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Change Record from previous Version

Affected Section(s)	Changes / Reason / Remarks
2	RD5 (TIE-33) becomes an applicable document AD10
4	New header “4 Terms and Definitions” Added section 4.2 “Eurocode Definitions”
5	Section 5 restructured - New sections and requirements added: 5.1.1.2 Modeling of Adhesive Materials in Bonded Joints 5.1.1.3 Modeling Singularities 5.2.5.4 Damping - section 5.4 Structural Verification by Analysis re-arranged and re-worked, e.g. - if not otherwise defined in specification * MSS to be verified acc. to EC norms * Subsystems either acc. to EC norms or acc. to section 5.4.1 and 5.4.2 - Electronic cabinets shall meet Bellcore Zone 4 requirements (#124) - Table 4 Material’s safety factors extended - extended requirement (#130) of max. allowable stress of glass-ceramic substrates - failure probability (#131) of glass-ceramic substrates less than 10^{-5} - requirements added to section 5.7 CFD Analysis

Contents

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AD	Applicable Document
CE	Constraint Equation
CFRP	Carbon Fibre Reinforced Plastic
DIN	Deutsche Institut für Normung e.V.
DLR	Damage Limitation Requirement
DOF	Degree of Freedom
DRD	Document Requirement Definition
EC	European Commission
EN	Euro Norm
EELT, E-ELT	European Extremely Large Telescope
ELT	Extremely Large Telescope
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FMECA	Failure Mode and Effects and Criticality Analysis
ISO	International Standards Organisation
MoS	Margin of Safety
MSS	Main Support Structure
NCR	No Collapse Requirement
RBE3	Rigid Body Equation
SOW	Statement of Work
SPE	Technical Specification
TBC	To Be Confirmed
TBD	To Be Defined
VDE	Verband der Elektrotechnik
VDI	Verein Deutscher Ingenieure
VLT	Very Large Telescope

1. Scope

12 This Standard specifies criteria and procedures for the analytical verification of the performance and mechanical safety requirements defined in the technical specifications for Telescopes, Antennas, Instruments and structural components to be installed at all ESO premises.

This document establishes general requirements and considerations for the development of Finite Element models used for structural, earthquake, thermal, buckling, fatigue and CFD analyses. Procedures for checking and validating the FE Models are provided as means to assess the model and analysis results reliability.

2. Related Documents

2.1 Applicable Documents

15 The following applicable documents form a part of the present document to the extent specified herein. In the event of conflict between applicable documents and the content of the present document, the content of the present document shall be taken as superseding.

AD1 Eurocode 0: Basis of structural design; EN 1990 : 2002

AD2 Eurocode 1: Actions on structures, All parts, EN 1991

AD3 Eurocode 2: Design of concrete structures, EN 1992

AD4 Eurocode 3: Design of steel structures, All parts, EN 1993-1-x:2005

AD5 Eurocode 8 - Design of structures for earthquake resistance
Part 1 General rules, seismic actions and rules for buildings.
BS EN 1998-1:2004

AD6 Seismic tests of mechanical structures for electronic equipment.
Part 2: Seismic tests for cabinets and racks.
International standard IEC 61587-2, Edition 2.0 2011-08.

AD7 EN 13001-2:2011. Crane safety. General design. Load actions

AD8 ISO 4304:1987. Cranes other than mobile and floating cranes. General requirements for stability

AD9 ISO 8686-2:2004. Cranes—Design principles for loads and load combinations. Part 2: Mobile cranes.

AD10 Technical Information, Advanced Optics, TIE-33: Design strength of optical glass and Zerodur, January 2009.

2.2 Reference Documents

25 The following reference documents provide background information as to the present Specification. Under no circumstance shall the content of reference documents be construed as applicable to the present standard, in part or in full.

RD1 The FEMCI Book. Finite Element modeling continuous improvement.
NASA Goddard Space Flight Center.

RD2 Preparation of Stress Analysis Reports, David McMahon, Aircraft Engineering NASA, December 2009

RD3 VDI 2230 Systematic calculation of high duty bolted joints - Joints with one cylindrical bolt

RD4 VDI 2014 Development of FRP components (fibre-reinforced plastics) Analysis

3. Introduction

5 This Standard establishes general requirements for generation and validation of analysis models which shall be applied to the development of structures to be installed at all ESO premises.

172 The following three analysis categories are defined:

1. Analysis for layout of systems, e.g. at conceptual design level
2. Analysis for verification of performance requirements
3. Analysis for safety verification

Certain analysis requirements defined herein may be relaxed for analysis categories 1 and 2. In this case the relaxation is defined in the Technical System Specification.

6 For E-ELT and new VLT instruments this standard is intended to harmonize and standardize as much as possible all kind of structural analysis already in the design phases. It is not intended that existing structures retroactively comply with this standard.

7 Furthermore, basic validation checks of the FE models are defined to ensure a standard level of reliability and accuracy of the analysis results.

8 The ESO Analysis Standard can help to reuse analysis methods and procedures that have been proven to work in the past. If improvement is proven, the ESO Analysis Standard can be extended and upgraded.

9 For the analysis verification of all structural parts and mechanical components the International and National Standards shall be applied where directly applicable.

10 The following hierarchy of Standards shall be applied:

1. Standard defined directly by ESO Technical Specifications and applicable documentation
2. EN Eurocode standards
3. ISO Standards
4. DIN, BS, or other equivalent national standards.
5. Design guidelines from professional organizations (e.g. VDE, VDI Richtlinien)

4. Terms and Definitions

4.1 Definition of Structures

215 The following definitions are used in this standard document:

- Main Support Structure (MSS):

An MSS is a mechanical supporting structure which is connected to the supporting ground. In regions exposed to earthquakes the seismic action is defined at ground level. The seismic action parameters are specified in the appropriate Environmental Specification. Typical MSS examples are Buildings, Telescope Main Structures and their Foundations, Dome structures, Instruments fixed to ground, etc.. An MSS is a structure that can support one or more subsystems.

- Subsystem Structure:

A subsystem is a mechanical structure which is physically connected to and supported by a MSS and not directly to the ground. Seismic actions defined at ground level cannot be directly applied to the subsystems in case of dynamic magnification effects. Typical examples of such systems are instruments, mirror units, appendages, electronic boxes, handling devices or other equipment.

4.2 Eurocode Definitions

338 If not defined otherwise in the technical specifications, the survival load values shall be understood as characteristic values according to AD1 section 4.1.2.

273 Unless otherwise defined in the Technical Specification, the following categories shall be assumed for the Eurocode norms:

344

Eurocode	Section	Type	Category/Class
EN 1991-1-1 (AD2)	6.3.1.1, Table 6.1	Building Category	B
EN 1990 (AD1)	Annex B3, Table B1	Consequence class	CC2
EN 1998-1 (AD5)	4.2.5, Table 4.3	Importance class	II

5. Analysis Requirements

5.1 Finite Element Analysis

31 The analysis requirements in this section are partly based on the recommendations described in RD2.

5.1.1 Finite Element Model Requirements

5.1.1.1 General

33 The FE Models shall be built for evaluating the performance of structures and quantifying internal stresses, strains and deformation patterns due to applied external loads and boundary conditions.

34 All the Finite Element Analyses shall be performed with an internationally recognized software package. The software provider must be an ISO 9001 certified company. ANSYS Classic and ANSYS Workbench are the preferred code.

35 If not agreed differently with ESO, all the FE Models shall be delivered to ESO in ANSYS[1] format.

[1] FE Models database in ANSYS Classic (ASCII file format: *. cdb and *.anf) or ANSYS Workbench.

36 Compatibility verification of the ANSYS models with the original models shall be provided. This verification shall contain as a minimum the validation of the

- total mass and mass moments of inertia
- center of gravity
- maximum deformation (static analysis)
- deformation distribution (static analysis)
- eigenfequencies and corresponding effective masses for the predominant modes (modal analysis)

37 The structural models used shall be adapted to the particular analysis for which they are going to be used and shall be accurate enough to provide a good description of the behavior of the structure under examination in terms of displacements, stresses and eigenfrequencies.

38 The difference between the element and nodal stress results shall be less than 10 % to ensure sufficient mesh refinement.

40 Degenerated elements (e.g. triangular, prism, tetrahedron, pentahedron shape) without midside nodes shall be avoided in high stress gradient regions. If used elsewhere, they should be used with caution.

42 For the lowest fundamental modes (lowest frequency modes with effective mass > 10 % of total mass) the eigenfrequency accuracy of FEA results shall be better than 5 %.

219 Non-structural parts like appendages, cabinets, cables, etc. can be modeled as equivalent mass/ mass-moment-of-inertia elements. These elements shall be connected to the MSS without introducing artificial stiffness to the interfaces.

321 The influence of tolerances (including overall dimensions and thickness) shall be assessed whenever potentially critical.

5.1.1.2 Modeling of Adhesive Materials in Bonded Joints

320 The models of adhesive layers in bonded joints shall comprise at least three to five elements through its thickness.

322 The aspect ratio of the elements (ratio of their sides, i.e. length:thickness) shall not exceed 10:1.

5.1.1.3 Modeling Singularities

337 All elements around singularities (e.g. at the interface between glass and adhesive) shall have similar element sizes with ratios less than 1.5 between neighbouring elements.

323 In regions where model singularities occur (e.g interface area between glass and glue) element stresses (average) and not corner (nodal) stresses shall be used for the stress evaluation.

5.1.2 Finite Element Analysis Requirements

46 Detailed static stress analyses when performed shall be based on FEM and supplemented by analytical Engineering calculations where appropriate, for verification of the load capability of all structural elements.

47 The outcome of the analyses shall be displacement, component loads, stresses and margins of safety considering the applicable stress limits and safety factors. Details are provided in # 128.

48 Modal analysis when performed shall be based on FEM and supplemented by analytical Engineering calculations where appropriate, for verification of the eigenfrequencies, mode shapes and effective mass contribution of the structure.

51 Based on the hazard analysis a buckling analysis verification shall be performed on structural members. The buckling analysis verification method is defined in # 76.

50 Based on the hazard analysis a fatigue analysis verification shall be performed on structural members. The fatigue analysis verification method is defined in # 78.

52 Based on the FMECA analysis FEA verification shall be performed as a minimum for the failure modes system failure, degraded operation and malfunction.

163 Any specific analyses which have to be performed as part of a project's specific requirements are defined in the relevant system technical specification or SOW.

5.1.3 Finite Element Model Validity Checks

5.1.3.1 Standard Finite Element model validation checks

56 The standard validity checks of the finite element model (partly based on RD1) as listed in Annex A shall be performed. The model shall be corrected in case of non-compliances.

5.1.3.2 ANSYS Specific Requirements

58 If possible, current-technology elements shall be used (element table see Annex B).

5.1.3.3 Documentation of Validation Checks

60 The validation checks of the FE models shall be documented in the analysis report (see Annex D). Remaining non-compliances shall be reported and justified.

5.2 Static and Dynamic Analysis

5.2.1 Stress Analysis Requirements

62 All load carrying structures shall be verified by stress analysis.

69 The contractor shall identify and verify all stress analysis categories relevant for his system. Annex C provides a list of general stress analysis categories which is not deemed to be complete.

5.2.2 Static Analysis Requirements

72 AD2 shall be applied to define the actions on the MSS structures.

73 AD4 shall be applied for the design, dimensioning and static calculations of all kind of structural steel construction works of MSS structures.

74 AD3 shall be applied to demonstrate the compliance of building and concrete structures.

5.2.3 Buckling Analysis Requirements

76 The buckling analyses verification shall be performed either

- by a global linear buckling (first order) analysis with a buckling safety factor ≥ 10, or
- in accordance with the requirements defined in AD3 and AD4.

Other verification methods may be used, with prior written agreement from ESO.

5.2.4 Fatigue Analysis Requirements

78 The fatigue analyses verification shall be performed in accordance with AD3 and AD4.

Other verification methods may be used, with prior written agreement from ESO.

5.2.5 Dynamic Analysis Requirements

5.2.5.1 Modal Analysis Requirements

82 As a minimum the relevant eigenfrequencies, the corresponding mode shapes and effective masses shall be analyzed and documented according to Annex D.

83 The sum of the effective modal masses for the modes calculated in a modal analysis shall amount to at least 90% of the total mass of the structure in each direction.

351 The mesh should be fine enough to resolve the highest mode shape of interest.

5.2.5.2 Harmonic Response Analysis Requirements

203 The Harmonic Response Analysis technique is used to determine steady-state reponse (transfer function) of a linear structure to dynamic (harmonically varying) load in the frequency domain.

204 The number of substeps within the frequency range calculated shall be defined such to have good resolution of the response curve, in particular around the peaks. Goal is about 20 substeps per resonant frequency.

206 The recommendations and restrictions of the FEA code shall be used for the Harmonic Response Analysis.

5.2.5.3 Transient Dynamic Analysis Requirements

208 The Transient Dynamic or Time-History Analysis technique is used to determine the dynamic response of a structure under the action of any general time-dependent loads.

209 For a linear system, a modal representation can be used for the transient simulation. Then, the modal selection shall exceed the relevant frequency range of the excitation by a factor of > 1.5.

210 If wave propagation effects (for example, a bar dropped exactly on its end) are of interest, the mesh should be fine enough to resolve the wave. A general guideline is to have at least 20 elements per wavelength along the direction of the wave.

207 Follow the recommendations and restrictions of the FEA code used for the Transient Dynamic Analysis.

5.2.5.4 Damping

328 If not otherwise defined in the superseeding technical specification, the following damping ratios shall be applied in the dynamic analyses:

- 0.75 % for bolted or welded steel structures excited by very low vibration amplitudes, e.g. micro-seismic noise or operational wind
- 1% for bolted or welded steel structures excited by low vibration amplitudes, e.g. below damage limitation level earthquake,
- 2% for bolted or welded steel structures excited by mid to high vibration amplitudes, e.g. equal or above damage limitation level earthquake, and
- 5% for reinforced concrete structures.

329 The use of higher damping ratios is only permitted by written agreement of ESO and, if properly justified and determined.

5.2.6 Thermal Analysis Requirements

212 The thermal models shall be able to simulate adequately the effects caused by thermal conduction, convection and radiation.

85 When specified or deemed to be necessary by the contractor, a thermal model of the structure shall be produced to compute the temperature distribution in the structure. Depending on the load cases defined in the technical specification, the thermal analysis can be a steady state or transient FE or CFD analysis.

5.3 Earthquake Analysis

5.3.1 Earthquake Analysis Instructions for Main Support Structures

88 The earthquake analysis of the Main Support Structure (MSS) shall be performed following the requirements defined in AD5.

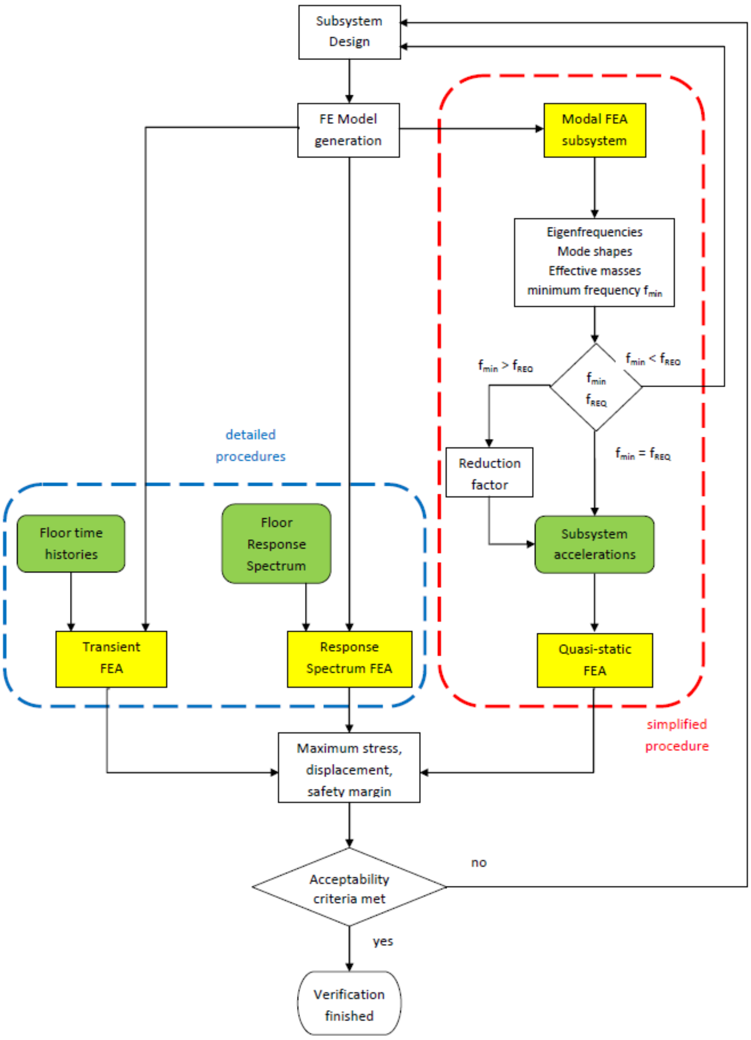
5.3.2 Earthquake Analysis Instructions for Subsystems

91 This section provides instructions on how to perform earthquake analysis for subsystems and appendages which are connected to a MSS and not directly to the ground.

92 In cases where the subsystem is dynamically decoupled from the MSS, the accelerations computed at the subsystem's centre of gravity can be applied to the subsystem in a quasi-static manner. In other cases more accurate analyses procedures need to be applied in order to take into account the dynamical coupling and magnification effects between the MSS and the subsystem.

93 The earthquake analysis method to be used for the subsystems is defined in the appropriate subsystem specification.

220 The procedure to verify the subsystem against the design earthquakes specified in the appropriate applicable Environmental Specification is illustrated in the flowchart here below and is stepwise explained in more detail in the following sections.



222 According to AD5 structures in seismic regions shall be designed and constructed in such a way that the fundamental earthquake requirements and compliance criteria are met. These criteria are generally related to the load carrying parts of the structure and are intended to guarantee the safety of personnel and the safety against catastrophic failures. Their verification is mostly linked to the mechanical safety as defined in section 5.4.2.

223 The requested minimum eigenfrequency of the subsystem, fixed at the MSS interface, is defined in the corresponding subsystem technical specification.

224 If quasi-static accelerations are defined for the subsystem, they shall be valid only, if the specified eigenfrequency of the subsystem is met.

225 If the subsystem's eigenfrequency exceeds the requirement, the quasi-static accelerations may be reduced depending on the MSS dynamic characteristics. The reduction factor must be agreed by ESO in writing.

226 For a subsystem a structural FE Model shall be created following the requirements specified in this document.

227 Non-structural elements, which may influence the response of the main resisting structural subsystem, shall also be taken into account.

352 The boundary conditions of the model shall be applied at the interface points to the MSS in such a way, that the fixed DOFs are correctly represented.

228 In order to assess the dynamic behaviour of the subsystem structure, the requirements defined in #82 and #83 shall be applied by using the structural model described in chapter 5.1.

229 A detailed analysis report shall be provided following the requirements defined in Annex D.

5.3.2.1 Simplified Earthquake Analysis Method

109 The quasi-static earthquake accelerations to be applied to the subsystem structure are defined in the subsystem technical specification or in the appropriate interface document. They depend on the calculated lowest significant eigenfrequency (f_{min}) of the subsystem and the required lowest eigenfrequency of the subsystem (f_{REQ}) as defined in the corresponding subsystem technical specification:

1. $f_{min} < f_{REQ}$:

   The subsystem eigenfrequency requirement is not met. Redesign of subsystem is necessary.

2. $f_{min} = f_{REQ}$:

   The subsystem eigenfrequency requirement is met. The quasi-static subsystem accelerations shall be applied to the subsystem structure.

3. $f_{min} > f_{REQ}$:

   The subsystem eigenfrequency requirement is met. The quasi-static subsystem accelerations may be multiplied with the appropriate reduction factor before it is applied to the subsystem structure.

111 By using the structural FE Model of the subsystem the static deformations and stresses shall be analyzed.

The maximum action effect (A_{Ed1}, A_{Ed2} and A_{Ed3}) due to the three orthogonal seismic acceleration components shall be calculated with the Percentage Combination Rule:

a) $A_{Ed1} = \pm E_{dx} \pm 0.3*E_{dy} \pm 0.3*E_{dz}$

b) $A_{Ed2} = \pm 0.3*E_{dx} \pm E_{dy} \pm 0.3*E_{dz}$

c) $A_{Ed3} = \pm 0.3*E_{dx} \pm 0.3*E_{dy} \pm E_{dz}$

where "±" means "to be combined with"

E_{dx} quasi-static earthquake acceleration in horizontal x-direction,

E_{dy} quasi-static earthquake acceleration in horizontal y-direction and

E_{dz} quasi-static earthquake acceleration in vertical z-direction.

The maximum seismic action effect due A_{Ed} is the worst case of all the possible load combinations:

$$A_{Ed} = \max (A_{Ed1}, A_{Ed2}, A_{Ed3})$$

112 If the subsystem structure is subject to different orientations, the earthquake analysis verification shall be performed for the various configurations, e.g. telescope altitude angles of 90° (Zenith), 45° and 0° (Horizon) as a minimum.

5.3.2.2 Detailed Earthquake Analysis Method

114 If a detailed analysis method is required, it shall be defined in the appropriate technical subsystem specification. The following are descriptions of various detailed analysis methods which can be applied subject to the requirement in the subsystem technical specification:

115 a) <u>Modal response spectrum analysis of the subsystem</u>

A seismic Response Spectrum analysis of the subsystem requires applying appropriate *Floor Response Spectra* at the interface to the MSS. The floor spectra can be derived from the earthquake time history analysis of the MSS. The analysis requirements for the Modal Response Spectrum analysis are defined in section 4.3.3 of AD5.

116 b) <u>Non-linear time-history analysis of the subsystem</u>

A seismic *time-history analysis* of the subsystem requires applying appropriate time-history input data at the interface to the MSS. The time-history input data can be derived from the earthquake time history analysis of the MSS. The analysis requirements for the time-history analysis are defined in section 4.3.3 of AD5.

117 c) Modal response spectrum analysis of the assembly

In a seismic response spectrum analysis of the assembled models of the MSS and the detailed subsystem the entire model is loaded with the ground response spectra as defined in the appropriate Environmental Specification and fixed at the interface to the ground. The analysis requirements for the Modal Response Spectrum analysis are defined in section 4.3.3 of AD5.

118 d) Non-linear time-history analysis of the assembly

In a seismic *time-history analysis* of the assembled models of the MSS and the detailed subsystem appropriate time-history input data *are applied* at the MSS interface to the ground. The time-history input data can be derived from the specified acceleration Response Spectra defined in the appropriate Environmental Specification. The analysis requirements for the time-history analysis are defined in section 4.3.3 of AD5.

119 By using the appropriate structural FE Model of the subsystem (see chapter 5.1) the static deformations and stresses shall be analyzed for each of the specified design earthquakes.

5.4 Structural Verification by Analysis

239 If not otherwise defined in the technical specifications, the MSS shall be verified according to AD1 and its applicable Eurocode norms (EN 1991 - EN 1999).

123 If agreed by ESO the MSS can be verified according to sections 5.4.1 and 5.4.2.

268 If not otherwise defined in the technical specifications, the subsystems shall be verified by one of the following approaches

a. according to AD1 and its applicable Eurocode norms or
b. according to sections 5.4.1 and 5.4.2 herein

124 The mechanical structure for electronic equipment should be verified according to AD6 by fulfilling the requirements of the seismic tests for cabinets and racks. All electronic cabinets shall meet or exceed the GR-63-CORE Zone 4 requirements (Bellcore Zone 4).

5.4.1 Load Combinations

264 For the verification of the performance and structural integrity the various load components and unit load cases defined in the technical specifications shall be conservatively combined.

265 If not defined otherwise in the technical specifications, the load combinations defined in the sections here below should be applied.

255

Load case	Category	Operating condition	Permanent load	Survival Temp.	Survival Wind	Maximum Earthquake	Maximum Shock
LC1	Operation al	Nominal	1.0 x O(1)				
LC2	Survival / Accidental	Nominal	1.0 x O(1)	1.0			
LC3	Survival / Accidental	Nominal	1.0 x O(1)		1.0		
LC4	Survival / Accidental	Nominal	1.0 x O(1)			1.0	
LC5	Survival / Accidental	Transport	Transport conditions	0.7			1.0

Load Combination factors example

(1) O: Operational load conditions (e.g. gravity, operational temperature range, preload)

5.4.2 Structural Safety Verification

126 All relevant criteria of structural failure shall be considered (strength, fatigue, buckling, etc) for any designed part.

267 The structural integrity and safety of the subsystems shall be verified for all load cases and load case combinations by fulfilling the Margin of Safety equation and its corresponding safety factors defined in section 5.4.2.

127 In order to verify the structural safety of the subsystems design, the general rules of AD4 shall be applied, where applicable. These rules are defined for buildings, steel structures, shell structures, joints (Bolts, rivets, pins, welds), material properties, tension components, structure stability (global and local buckling), fatigue, etc

128 Unless otherwise required by this or any superseding standard, the Margin of Safety (MoS) including the safety factors shall be greater than or equal to zero:

$$MoS = \sigma_m / (\sigma * SF * SFM) - 1 \geq 0$$

where

σ_m = yield strength for ductile materials, ultimate strength for brittle materials

σ = maximum working stress of any applicable load case or combination thereof; von Mises stress for ductile materials, maximum principal stress for brittle materials

SF = Load Safety Factor (according to # 129)

SFM = Material Safety Factor (according to # 168)

An equivalent verification approach is the "Reserve Factor" RF which shall be greater than or equal to 1.0:

$$RF = s_m / (s * SF * SFM) \geq 1.0$$

129 Unless applicable standards require higher values, the following safety factors shall be applied in the formula of # 128:

Loading and environmental conditions	**Load Safety Factor (SF)**
On Site Assembly, Integration	1.35
Operation, Stand-by and Maintenance	1.35
Survival, Accidental	1.1

Table 1: Safety factors for allowable stress

Note:

Transport on site during operations falls in the category "Operation, Stand-by and Maintenance".

"Survival" load conditions include e.g. NCR earthquake, survival wind, survival temperature, survival snow, survival ice.

"Accidental" conditions are usually of short duration but of significant magnitude, that is unlikely to occur, e.g. shock load.

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Material	Material's Safety Factor (SFM)	
	Yielding	Rupture or Collapse
Metal	1.1	1.5
Optical glass, glass-ceramic	N/A	2.0
Glue, Adhesive bonding	N/A	2.0
CFRP	N/A	2.0
Concrete	N/A	2.0
Reinforcement steel	1.15	1.5

Table 2: Material's safety factors

169 It is suggested to use RD4 for the verification of CFRP parts. Alternatively, the equivalent stress safety factor shall be applied to the relevant failure mode to be considered for the part under examination. All relevant failure criteria shall be considered (delamination, fatigue, cracking, gluing failure etc.).

167 Analyses verification shall be carried out, where necessary, to ensure the safety of the mechanical structures under all environmental conditions and during manufacturing, transport, erection and AIV/commissioning phases.

166 Any phase of the project may be subjected to earthquake conditions. Depending on the estimated time in a particular phase (e.g. maintenance, Integration, storage) a reduced earthquake requirement may be defined in the System Technical Specification taking into account a lower probability of occurrence.

130 If not defined in the System Technical Specification, the maximum allowable principal tensile stress of glass-ceramic substrates shall be less than

a. 10 MPa for permanent load.

b. 15 MPa for short-term load over any maximum duration of 24 hours within the lifetime of the structure.

This requirement excludes local stresses caused by singularities, i.e. stresses within a distance to a singularity of less than 50% of the characteristic length can be excluded. E.g. typical characteristic length would be the diameter of a circular pad.

131 The probability of failure of glass-ceramic substrates and optical glass shall be less than 10^{-5}. That requirements applies as well to the interfaces between the substrate and its support system (typically bonded pads).

171 The analytical verification of the probability of failure shall be performed using the Weibull statistics for the entire lifetime of the equipment following the procedure described in AD10. For Zerodur (and other glasses provided by Schott), the corresponding material parameter values (Characteristic strength, Weibull factor, surface condition and stress corrosion constant) shall be applied as defined in AD10.

5.5 Safety against other Hazards

134 The possible effects of excessive loading on structural components relevant for safety and not directly linked to stresses in the mechanical structure shall be evaluated. The corresponding safety related items derived from the hazard and risk analyses shall be included in this evaluation. A typical (but not unique) example can be the effect of mechanical contacts in electrical and electronic subsystem leading to short circuits and other damages.

5.6 Engineering Calculations

136 Engineering calculations are e.g. hand calculations based on formulas in Engineering standards or hand books by using specific analysis programs. Engineering calculations can be carried out where it is more adequate than FEA.

137 The agreement of ESO shall be obtained, if manual engineering calculations and verifications are performed instead of FEA.

138 Any code used in Engineering calculations shall be indicated and all the references for formulas, assumptions, material data, etc. shall be provided.

139 References in English shall be used whenever available.

140 For high duty bolted joints the guidelines defined in RD3 should be used.

141 AD7, AD8 and AD9 shall be applied for moving structures and moving equipment, e.g. lifting, handling and transport equipment for Instruments. Design principles and load factors for crane rails and wheels shall be used for steel wheel/rail systems such as enclosure rotation or handling tools.

5.7 Computation Fluid Dynamics Analysis Requirements

143 To verify the correct modelling of turbulence a check on the dimensionless wall distance (y+) shall be conducted. The values shall be between 30 and 500. In the Boundary layer region the mesh expansion ratio shall be less than 1.2.

240 If CFD analyses are required by the design activities, an internationally recognised and proved Software package shall be used. ANSYS-CFD is the preferred package.

5.8 Analysis documentation

145 The analysis shall be documented to such detail and include all references so that an independent verification and rerun of the calculation is possible from the analysis report and supplied data only.

All the analysis carried out shall be documented according to Annex D.

6. Annex A

6.1 Model Accuracy Checks

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Model check		Requirement
1	Free nodes	Delete nodes in the model which are not connected to elements or constraint equations.
2	Free connections	Assure that elements in the model are properly connected by using free-edge check.
3	Coincident elements	Delete coincident elements (same node connectivity), if it is not intended.
4	Elements shape	Assure that plate element distortion (e.g. warping, aspect ratio, face angle, Jacobian Ratio) meets the recommended limit requirements.
5	Element normals	Assure that plate element normals of a component are oriented uniformly.
6	Model mass	Check if model's mass is reasonable and accurate.

6.2 Model Common Sense Accuracy Checks

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Model check		Requirement
7	Units	Check consistency of units (dimensions, material properties, loads).
8	Constraints check	Check carefully the adequacy of boundary conditions. Make sure their locations and DOFs are correct. Avoid incorrect over- or under-constraint system.
9	Material properties	Check whether material property values are correct and match the units used elsewhere. Check completeness of properties depending on the analysis type.
10	Element properties	Verify beam cross sections and area moment of inertias, plate thicknesses, mass and stiffness properties.
11	Dimensions	Ensure correlation between overall geometry and drawings / 3D CADD data.
12	Element selection	Select proper element type for the analysis.
13	Constraint equations	Cross check correct formulation of the constraint equations (CE, RBE and MPC). Avoid over-constraining the model with constraint equations.
14	Coordinate systems	Check carefully the input and output coordinate systems applied.

6.3 Mathematical Model Checks

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Model check		Requirement	Action / Criteria
15	Gravity load check	Verify that the model provides plausible displacements and reaction forces under unit gravity loading, applied separately along the three orthogonal Axes.	Check consistency of total mass, acceleration and total reaction force. Total reaction forces in other than loading direction should be zero.
16	Enforced displacement check	The unit enforced displacement and rotation check verifies that no illegal constraint (such as incorrect CE or RBE) is present in the model.	Constrain only a single node close to the center of gravity in all six DOF. The unit displacements and rotations should be applied to this node. The check shall be performed in all 6 DOF directions, one at a time. The model should move as a rigid body when it is translated by one unit or rotated one radian. The displacement results from the three translational

			load cases should be 1.0 along the input direction and zero in the other five directions. From the rotational load cases the rotation in the input direction should be 1.0 and the other two rotations should be 0.0. The element forces and nodal force balances should be close to zero.
17	Free-free dynamic	The free-free dynamics check verifies that the model moves as a rigid body when it is unconstrained. It also checks the stiffness matrix in terms of internal constraints, such as erroneously defined CE.	Perform modal analysis after all external constraints have been removed. The ratio between the first six frequencies and frequency of the lowest elastic mode shall be less than 1E-3. Additional rigid body modes should be justified case-by-case (e.g. free motor axis, mechanisms).
18	Conditioning check	The purpose of the conditioning check is to identify regions that can cause numerical rounding errors in the stiffness matrix and hence erroneous results.	The maximum stiffness ratio (ratio between highest and lowest stiffness coefficient values) of the model shall not exceed 10^{12} (goal 10^{8}).
19	Thermal-structural check	The purpose of the thermal-structural check is to verify that the model is well conditioned for the thermo-elastic analysis. This check should be performed on all models used for thermal distortion analyses.	The model must be iso-statically supported (e.g. all 6 DOFs constrained at one node). For this check all the material properties used in the model have been replaced with the same homogenous and isotropic ones. A uniform temperature increase must be applied to the model. The resulting displacements must comply with the theoretical displacements. The nodal forces balance and the resulting stresses should be close to zero, i.e. E=100 GPa, n=0.3, CTE=10^{-5} 1/K, dT=80 K,→ σ_{max}< 100 Pa

7. Annex B: ANSYS Current Technology Elements

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Category	Elements
Solid	PLANE182, PLANE183, SOLID185, SOLID186, SOLID187, SOLID285
Coupled Physics	SOLID223, SOLID226, SOLID227
Shell	SHELL181, SHELL208, SHELL209, SHELL281
Solid-Shell	SOLSH190
Beam	BEAM188, BEAM189
Link	LINK180
Pipe	PIPE288, PIPE289
Elbow	ELBOW290
User Element	USER300
Reinforcement	REINF264,REINF265
Interface / gasket	INTER191 – INTER195
Cohesive	INTER202 - INTER205
Target	TARGE169, TARGE170
Contact	CONTA171 - CONTA177, CONTA178, PRETS179
Constraint/Joints	MPC184
General Axisymmetric	SOLID272, SOLID273
Special purpose	SURF151 – SURF156, FOLLOW201, Discrete Elements

Note: These elements are referring to mechanical applications only. The list may not be complete.

8. Annex C

8.1 Stress Analyses Categories

156 a. Bending, flexural shear and/or torsion analysis of a beam, frame, rib, shaft, or ring of various open or closed sections

b. Plate and shell analysis

c. Beam on an elastic foundation

d. All types of stability analysis including general and local stability of plates, skins, webs, shells, web shear buckling or diagonal tension, local buckling or crippling of composite shapes, column stability, and beam-column stability

e. Analysis of composite, honeycomb, and reinforced materials

f. Large elastic deformations, geometrical nonlinearity, and gapping analysis

g. Nonlinear analysis beyond the elastic range of the material

h. Vibration analysis

i. Dynamic, impact, and fatigue analysis

j. Stress concentration and fracture analysis

k. Crack growth analysis

l. Machine components (spring, gear, shaft, clutch, brake, ropes, belts, chains, cables, etc.) analysis

m. Thermal structural and other analysis

8.2 Stress Analyses Categories for Fasteners, Fittings and Connections

157 n. Bolted joint, fitting, splice plate, and bolt group analysis

o. Riveted joint and connection analysis

p. Lug, pin, and bushing analysis

q. Bolt preload and installation torque analysis

r. Welded joint analysis

s. Bonding, adhesive, and friction analysis

t. Linear and nonlinear residual stress analysis

u. Tolerance, interference, mismatch, thermal and other structural analysis

9. ANNEX D: Document Requirement Definition (DRD) for ANALYSIS REPORT

195 The Analysis Report summarises all the calculations which support the design (e.g. F.E. calculations. etc.).

196 The Analysis Report shall identify which issue of the specification and which design/manufacturing configuration has been used for the analysis.

197 An Analysis Report shall be produced every time if a verification by analysis is required in the verification matrix.

198 The Analysis Report shall contain the following information:

1. Scope of the analysis

In this section the purpose of the analysis shall be given as well as a general description of the contents of the Analysis Report.

2. Applicable documents

In this section all the documents referred to in the Analysis Report shall be listed.

3. Assumptions

In this section all the assumptions used in the analysis shall be listed and discussed. In particular:

assumptions used in the definition of the model

assumptions used in defining the boundary conditions (if applicable)

assumptions used in defining the material properties (if applicable)

assumptions used in defining loads and loading cases (if applicable)

assumptions used in processing the results, (if applicable)

analysis methods

4. Model

In this section the model used in the analysis shall be described in detail, in particular:

the geometry

the coordinate system

quality of CAD model when used as basis

the configuration

the sectional properties (if applicable)

material properties

boundary conditions

loads topology

type of elements used (if applicable)

type of component') used (if applicable)

correspondence between the model and the actual modeled component

Plots and sketches illustrating the model shall be included and shall be readable in all details. The detail of the description shall allow reproducing the model.

5. Loading cases

In this section the loading cases shall be identified.

The loading applied to the model shall be described, justified and illustrated in plots and/or sketches. A list of the loaded nodes shall be given (if applicable).

6. Results

In this section the results shall be presented and discussed.

The pass/fail criteria including safety factors shall be clearly described

References to the regulations or specifications shall be made

The results coming out from the analysis shall be processed in such a way that they are directly comparable with the verification and failure criteria. A comparison table shall summarise the calculated values with the allowable values (verification criteria) including the minimum safety margins for each part of the structure.

7. Conclusions

This section shall include the major results and conclusions in the report. A clear statement about the compliance of the results with the design and performance requirements shall be given. Non-Conformities shall be discussed. This section shall also include any recommendations based on the analysis.

Annex: Model Validation Checks

This section shall include the FE Model validation checks. Boundary conditions, applied loads, results and any non-conformancies shall be documented here.