with other structural components and associated interactions

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- Amplitude and frequency of actions that may happen to bear on the structural component, directly or from higher level transfer
- Expected behaviour of the structural component, including stress paths, amplitude of nonlinear components of response, sensitivity to small variations in geometry, properties, load amplitudes and directions, etc.

When the structural component is itself an assembly, similar discussion should be provided for its components.

Some of this information may already be given in a general set of documents available to Company that describes functions, operations and behaviour of the structural component or for a higher level structural system including the structural component being analysed, in which case appropriate reference to these documents may be given in lieu of full discussion.

4.5 Analysis Verification & Validation

Appropriate analysis Verification and Validation (V&V) should be performed according to the present Specifications. Description of the processes and results for V&V should be reported (see detailed instruction in Appendix 1 - Form 1 & 2).

4.6 Software Verification

Software functions, tools and techniques used in the analysis should be described, including relevant accuracy information. Extracts from software documentation may be provided as needed. Company may require additional proof of software verification in relation to the type and scope of FEA as performed.

4.6.1 Analysis Validation

Validation should address the adequacy of the selected models to represent the reality of interest. Validation concerns both the mathematical and numerical models.

In cases where uncertainties in the basic variables are too high, it may happen that validation could only be achieved by comparing with results from small scale or full scale tests on the structure or structural component, as practicable. Full scale measurements that may also be available from in-situ monitoring on similar existing structures could be used, subject to data filtering, scaling and interpretation by appropriate means.

4.7 Analysis Reporting

Analysis process and results should be reported such that there is no ambiguity as to the adequacy, accuracy and relevance of the calculations and conclusions. The analysis report should include at least the following information and/or data:

- Analysis definition and scope
- Description of the physical problem, including relevant drawings for the structure being analysed
- All assumptions used in performing the analysis, including physical and behavioural simplifications

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- Geometry used in the engineering model, including any simplifications, showing the model reflects properly the modelled reality in relation to the analysis scope
- Material properties & physical properties, relevant to the analysis
- Actions applied and the source for these actions, including uncertainties. Combinations of actions used to achieve realistic representative values in the basic variables
- Boundary conditions used and the justification for these boundary conditions
- Allowable limits of basic variables and the justification for the selected variables and their limits
- Description of the Finite Element model properly qualified for its accuracy in relation to the analysis scope and selected basic variables
- Description of all analysis steps, iterations and/or phases, with a summary of the computational procedure and analysis processes including V&V
- All results of interest clearly labelled with the corresponding analysis step, iteration or phase, with close up views and/or detail listings whenever appropriate
- A summary of the meaning of the results as they relate to the goal of the analysis
- A conclusion as to the goal of the analysis.

Some of these reporting requirements may be met by reference to relevant Standards, Codes of Practice and/or Rules, state-of-the-art publications and recommendations in the present Specifications, as appropriate.

The complete documentation package, which can be defined as that required by a third party to reproduce the analysis and including final input and output files used in the FEA, should be available and submitted if required by Company.

The analysis process and results should be checked according to the evaluation form provided in Appendix 1.

5. Modelling & Simulation requirements

FEA modelling should start from the physical reality of interest and proceed to the numerical model following several steps.

In many cases, these steps are not formally followed and the numerical model is established directly from the physical reality. This may be acceptable whenever the modelled reality and the scope of the analysis fall within the current experience of the analyst as supported by previous analyses of similar structures and associated actions. However, appropriate documentation should be provided of the assumptions and simplifications that have been used in establishing the model.

5.1 Physical Modelling

The physical level is concerned with the physical properties and behaviour of the reality to be modelled. This includes physical representations of the structure, of relevant actions and boundary conditions. Basic variables should be identified at this stage.

5.1.1 General

As the main concerns within the present specifications are strength, durability and fitness for purpose, the basic variables to be retained are those that have a bearing on operational constraints, structural strength, durability and survivability of the structure or structural component.

Type	Basic Variables	Relevant values
Geometry	Dimensions	Nominal values and deviations due to manufacturing or fabrication tolerances
	Initial Distortions	Out-of-shape variations due to fabrication and/or assembly and/or abnormal event
	Lifecycle Variations	Corrosion thickness, thickness "increment"
	Global Deformations	Maximum allowable values, globally
	Local Deformations	Maximum allowable values, per structural area or component
Actions	Permanent Actions (G)	Self-weight, weight of permanent structures and equipments, hydrostatic pressure, actions from initial distortions in fabrication or installation stages
	Variable Actions (Q)	Actions caused during construction, installation and operation of the structure, weight of temporary equipments and structures, all moving actions, contained fluid motions and associated pressure distributions, deformations due to temperature changes
	Environmental Actions (E)	Actions caused by interactions with the environment such as wave, wind, snow, ice, current, soil motions, environmental temperature changes, and their indirect effects on permanent and variable actions
	Accidental Actions (A)	Actions resulting from collisions, dropped objects, fire, explosion, leaks, unintended changes in installation or operation of the structure and its ancillary equipment

Type	Basic Variables	Relevant values
Boundary Conditions	Global Stiffness	Maximum forces through attachment, elastic parameters
	Local Stiffness	Maximum (contact) stresses and/or strains, elastic and/or inelastic parameters
	Local Matching - Contacts	Support subsidence, explicit support motions, distributed contact conditions, relative motions and deformations of structural components
Material	Constitutive Relations	Material rigidity parameters, including temperature dependencies and inelastic behaviour whenever relevant
	Strains	Maximum elastic strains, strain hardening, ultimate strains to failure
	Stresses	Elastic stress limit, stress/strain curves, ultimate stresses to failure
	Stress or Strain Cycles	S/N curves appropriate for high cycle fatigue calculations, according to fatigue analysis procedure used

5.1.2 Geometry

The geometry of the structure or structural component to be considered in the analysis should extend to boundaries where physical interactions are reasonably well known and/or where local uncertainties are expected to have little or no effect on the basic variables in the region(s) of interest.

Geometrical parameters that define shape, size and overall arrangement of the structure, its components and cross-sections shall be defined.

When the deviation of any of the geometrical parameters from its prescribed value may have a significant effect on the behaviour and strength of the structure, the magnitude and variability of the deviation shall be taken into account by prescribed tolerance limits, and subject to Company approval.

In most cases, the average or design values of the geometric parameters should be used in modelling. In some cases, geometric imperfections such as misalignment or lack of straightness should be taken in account by appropriate means: directly in the geometry when considering nonlinear action effects such as in structural buckling, or indirectly through directional adjustment and scaling of actions in other situations.

For the geometric parameters that are defined by a upper and lower value, it is appropriate to retain the value that is unfavourable to the structural strength being ascertained by the FEA. Different values may be retained in respect of action effects and of resistance.

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5.1.3 Actions

The actions that may happen to bear on the structure or structural component should be inventoried and classified according to their likelihood or frequency of occurrence during the design life. Uncertainties in the geometry and amplitude of the actions should be quantified.

Actions may be classified according to their variation in time, their variation in space or the associated structural responses.

5.1.3.1 Classification According to Variation with time

Actions shall be classified according to their variation with time.

- **Permanent Actions**

Actions that are likely to act throughout a given design situation, the variation of which with time either is negligible with respect to the mean value or attain some limiting value in a monotonous manner.

- **Variable Actions**

Actions that are likely to act throughout a given design situation, the variations of which with time are neither negligible nor monotonous.

- **Environmental Actions**

Actions that can be sustained or repeated or both repeated and sustained, the variations of which with time are described as random processes.

- **Accidental Actions**

Actions mostly of short duration but with significant magnitude that have a small likelihood of occurring on a structure during its design life. However, accidental actions to be considered are those that may have significant effects on the integrity of the structure.

Variation with time implies consideration of simultaneous actions that may happen to bear on the structure. Combinations of potentially simultaneous actions should be applied to the structure in such a way that their combined effect is maximized locally or globally.

5.1.3.2 Classification According to Variation in Space

Actions shall also be classified according to their variation in space as:

- **Fixed Actions**

Actions that have a constant spatial distribution across the structure in respect of position, magnitude and orientation.

- **Free Actions**

Actions whose position, magnitude and/or orientation can vary relative to the structure.

Free actions require the consideration of different arrangements and combinations of such actions such that the most unfavourable action effects are discovered. In some situations, a sensitivity analysis in respect of the free actions parameters will be required in order to achieve convincing worst cases.

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5.1.3.3 Classification According to Action Effects

Several classifications of actions are relevant as to their effects or structural responses. In this category, we may consider inertia effects

- **Static Actions**

Actions that produce static or quasi-static responses, i.e. no significant acceleration of the structure or its components.

- **Dynamic Actions**

Actions that cause motion and acceleration of the structure, or its components, significant enough to require specific consideration.

5.1.4 Boundary Conditions

The boundary conditions should be chosen in such a way that interactions between the structure and the un-modelled reality are as accurate as possible. When detailed interface data is not available or difficult to define, simplified boundary conditions should be selected to be conservative in respect of other basic variables.

Particular attention should be given to possible stiffness and geometric variations of support at or along boundary lines or surfaces, including lack of geometric fit and differential response or settlement.

Boundary conditions also occur between structural components of the modelled reality, where connections may be hinged, elastic, clamped or subject to nonlinear behaviour, for example through contact and other inelastic conditions.

As for actions, boundary conditions may vary with time and in space, and appropriate model variations should be established for each design situation.

5.1.5 Material Properties

Material property values should be selected in a conservative manner. Structural materials used in the structure should be precisely identified according to their classification as per **GS EP STR 201**, **GS EP STR 202** and **GS EP STR 203**.

Temperature and other dependencies such as thickness effects should be taken in account. Aging and other effects such as creep or corrosion effects should also be accounted for whenever relevant.

Properties of non-structural materials such as paints, PFP and other coatings should be considered at least for their mass distribution.

5.1.6 Fabrication Effects

Residual stresses from welding processes need not be modelled. However, they may have a bearing on the selection of material properties, particularly for fatigue strength calculations.

Fabrication induced initial imperfections in the form of initial distortions should be considered as basic variables for some design situations particularly when evaluating nonlinear response of the structure. Otherwise their stress raising effects may be included either explicitly with stress correction factors or implicitly in the local resistance safety factor.

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Pre-stressing induced by some fabrication processes should be included in the model, whenever they result in indirect actions

5.1.7 Structural Deterioration

Structural deterioration of the kind considered here is a progressive phenomenon. It does not include effects from accidental events that are considered elsewhere.

Structural deterioration that may occur during the design life should be accounted for by appropriate means. This includes cumulative deformation from cyclic actions.

In particular, dimensional reduction from corrosion should be properly accounted for. In the offshore industry, it is now customary to use reduced dimensions in evaluating the strength of the structural components, but full dimensions for the evaluation of actions. Use of other assumptions as to the action effects for structures subject to corrosion is to be submitted to Company for approval.

5.2 Mathematical Modelling

The structure behaviour is assumed to follow the theory of solid mechanics. On the other hand, actions may be mechanical or may follow other relevant mathematical models such as fluid mechanics and/or heat transfer. In this specification, only the mathematical models of solid mechanics are discussed. Mathematical models of environmental actions are assumed to be provided in “closed form” as transfer functions (motions, pressure, temperature, etc.) and statistical distributions.

Furthermore, the mathematical modelling process also includes assigning representative values to some of the basic variables, using statistical information whenever available.

5.2.1 Geometry

Excepted for extremely simple structures, the mathematical representation of the structure’s geometry is generally simplified in various ways.

5.2.1.1 Dimensional Reduction

The geometry of the structure could frequently be simplified by dimensional reduction. The advantage of such reduction is in achieving a much simpler global model of the structure. The drawback is loss of accuracy in actual interactions between such structural parts at their joints.

When dimensional reduction is used, the assumed behaviour of the joint should be evaluated in terms of global and local effects. In many instances, the state of the art is to assume the joints are rigid, and this may be considered conservative in respect of the stress or stress resultants obtained from the lower dimensional model.

However, rigid representation of joint behaviour is not conservative in the deformations parameters. In particular, appropriate joint flexibilities should be introduced when assessment of the design situation of interest relies on the ductility of the structure, such as in prediction of buckling or reserve strength or survivability to damage or accidental events. Joint flexibility may also be introduced when estimates of peak stresses are required such as in fatigue analysis.