TÜRK LOYDU

Chapter 53 – Submersibles
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This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction as defined in IACS PR No.29 is on or after 6th of July 2013. New rules or amendments entering into force after the date of contract for construction are to be applied if required by those rules. See Rule Change Notices on TL website for details.

"General Terms and Conditions" of the respective latest edition will be applicable (see Rules for Classification and Surveys).

If there is a difference between the rules in English and in Turkish, the rule in English is to be considered as valid. This publication is available in print and electronic pdf version.

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SECTION 1

CLASSIFICATION AND CERTIFICATION OF MANNED SUBMERSIBLES

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A. Scope

1. These Rules are valid for the construction of manned submersibles which shall be classified or certified by **TL**, including their mating, control and monitoring systems.

The requirements for the necessary control and supply systems as well as the required systems for launch, recovery and stowage aboard of the support ship are summarized in Section 17.

As submersibles are to be understood:

Manned, non-military, autonomous, non-autonomous or independent, free-floating vehicles, including their mating and supply systems for life support.

2. Autonomous submersibles

For the purpose of these Rules submersibles, which are during the mission not physically connected to the relevant support ship (e.g. by an umbilical), are regarded as autonomous submersibles.

3. Non-autonomous submersibles

For the purpose of these Rules submersibles, which are during the mission always physically connected to the relevant support ship (e.g. by an umbilical), are regarded as non-autonomous submersibles.

4. Independent submersibles

For the purpose of these Rules submersibles, which are able to operate offshore without support ship, are regarded as independent submersibles.

5. For further definitions, see Section 2, C.

B. Classification and Characters of Classification

1. Classification

1.1 Opportunity for Classification

Manned submersibles may be classified and have then to be subjected to repeated surveys by **TL** according to the duration of Class.

1.2 Basis for Classification

The following Rules for Classification and Construction constitute the basis for the Classification of submersibles.

For requirements not defined in these Rules, the other Rules for Classification of **TL** have to be applied.

The term "Rules for Classification" includes Rules for Materials and Welding as well as other Rules for Construction issued by **TL**, compare Section 2, B.

1.3 Scope of Classification

Classification covers the entire submersible including its machinery, structural elements and electrical equipment.

An overview which additional system elements of the total system are to be classified shows Table 1.1.

1.4 Class Certificate

The Certificate of Classification for submersibles is issued by the **TL** Head Quarter. It is to be kept on board.

1.5 Class Register

Submersibles classified by **TL** are entered in the Register Book with a note of the relevant Character of Classification and of the essential technical data and are included in the list of submersibles.

1.6 Operational records

Submersibles are required to carry an operational record in which details of operations (diving depth, mission time, damages, maintenance, repairs, etc.) are entered. The record is to be submitted to the **TL** Surveyor on request.

2. Class designation

2.1 The Character of Classification and notations are:

– For the submersible

100A5 SUBMERSIBLE

The figure 5 denotes the duration of Class in years.

– For machinery installations

MC S

– If the range of operation is restricted, this has to be added in the Class Certificate.

2.2 Submersibles built under the survey and in accordance with the Rules of **TL** using materials and components tested by **TL** in conformity with its Rules receive “+” in front of the Character of Classification.

2.3 Submersibles built under the survey and in accordance with the rules of another recognized classification society receive, on being awarded **TL** Classification, [+] in front of the Character of Classification.

Table 1.1 Classification and Certification of manned submersibles

System elements	Types of manned submersibles		
	Non-autonomous	**Autonomous**	**Independent**
Submersible (Section 1 – 16)			
Submersible as such including umbilical and mating system, if applicable	Classification Submersible Certification	Classification Submersible Certification	Classification Submersible Certification
Communication equipment of the supply ship, if applicable	Classification Submersible Certification	Classification Submersible Certification	–
Supporting systems aboard the support ship (Section 17)			
Supply systems **(1)** and their control	Certification **(2)**	Certification **(2)**	–
Launch and recovery equipment including umbilical winch, if applicable	Certification **(3)**	Certification **(3)**	– **(4)**
Stowage and deck transport	Proof of Suitability **(5)**	Proof of Suitability **(5)**	– **(4)**

(1) *Life support systems are part of Classification respectively Submersible Certification*
(2) ***TL*** *Certificate or Certificate of a recognized institution, as far not content of the Classification of the support ship*
(3) ***TL*** *Certificate or Certificate of a recognized institution*
(4) *If existing for this type, this equipment may be certified by* ***TL***
(5) *Test stamp, test mark for lashing devices, etc.; proof for winches, deck fastening, etc.*

2.4 For submersibles and their equipment which are non-standard design, **TL** reserve the right to impose additional tests, to order a special survey schedule and to make special entries in the Submersible Certificate and the Register Book.

3. Validity of Class

3.1 Submersibles and their machinery installations always have the same period of Class. The Class will be maintained as long as the submersible and its machinery installation are subjected to all prescribed surveys, and any modifications and repairs found to be necessary are carried out to the satisfaction of **TL**.

3.2 If the submersible is not subjected to the prescribed surveys at their due dates, the Class will be suspended.

3.3 If the submersible or its machinery installation has suffered damage affecting its Class or if such damage may be assumed, a survey has to be performed before departure or before operation with the submersible begins. **TL** is to be notified of such damage as a matter of course.

3.4 Where it is found that the submersible no longer complies with the requirements on the basis of which the Class was assigned, and if the operator fails to carry out repairs or modifications considered necessary by **TL** within a specified period to be agreed upon, the Class of the submersible expires.

3.5 If the repairs or modifications required by **TL** have been carried out and the vehicle is subjected to a Reclassification Survey, the original Classification may be reinstated. This survey is to be carried out in accordance with the scope for a Class Renewal Survey.

3.6 The period of Class of laid up submersibles continues unchanged. On request, any surveys which fall due may be deferred until the submersible is replaced into service. In these circumstances, the total scope of the surveys required thereafter shall be determined by **TL** for each case individually.

3.7 If for some reason the Class has expired or has been withdrawn by **TL**, the Class will not be carried further on in the Register Book. The Certificates of Classification shall be returned to **TL**.

C. Classification of Submersibles built or converted under the Survey of and in Accordance with the Rules of TL

1. General

1.1 Application for the Classification of a submersible is to be submitted to **TL** in writing by the manufacturer or operator.

1.2 In general, documents of the submersible are to be submitted to **TL** in general in triplicate respectively in case of electronic transmission as single issue for examination.

1.3 Any deviations from the approved drawings and documents are subject to the approval of **TL** before work is commenced.

1.4 The Surveyor is to be advised in good time for tests to be performed under the supervision of **TL**.

1.5 On the completion and successful testing of the submersible, **TL** will issue the Classification Certificate.

2. Supervision during construction

2.1 Materials for new constructions, replacements and repaired parts have to be tested as defined in the **TL** Rules for Materials.

2.2 Parts of the submersible requiring approval will be checked during manufacture for conformity with the approved documents.

2.3 The separate components of the submersible are to be tested at the manufacturer's for mechanical strength and, where appropriate, for functional efficiency. Where components are novel in design or have not yet sufficiently proved their efficiency on board ships or in submersibles, **TL** may demand more extensive tests.

2.4 The Surveyors to **TL** will supervise the assembly of the submersible and the installation of the machinery and electrical equipment, the workmanship will be examined and the required tightness and functional tests will be carried out.

2.5 Upon completion, the submersible, including all its structural elements, machinery and electrical installations and, where applicable, the necessary supply systems, will be tested under working conditions in accordance with the Rules set out in Section 2.

2.6 To enable the **TL** Surveyor to fulfil his duties, he is to be given free access to the submersible and to the workshops where parts requiring approval are manufactured, assembled or tested. Assistance by providing the necessary staff and equipment has to be granted by the shipyard or the manufacturer. The compliance with the requirements for workmanship according to H. is to be checked by the Surveyor.

D. Classification of Submersibles not built under the Survey of TL

1. General

1.1 The application for the Classification of submersibles not built under the survey of **TL** is to be submitted to **TL** in writing.

1.2 With the application for Classification, documents relating to the submersible and any necessary supply systems are to be submitted for examination, the scope of which shall be as stated in the Rules for Construction. The documentation relating to functional tests is to be submitted and, where necessary, individual tests are to be repeated.

1.3 Existing Class and period of Class, as well as any requirements which have been made conditional upon the existing Class are to be reported.

1.4 Where the submersible has an existing Class awarded by a recognized classification society, it may in exceptional cases be sufficient to forward one set of the necessary documents.

2. Procedure of admission to Class

2.1 For admission to Class the submersible is to be surveyed in accordance with the provisions for a Class Renewal Survey.

2.2 If the submersible holds the Class of another recognized Classification Society, the survey of individual parts may be deferred pending the next due date a survey of these parts within the scope of an Annual Survey may be declared as sufficient.

2.3 A Classification Certificate will be issued on the basis of satisfactory Surveyor's Report on the admission to of class. Once a submersible has been classed with **TL**, the same regulations will apply as for submersibles built under survey of **TL**.

E. Surveys for Maintenance of Class

1. Kinds of surveys

Submersibles classed with **TL** are to be subjected to the following surveys, if their Class is to be maintained:

1.1 Annual Survey, see 3.1.

1.2 Intermediate Survey, see 3.2.

The Intermediate Survey falls due nominally 2,5 years after commissioning and each class renewal and may be carried out on the occasion of the second or third annual survey.

1.3 Class Renewal Survey after five years, see 3.3.

1.4 Damage Survey, where the submersibles or parts thereof have suffered damage liable to affect the serviceability of the submersible, see 3.4.

1.5 **TL** reserve the right to demand for extraordinary surveys in justified cases. Such surveys may be credited against the prescribed regular surveys.

1.6 Apparatus and components are to be arranged accessible for surveys. If it is either not possible or excessively costly to prepare these for survey on board, surveys may also, on application, be performed in the manufacturer's works or another authorized workshop.

2. Explanatory notes on surveys

2.1 The locally responsible Surveyor to **TL** is to be given timely notice when regular surveys become due or when it is intended to carry out repairs or alterations, so that the work can be supervised.

2.2 The records of each survey, as well as special requirements upon which the maintenance of class has been made conditional, will be entered in the Classification Certificate. In addition to the Character of Classification and the month and year of Classification, the Register Book shall also state the month and year of the last Annual Survey or the last Class Renewal Survey.

2.3 The reports prepared by the Surveyors are checked by **TL**. The results of surveys carried out are published in the Register Book, Part 2, upon acceptance.

2.4 Where defects are repaired provisionally only, or where the Surveyor does not consider immediate repairs or replacements necessary, the Class of the submersible may be confirmed for a certain limited period by making an entry in the Certificate of Classification. The withdrawal of such restrictions will be entered in the Certificate of Classification.

2.5 Where parts are damaged or worn to such an extent that they no longer comply with the requirements of **TL**, they are to be repaired or replaced.

2.6 If a submersible has to be surveyed in a port where, or near which, there is no Agent of or Surveyor to **TL**, the locally responsible Consul, a competent Office or Authority, or the Average Commissioner of the Insurance Company concerned is to be requested to cause the vehicle to be surveyed by an Expert. The commission of the Expert is to be confirmed by the Consul, the Office or Authority, or the Average Commissioner. The consulted Expert shall be requested to forward to **TL** forthwith a report on the condition of the submersible and on the repairs as well as on the decision arrived at. A copy of the report is to be retained on board the vehicle. The decision of the Expert is subject to the approval of **TL**, who will decide on whether the submersible has to be surveyed again.

3. Performance of surveys

The surveys are to be performed according to the following criteria. If the operational systems of a submersible should be different from the standard case, the scope of the surveys may be adjusted accordingly in coordination with **TL**.

3.1 Annual Survey

The Annual Survey of the submersible shall include at least the following tests and checks:

3.1.1 Examination of the documents relating to the submersible and scrutiny of the operational records.

3.1.2 The pressure hull outside and inside and external structure including all fixtures, penetrations, viewports, doors and covers, seals, locking systems, etc. are to be inspected for visible damage, cracks, deformation, corrosion and fouling, etc.

3.1.3 Check of the measures for corrosion protection (e.g. anodes).

3.1.4 All other pressure vessels and apparatus under external or internal pressure, valves, fittings and safety equipment are to be subjected to external inspection.

3.1.5 The entire machinery installation and the electrical equipment including all redundancy systems are to be subjected to external inspection.

3.1.6 Check that insulation measurements have been performed on the electrical equipment.

3.1.7 Review of safety systems including response pressure of the safety valves and the set points of the safety devices.

3.1.8 Function test of all alarm systems

3.1.9 Switching from the main to the emergency electricity supply is to be tested.

3.1.10 The accuracy of all essential instrument readings is to be checked (e.g. depth gauge, gas analyzer, etc.).

3.1.11 All emergency and safety systems (e.g. jettisoning mechanism, marking buoy, rescue devices) are to undergo a functional test - as far as appropiate.

3.1.12 Functional test of all life support systems.

3.1.13 Tightness test of the life support systems and of the ballast system at maximum allowable working pressure.

3.1.14 Review of the function of the fire surveillance and extinguishing systems.

3.1.15 Hose lines are to be checked for visible damages.

3.1.16 Acryl glass panes are to be subjected to a visual check for cracks, scratches, changes of structure (crazing). As far as possible at installed condition, the contact area and the window sealing are to be checked.

3.1.17 The umbilical and lifting cable if applicable – is to be checked for visible damages, cracks, deformations and corrosion.

3.1.18 The function of data transfer and communication systems is to be checked.

3.1.19 If compressors for breathing air are used the quality of the compressed air is to be proven, e.g. according to EN 12021.

3.1.20 Compression chambers/diver lockouts of the submersible are subjected to functional tests and a tightness test at maximum allowable diving pressure with the relevant operational media.

3.1.21 The mating arrangement of the submersible, if applicable, will be checked for visible damages, cracks, deformations and corrosion and, as far as possible, subjected to a functional test.

3.1.22 The functional efficiency of the total system is to be checked by means of a trial dive.

3.2 Intermediate Survey

An Intermediate Survey is an Annual Survey according to 3.1 extended by the following scope.

3.2.1 Performance of a tightness test on pressure hull penetrations and closing appliances by application of a vacuum of at least 0,2 bar below atmospheric pressure.

3.2.2 Tightness test on diving tanks which can be shut off using air at a test pressure of approximately 0,2 bar preferable at the completely dived submersible respectively tightness test of the ventilation valves for open diving tanks.

3.2.3 Tightness test on pressure vessels under external pressure by underpressure test with at least 0,2 bar below atmospheric pressure or other suitable test procedure, as far as required.

3.2.4 Tightness test of the compensating system.

3.2.5 Tightness test of hose lines.

3.2.6 External visual check and functional test, if applicable, of the extension elements/working devices belonging to the submersible.

3.3 Class Renewal Survey

In addition to the surveys defined in 3.2 the following tests and examinations are to be carried out for Class Renewal Surveys:

3.3.1 Visual check of the fastenings, bearing and coupling elements of all machinery and devices.

3.3.2 Inspection of the shell cladding and buoyancy aids (pressure resistant foam) from all sides. If necessary the cladding has to be removed.

3.3.3 Dimensional checks and non-destructive wall thickness tests are to be performed on the pressure hull and the diver's lockout. Where necessary, buoyancy aids, cladding and layers of thermal insulation are to be removed for this purpose.

3.3.4 Check of the structural areas which are not easily accessible with the aid of a non-destructive test procedure.

3.3.5 An emergency ballast release followed by a buoyancy test are to be performed.

3.3.6 Internal visual check of vessels and apparatus under pressure. If these cannot be satisfactorily inspected internally or their satisfactory condition cannot be fully verified by internal inspection, another non-destructive test method is to be used and/or a hydraulic pressure test is to be additionally performed. Where necessary, buoyancy aids, cladding and layers of thermal insulation are to be removed for this purpose.

3.3.7 The examinations according to 3.1.16 are to be performed for dismantled acrylic glass panes.

3.3.8 Check that accessories, especially hose lines and compensators are changed according to the maintenance plan.

3.3.9 Where surveys are performed on a submersible or parts thereof during the period of Class, the scope of which corresponds to a Class Renewal Survey, then the regular Class Renewal Survey for the parts concerned may at the operator's request be deferred accordingly.

3.4 Damage Survey

3.4.1 If the submersible has suffered damage affecting its Class or if such damage may be assumed, a Damage Survey is to be carried out.

3.4.2 Following damage, the submersible is to be presented for survey in such a way that a satisfactory inspection can be carried out. The extent of the Damage Survey will be determined by **TL** in each individual case.

3.5 Extraordinary Survey

3.5.1 When any modification is made in respect of design, mode of operation or equipment, and after major repairs to the submersible, a Special Survey is to be carried out.

3.5.2 Where modifications are made to the submersible which affect its buoyancy or stability, appropriate heeling and trim experiments are to be performed in the presence of the Surveyor.

F. Surveys other than for Classification

1. Survey by special agreement

Where surveys are required by official ordinances, international agreements or other provisions, **TL** will undertake them on application, or by official order in accordance with the relevant provisions.

2. Surveys relating to the safety of equipment

2.1 For all components with an important safety aspect (e.g. vessels and apparatus under pressure, etc.), **TL** will, on application, examine the drawings, carry out all the necessary surveys, acceptance tests and pressure tests and issue the relevant Certificates.

2.2 On application, **TL** will also perform the repeated surveys required for vessels and apparatus under pressure.

G. Certification

1. General

1.1 The application for Certification of a submersible is to be required from **TL** by the manufacturer or operator in written form.

1.2 Documents for the submersible are to be submitted to **TL** generally in triplicate respectively in case of electronic transmission as single issue for approval. The scope of the documents to be submitted depends on the type and equipment of the submersible and follows from Section 2, E.

1.3 Surveys which have to be performed by **TL** are to be noticed to **TL** in due time.

2. Certification according to TL Rules

2.1 Opportunity for Certification

Manned submersibles, which are constructed and tested according to the rules and surveys of **TL** may receive a Submersible Certificate from **TL**.

2.2 Scope of Certification

The Certification comprises the complete submersible including its machinery, shipbuilding and electric installations.

An overview which additional system elements are certified shows Table 1.1.

2.3 Submersible Certificate

2.3.1 After completion and successful testing of the submersible a Submersible Certificate will be issued by **TL**.

2.3.2 **TL** certifies with the Certificate the technical condition of the submersible at the time of the tests and approvals. In addition it will be confirmed that no safety reservations are opposing the operation of the submersible.

2.3.3 The validity of the Submersible Certificate is 5 years at maximum and can be prolonged after a renewed test. For maintaining the Certificate the submersible is in general to be subjected to an Annual Survey. The scope has to be agreed with **TL** in each single case.

The Submersible Certificate looses its validity if substantial changes are performed at the submersible respectively if the submersible has been severely damaged and the change or the repair has not been agreed and approved by **TL**.

3. Certification according to other rules

3.1 For manned submersibles, which are not built according to the Rules of **TL**, the applied rules have to be defined in a binding way in the application for Certification.

3.2 Submersibles which have been constructed and tested under survey of **TL** according to other recognized rules may receive a Certificate of **TL**.

H. Workmanship

1. General

1.1 Requirements to be complied with by the manufacturer and supplier

1.1.1 Each workshop of a manufacturer/supplier has to be provided with suitable equipment and facilities to enable proper handling of the materials, manufacturing processes, structural components, etc. **TL** reserve the right to inspect the workshops accordingly and ask for related requirements or to restrict the scope of manufacture to the potential available at the plant.

For safety relevant components and elements it is to be defined by **TL**, if the manufacturer/supplier needs an approval by **TL**. Components and elements are regarded as safety relevant, if a direct danger for persons may be created by them.

1.1.2 The manufacturing plants are to have at their disposal sufficiently qualified personnel. The supervisory and control personnel is to be named to **TL**, the areas of responsibility are to be defined. **TL** reserve the right to require proof of qualification.

1.2 Quality control

1.2.1 The manufacturer/supplier has to apply a quality management system, like e.g. ISO 9001 or equivalent.

1.2.2 As far as required and expedient, all components both during manufacture and on completion are to be checked by the manufacturer for completeness, correct dimensions and faultless workmanship according to the standard of good engineering practice.

1.2.3 Upon inspection and corrections by the manufacturing plant, the structural components are to be shown to the **TL** Surveyor for inspection, in suitable sections, normally in uncoated condition and enabling proper access for inspection.

1.2.4 The Surveyor may reject components that have not been adequately pre-checked and may demand their resubmission upon successful completion of such checks by the manufacturer and, if necessary, corrective actions.

2. Details in manufacturing documents

2.1 All significant details concerning quality and functional ability of the component concerned shall be entered in the manufacturing documents (workshop drawings, etc.). This includes not only scantlings but where relevant such items as surface conditions (e.g. finishing of flame cut edges and weld seams), special methods of manufacture involved as well as inspection and acceptance requirements and where relevant permissible tolerances.

As far as a standard shall be used (works, national standard, etc.) it has to be harmonized with **TL**.

2.2 If, due to insufficient or missing details in the manufacturing documents, the quality or functional ability of the component cannot be guaranteed or is doubtful, **TL** may require appropriate improvements. This is valid for supplementary or additional parts (for example reinforcements) even if these were not required at the time of plan approval or if – as a result of insufficient detailing – could not be required.

SECTION 2

PRINCIPLES FOR THE CONSTRUCTION OF MANNED SUBMERSIBLES

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A. General Principles

1. Wherever expedient and feasible, submersibles are to be designed and constructed in such a way that failure of any single component cannot give rise to a dangerous situation.

2. Submersibles and their components are to be designed to meet the service conditions stated in the specification.

3. Submersibles are to be designed and built to ensure safe operation and facilitate proper maintenance and the necessary surveys.

4. Submersibles are to be designed and constructed in such a way that the skipper has an adequate forward view when submerged. The possibility of an all-round vision when navigating on the surface shall be given. This can be reached either by suitable windows or optical instruments.

5. Submersibles with a diver's lockout are to be designed and constructed to ensure the safe transport and the safe exit and entry of the divers under pressure.

B. Rules and Regulations to be considered

1. Rules of TL

1.1 The following Rules are valid as additional requirements for the Classification and construction of submersibles in addition to the Rules for Classification and Construction of these vehicles:

- Classification and Surveys

- Part A – Chapter 1, 2, 3

- Part B – Chapter 4, 4-1, 5

1.2 For submersibles with diver's lockout besides of the rules defined in the following also the **TL** Rules for Diving Systems and Diving Simulators, Chapter 52 have to be considered for the relevant components.

1.3 Concerning the supporting systems aboard the support ship see Section 17.

1.4 Designs differing from the Rules of Construction may be permitted provided that they have been recognized by **TL** as equivalent.

1.5 Submersibles or parts thereof whose development is based on new principles and which have not yet been sufficiently tested in practical operation require special approval by **TL**.

1.6 In the cases mentioned in 1.4 and 1.5, **TL** is entitled to require the submission of additional documentation and the performance of special tests.

1.7 **TL** reserve the right to impose requirements additional to those contained in the Rules in respect of all types of submersibles when such action is necessitated by new knowledge or practical experience, or to sanction deviations from the Rules in specially justified cases.

2. National regulations

National regulations existing alongside **TL** Rules are unaffected.

3. International Conventions and Codes

Where reference is made to international Conventions and Codes examples are listed in the following:

3.1 ILLC 66

International Convention on Load Lines, 1966, as amended.

3.2 MARPOL 73/78

International Convention for the Prevention of Pollution from Ships, 1973 including the 1978 Protocol as amended.

3.3 SOLAS 74

International Convention for the Safety of Life at Sea, 1974, as amended.

3.4 LSA

International Life-Saving Appliances Code issued by IMO in actual version.

3.5 COLREGS 1972

International Regulations of 1972 to prevent collisions at sea.

3.6 MSC/Circ. 981

Guidelines for the Design, Construction and Operation of Passenger Submersible Craft according to IMO MSC/Circ. 981 of 29 January 2001.

C. Definitions

1. General

Autonomous submersible

Submersible which is not physically connected to the support ship during operation (e.g. by an umbilical).

Breathing gas

All gases/mixtures which are used for breathing during underwater operations.

Compression chamber

Chamber for accommodation of persons at more than atmospheric pressure.

Control stand

Central station at which all essential indicators, controls, regulating devices, monitoring devices as well as communication systems of the submersible are arranged.

Diving pressure

The respective overpressure, corresponding to the relevant diving depth, to which a submersible or diver is exposed during underwater operations.

Diver's lockout

A compression chamber including exit hatch in a submersible for the entry, egress and accommodation of divers at diving pressure.

Exostructure

External cladding, supporting structures and fixtures outside the pressure hull which are normally not designed to withstand the diving pressure.

Fixing system

Working device for short time fixing of a submersible e.g. on a structure.

Gas cylinders

Bottles for the storage and transport of gases under pressure.

Independent submersible

Submersible which is able to operate offshore without a support ship.

Launching and recovering system

The plant and equipment necessary for launching and recovering a submersible.

Life support systems

Systems for gas supply, purification, exchanging and conditioning of the atmosphere in the pressure hull as well as for the supply of water and food and for the removal of waste.

Lifting cable

Cable for launching and recovering, and also for lifting and lowering of a non-autonomous submersible.

Mating device

The equipment necessary for the connection of a submersible with diver's lockout resp. rescue chamber to a compression chamber or another submersible.

Non-autonomous submersible

Submersible which is physically connected to the support ship (e.g. by an umbilical) during operation.

Positioning system

System for keeping a defined position (breadth, length, depth)

Pressure hull

The main component of a submersible which accommodates the crew at atmospheric pressure and with- stands the diving pressure.

Pressure vessel

A container which is exposed to internal or external overpressure.

Safe working load of the launching and recovery system SWL

The safe working load **SWL** is the load which may be loaded directly to the launching and recovery system. The dead load of lifting tackles which are not fixed to the launch and recovery system, but are used as connection between load and loading gear, is part of the safe working load **SWL**.

Submersible for tourist services

Submersible which operates in already defined, explored diving areas in depths at any time accessible to surface divers and is able to transport more than 6 passengers.

Supply systems

Systems aboard of the support ship which are supplying non-autonomous, but also autonomous and independent submersibles with the supply goods necessary for operation, like e.g. electrical power, hydraulic fluid, breathing air as well as communication and monitoring data.

Support ship

A surface vessel resp. floating structure for support and supply of autonomous and non-autonomous submersibles. Within these Rules the support ship may also be a stationary supply station (e.g. on the coast or on a stationary offshore plant).

Total system

The submersible including its mating, launching, recovery, stowage, transport and supply systems.

Umbilical/supply line

Connection between support ship and non- autonomous submersible, which might contain hose lines for gas and liquid transport and control, communication/data transfer and energy supply cables as well as, if applicable, a lifting cable.

This bunched or integrated supply line can also be used between the submersible and a diver.

Viewports

Openings in pressure hulls or compression chambers for fitting pressure-tight, flat or spherical acrylic windows.

Working devices (underwater)

Devices, e.g. manipulator, sample container and tool, which is fixed to a submersible and which are designated to the performance of underwater works and of taking e.g. samples.

Working machines (underwater)

Machines, e.g. grab, driver, bucket and their combination, which are normally used from a support ship to perform underwater tasks (see Chapter 54 – Underwater Equipment).

2. Main dimensions and main parameters

All dimensions are related to permanently installed equipment in drawn in/turned in condition.

2.1 Coordinate system

In relation to the submersible a fixed, right-handed coordinate system x, y, z according to Fig. 2.1 is introduced. The origin of the system is defined by the aft perpendicular, the centre line and the basis line of the submersible. The x-axis points in longitudinal direction of the vehicle positive forward, the y-axis positive to port and the z-axis positive upwards. Angular motions are considered positive in a clockwise direction about the three axes.

2.2 Aft perpendicular AP

The aft perpendicular **AP** is vertical to the x-axis through the intersection of rear edge of the stern boss with mid of propeller for vehicles with central shaft, for vehicles with several shafts and special propulsion arrangements to be defined case by case.

2.3 Forward perpendicular FP

The forward perpendicular **FP** is vertical to the x-axis through the intersection with foreside of the stem, for special arrangements to be defined case by case.

2.4 Length between the perpendiculars LPP

The length **LPP** is the distance between **AP** and **FP** measured parallel to the x-axis.

2.5 Length over all LOA

The length **LOA** is the length between the most forward and most aft point of the submersible including fixed installed components of equipment, measured parallel to the x-axis [m].

2.6 Total breadth B

The total breadth **B** is the maximum breadth of the submersible including all fixed installed parts of equipment, measured parallel to the y-axis [m].

2.7 Radius of the pressure hull R_m

The radius of the pressure hull $\mathbf{R_m}$ is the radius of the cylinder or the sphere related to the middle of the wall thickness.

2.8 Total height H

The total height **H** is the total height from baseline to upper edge of the vehicle including all permanently installed parts of equipment, measured parallel to the z-axis [m].

2.9 Draught T

The draught **T** in surfaced condition is the maximum vertical distance between the baseline and the water surface [m].

2.10 Displacement

The displacement of the surfaced submersible ready for surfaced operation is $\Delta\uparrow$, the displacement of the completely dived vehicle is $\Delta\downarrow$ [t].

2.11 Payload NL

The maximum additional load **NL** for devices, equipment, materials, which are not necessary for the direct operation of the submersible, but are serving for work to be performed, investigation of the sea and scientific research [kg]. This includes the passengers according to Table 3.1. The crew is not part of the payload.

2.12 Diving depths

All diving depths are related to the lower edge of the pressure hull.

2.12.1 Nominal diving depth NDD

The nominal diving depth **NDD** is the diving depth for the unrestricted operation of the submersible [m].

2.12.2 Test diving depth TDD

The test diving depth **TDD** is the diving depth which is related to an external overpressure, to which the submersible is subjected to test conditions after completion or after essential repairs [m].

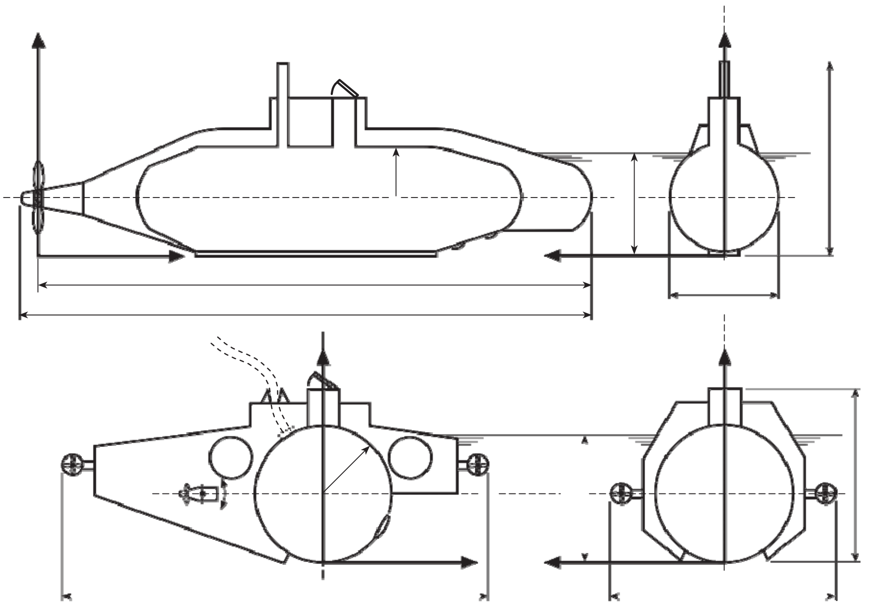

Fig. 2.1 Fixed coordinate system and main dimensions

2.12.3 Collapse diving depth CDD

The collapse diving depth **CDD** is the diving depth decisive for the design of the pressure hull, where a collapse of the pressure hull is to be expected [m].

2.13 Velocities

2.13.1 Velocity $v_0\uparrow$

The velocity $\mathbf{v_0}\uparrow$ is the maximum operational speed of the surfaced submersible [kn] at a number of revolutions of the propeller according to the maximum continuous propulsion power surfaced (MCR **(1)**).

2.13.2 Velocity $v_0\downarrow$

The velocity $\mathbf{v_0}\downarrow$ is the maximum operational speed of the dived submersible [kn] at a number of revolutions of the propeller according to the maximum continuous propulsion power dived (MCR **(1)**).

D. Environmental Conditions

1. General

As a minimum requirement, the design, selection and arrangement of all machinery, instruments and equipment located on board submersibles are required to conform to the environmental conditions stated below. For submersibles which are operating in defined areas only, deviating environmental conditions may be approved.

For special missions, like diving under ice or in caves the environmental conditions experienced there are to be considered and special measures agreed with **TL**.

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(1) *MCR = maximum continuous rating*

2. Inclined positions

Satisfactory operation shall be ensured at (static and dynamic) inclinations of up to 22,5° in any direction measured in relation to the datum level. Transient inclinations of up to 45° shall not adversely affect operation and shall not cause damage, particularly to machine mountings. Greater operational inclinations have to be adequately observed for design and testing.

3. Water

For the design of submersibles and components the temperature range of the water as well as the range of salt content and therefore of the density is to be defined. If not agreed otherwise, seawater with a temperature range from -2 °C to +32 °C, with a salt content of 3,5 % and a density of 1,028 kg/m^3 may be used as a basis. A value of 0,101 bar/m is to be applied when converting diving depth to pressure.

4. Seaway

The seaway up to which the submersible shall be operated in surfaced condition are to be agreed with **TL**. If not agreed otherwise, submersibles are to be designed for sea states with a significant wave height of at least 2 m, allowance being made for accelerations of 2 g downwards and 1 g upwards in the vertical and 1 g each in the longitudinal and transverse directions (g = 9,81 m/s^2).

5. Tide and currents

For the design of the propulsion and manoeuvring arrangement the different factors influencing currents according to the operation area and their possible combinations are to be considered.

As basis for the design the maximum as well as the minimum tide at the relevant operation area shall be included. In addition currents created by storms or geographic specialities (e.g. narrow channels) are to be considered.

6. Climate

In all spaces, allowance is to be made for oil and salt impregnated air ranging in temperature from 0 to +55 °C. Atmospheric humidity may attain 100 % in the lower temperature range. Condensation is liable to occur. In specially protected control rooms, a relative atmospheric humidity of 80 % at a reference temperature of +45 °C is to be assumed.

Equipment and instruments have to continue to function satisfactorily despite fluctuations in the air pressure inside the pressure hull ranging from 0,7 to 1,3 bar.

7. Vibrations and shaking

Machinery shall not cause any vibration or shaking which imposes unacceptable stresses on other machines, equipment or the hull of the submersible. The amplitudes and accelerations defined in the **TL** Rules, Chapter 4, Machinery, Section 1, C are to be complied with.

8. Explosion protection

Submersibles which are used in respectively from explosion endangered areas (e.g. from oil or gas production platforms) are to be designed for the relevant explosion endangered zones. This is also valid for control stands.

9. Further environmental conditions

For the design of the submersible also the environmental conditions which may occur during an eventual air transport (e.g. underpressure/temperature) are to be considered.

E. Documents for Approval

1. General

1.1 Before the start of manufacture, documentation of the total system and drawings of all components subject to compulsory inspection, wherever applicable and to the extent specified below, are to be submitted in triplicate respectively in case of electronic transmission as single issue.

1.2 The documentation shall contain all the data necessary to check the design and loading of the system. Wherever necessary, calculations relating to components and descriptions of the system are to be submitted.

1.3 Once the documents submitted have been approved by **TL**, they become binding for the execution. Any subsequent modifications require **TL**'s consent before they are implemented.

2. Total system

The following documents are to be submitted:

2.1 A description of the submersible with details of its mode of operation, the proposed application and the essential design data like e.g.:

– Nominal diving depth

– Maximum operating time and maximum survival time

– Maximum range of a mission (radius)

– Maximum number of persons in pressure hull

– Divers' compression chamber

– Diving procedure

– Operating limits for launching and recovery (seaway)

– Other operating limits in relation to environmental conditions (e.g. operating temperatures, fresh/salt water or geographical or current conditions)

– Speed above or below water level as well as maximum towing speed

– Type of drive and manoeuvring equipment

– Type and extent of working devices and equipment

– Type of fixing system

– Weight of vehicle, pay load and ballast, displacement (submerged)

2.2 General drawing and plans showing arrangement and design details of the submersible, including specifications for materials, manufacture and testing.

2.3 Arrangement drawings (block diagrams) of the total system.

2.4 Failure Mode and Effects Analysis (FMEA), if required.

2.5 A comprehensive presentation of the measures taken to prevent corrosion.

2.6 Stability documentation

For every submersible a proof of stability is to be delivered, which shall contain:

– Results of the stability investigations for the intact and damaged submersible, as well in submerged as surfaced condition and if applicable also in intermediate conditions

– Permissible ice load

– Presentation of the stability behaviour of the submersible

– Measures for maintaining sufficient stability

2.7 Manual for operation and maintenance

The manual for the operation shall include in detail the steps necessary for normal operation as well as for emergency operation in a clear and conceptual form and in the necessary sequence (e.g. as checklist). In addition the measures for the loading of the operating systems (e.g. batteries, gases) – mostly with external installations – are to be defined. In addition the planned lifetime and the permissible load and mission cycles of components of the equipment (e.g. acrylic windows, batteries, etc.) is to be defined herein.

The maintenance manual shall include all procedures for the preventive maintenance as well as for periodic inspections.

2.8 Operational records

All conditions relevant for operation (diving depth, mission time, damages, etc.) are to be documented herein.

2.9 Trial program.

3. Pressure Hull

3.1 Drawings and calculations for the pressure hull are to be submitted with all essential particulars and details necessary for appraising the safety of the equipment and including the specifications for materials, manufacture and testing. The drawings have to show all the internal and external fixtures of the pressure hull (e.g. strengthening ribs, machine bedplates, mountings, etc.).

3.2 In addition, component drawings of the pressure hull equipment are to be submitted, like e.g.:

– Entry and exit hatches

– Windows, window flanges and counter flanges

– Pressure tight bulkheads including doors

– Block flanges

– Pressure hull wall penetrations and their arrangement

– Diver's lockout, if existing

3.3 Drawings and descriptions of the space allocation and internal arrangements are to be submitted.

4. Exostructure

Plans and sectional drawings of the vehicle envelope and supporting structure are to be submitted including details of such pressure hull fixtures as diving tanks, gas tanks, buoyancy elements, stabilizing fins, rudder, disengaging gear, umbilical connection, keel runners, anti-ramming device, streamlining elements, manipulators, instrument mountings, anchoring equipment, masts and venting pipes, etc.

5. Diving, compensating and trimming systems, ballast systems

5.1 Submission of details for arrangement of diving, compensating and trimming tanks and of the ballast system with mathematical proof of the vehicle's static diving capability.

5.2 For the open and closed loop control are to be submitted:

– Description of the control systems for depth, trim and positive and negative buoyancy as well as of the safety devices to prevent the nominal diving depth **NDD** from being exceeded, including the necessary piping diagrams and component drawings. This includes drawings of:

– Compressed air system for blowing diving tanks

– Ballast systems

– Solid buoyancy elements and their mountings

– Weights and gear capable of being jettisoned and their means of release

6. Pressure vessels and apparatus

Drawings and calculations of the pressure vessels and apparatus are to be submitted with all essential particulars and details necessary for appraising the safety of the equipment and including the specifications for materials, manufacture and testing.

7. Piping systems, umbilicals, pumps and compressors

The following are to be submitted:

7.1 Schematic diagrams of all piping systems including details of:

– Materials

– Maximum allowable working pressure

– Allowable working temperature

– Dimensions (diameter, wall thickness)

– Media carried

– Type of valves and connections used and their operational parameter

– Type of hose lines

7.2 Description of pumps and compressors and their drives together with all important design and operating data.

7.3 Description of the design of the umbilical and its single elements according to Annex E, C. if applicable.

7.4 Listing of the components filled with liquids with definition of the type of liquid (e.g. oil, water, etc.).

8. Propulsion and manoeuvring equipment

Drawings and descriptions are to be submitted of the propulsion and manoeuvring equipment including gears, couplings, shafting, propellers and rudders with details of:

– Mode of operation and control of the systems

– Power consumption (type and quantity)

– Method of power transmission to propulsion unit

– Seals of pressure hull wall penetrations

– Operating range and response time of rudder

9. Positioning system

The type and control of the positioning system is to be explained.

10. Working devices

(Compare also Chapter 54)

10.1 For extension elements and working devices the effects on the total system are to be defined.

10.2 Plans and descriptions of the planned working devices are to be submitted with data about:

– Task of the devices

– Type of operation and energy supply

– Control and monitoring

– Safety devices

– Location and fixing at the carrying structure

– Applied materials

– Type of release system, if applicable

10.3 Plans and descriptions of the fixing system are to be issued with information for

– Type and control of the fixing system

– Size of holding power

– Behaviour at energy failure

– Type of release system

11. Electrical equipment

The following are to be submitted:

11.1 A general arrangement drawing of the electrical equipment containing at least the following information:

– Voltage rating of the systems

– Power or current ratings of electrical consumers

– Switchgear and safety devices (e.g. overcurrent relay) with indicating settings for short-circuit and overload protection; fuses with details of current ratings

– Cable types and cross-sections

11.2 The energy balance of the main and emergency power supply systems.

11.3 Drawings of switchgear and distribution equipment with parts lists.

11.4 Complete documentation for electric motor drives with details of control, measuring and monitoring systems.

11.5 Battery installation drawing with details of battery types, chargers and battery room ventilation.

11.6 Details of electrical penetrations through pressure hull walls.

11.7 Diagrams showing allocation of electrical pressure hull wall penetrations.

11.8 Diagrams showing arrangement of emergency light fittings.

11.9 Calculation of short-circuit conditions with details of circuit-breakers, power protection switches and fuses fitted to main, emergency and distribution switchboards indicating their current ratings and breaking capacity.

11.10 The installer of the electrical equipment has to submit confirmation on form F 184 to the effect that the electrical equipment in hazard areas is of explosion-proof design.

The form can be obtained from **TL**. The hazard areas are to be specified.

11.11 For the operation in explosive endangered areas the required explosion classes are to be proven.

12. Automation, communication, navigation and locating systems

The following are to be submitted:

12.1 Description of the complete instrumentation layout of the control stand.

12.2 Description of the control and operating elements for the submersible and its equipment.

12.3 Description of the nautical and diving instrumentation, including speed and position indicators.

12.4 A description of the safety and alarm systems.

12.5 Arrangement drawings/block diagrams of monitoring systems including lists of measuring points.

12.6 Documentation for electronic components such as instrument amplifiers, computers and peripheral units.

12.7 General diagrams and equipment lists for the data transfer systems and signalling equipment.

12.8 General diagram and description of the TV system.

12.9 Descriptions, general diagrams and equipment lists for the locating equipment.

13. Life support systems

The following are to be submitted:

13.1 Piping diagrams, block diagrams and descriptions of the systems and equipment used for breathing gas supply, circulation, purification and conditioning of the atmosphere in the pressure hull, including the monitoring equipment, for both normal and emergency operation.

13.2 Mathematical proof of the adequate capacity of the breathing gas supply and air renewal systems under normal and emergency conditions.

13.3 Description of the facilities for supplying water, food and medicines and for disposal of waste.

13.4 In the case of non-autonomous submersibles, drawings and descriptions of the umbilical are to be submitted.

14. Fire protection and fire-extinguishing equipment

The following are to be submitted:

14.1 Description of preventive fire precautions.

14.2 Fire protection plans.

14.3 Details of the nature and quantity of combustible materials in the submersible.

14.4 Drawings and descriptions of:

– Fire detectors

– Fire extinguishers

– Fire alarms

14.5 Analysis of the dangers arising from possible outbreaks of fire.

14.6 If submersibles are used in explosion endangered areas, a description of the measures for explosion protection is to be presented.

15. Rescue systems

Drawings and descriptions are to be submitted of the systems and equipment for evacuating the vehicle crew, passengers and divers.

16. Mating system

16.1 Description of system with details of operating conditions

16.2 Data concerning connecting conditions.

16.3 Design drawings of the mating system.

16.4 Control diagram and description of safety devices.

F. Failure Mode and Effects Analysis (FMEA)

1. General

1.1 The Failure Mode and Effects Analysis (FMEA) has the purpose to identify possible failures in the total system, in subsystems and components of manned submersible and to describe the effects on the total system and its submersibles resp. components.

1.2 For manned submersibles an analysis concerning the function and availability of the submersible after occurrence of a single failure has to be submitted if requested by **TL**.

1.3 The FMEA shall be executed in an early stadium accompanying the design to be able to realize system modification in due time. A tabular form, e.g. according to IEC 60812 or IMCAD 039 is to be used.

2. Description of the subsystems relevant for the analysis

2.1 The FMEA shall represent an independent document and be understandable without consulting further documentation. This means that all relevant submersible are to be described concerning the structure of their basic functions, the installed redundancies and especially the interfaces of the subsystems to each other.

2.2 The description shall provide the crew with a good overview of the vehicle structure and the functionalities of the relevant subsystems. For all subsystems typical failure modes and their effects on the overall function of the submersible shall be indicated. Further on the corrective actions to manage these failures and their effects are to be provided.

2.3 For manned submersibles the following subsystems are relevant for maintaining the overall function:

– Pressure hull penetrations and equipment

– Interior arrangement

– Exostructure and related equipment

– Systems for diving/ballasting, control/compensation and trimming

– Vessels and apparatus under pressure

– Piping systems, pumps and compressors

– Umbilicals, for non-autonomous submersibles

– Propulsion and manoeuvring equipment

– Generation and distribution of electrical power

– Emergency power supply

– Electrical protective systems

– Automation, communication, navigation and locating equipment

– Life support systems

– Fire protection

– Rescue systems

– Additional arrangement for tourist services, as far as relevant

– Systems for control aboard the support ship

– Supply systems aboard the support ship

– Launch and recovery system

– Coil-up/coil-off mechanism for umbilicals

– Stowage and deck transport

– Mating equipment

The system descriptions are to be completed by block diagrams according to 3.

3. Block diagrams of the relevant subsystems

For each relevant subsystem a block diagram is to be established. This block diagram shall contain the essential information on the system required for the failure analysis, which is normally:

– Definition of the subsystems

– All essential components of the subsystems

– Interfaces between the components of the subsystems

– Interfaces to or from other subsystems (typical for hydraulic drives, compressed air systems and controls, etc.)

– Arrangement for control of the total system

– Supplies from outside the total system, if applicable

– Further aspects depending on the actual design of the total system

At interfaces the different types of power, media and data may be transferred.

4. Analysis of the different relevant subsystems

Each relevant subsystem is to be analyzed with regard to the following essential aspects, in course of which further aspects may occur during the execution of the analysis, compare worksheet in 5.:

– Failure of subsystems

– Malfunctions of subsystems

– Failure of components in a subsystem

– Malfunctions of components

– interface failures between the subsystems, a subsystem and its components as well as between components themselves

Interface analysis of which data, medium and power are transferred and how failures are spread via the interfaces to other subsystems/components.

– Hidden failures

  Check for hidden failures and the evidence of alarms to be provided

  Arrangement of periodic testing where alarms are not practical

– Failures because of external influences which may lead to simultaneous failure of redundant subsystems, e.g. changed environment conditions and their control, voltage and amperage fluctuations on power supply, contamination of supply media, etc.

– Faulty operation of subsystems or components, only with certain probability

5. Tabular work sheet

The analysis shall be carried out in tabular form with a work sheet according to the following example or e.g. according to IEC 60812.

The analysis has to consider all operational modes.

Table 2.1 Example of a tabular work sheet

ID Number	Subsystem/ component	Type of failure	Failure cause	Failure detection	Consequences for subsystem/ component	Consequences for total system	Failure-correction	Remarks
1								
2								
3								

6. Assumptions and defined limits for the analysis

During the analysis the assumptions are to be defined which influence the result of the analysis. Typical assumptions are e.g.:

– The crew is qualified and trained to safety operate the manual submersible

– The supply of energy and as far as necessary with other consumables from outside the manned submersible is secured in redundant way (for non-autonomous submersibles)

– The adjustments and switching operations prescribed in the operation manual are followed by the crew, etc.

7. Treatment of changes

In case of changes at the submersible respectively at the supporting systems aboard the support ship the FMEA is to be adjusted accordingly.

8. Conclusions

The FMEA shall contain a summary of the results of the analysis for the relevant submersible. In addition it should contain a listing of the main failures which may occur for the operation of the vehicle and especially for keeping the manoeuvrability and ability for submersing as well as the desired atmosphere in the pressure hull. For the crew and the service personnel aboard the support ship training measures for incontestable handling of the vehicle and the supporting systems in the event of such failures are to be proposed.

A periodic check of the FMEA including practical trials is recommended.

9. FMEA test program

9.1 According to the FMEA a test program is to be established. The purpose of this program is to verify the assumptions and the expected operation behaviour of the submersible as defined in the analysis.

9.2 The program has to consider typical modes in the relevant systems and components including the worst case failure. All possible operational modes of the submersible are to be reflected.

9.3 The test program is to be agreed with **TL** and needs to specify in detail how the test shall be carried out respectively how simulation is done.

G. Tests and Trials

1. General

1.1 Manned Submersibles are subject to constructional and acceptance testing at the manufacturer's works. As a minimum requirement, this shall include verification of compliance with the approved documents, inspection of workmanship, verification of materials and checking of dimensional tolerances. All the tests prescribed in the following are to be performed and documented, wherever applicable. About the presence of **TL** Surveyors at these tests and trials **TL** will decide in each individual case.

Tests and trials for supporting systems aboard the support ship in connection with the submersible are defined in Section 17.

1.2 For series-manufactured parts, test procedures other than those prescribed may be agreed with **TL** provided that they are recognized as equivalent by **TL**.

1.3 **TL** reserve the right to extend the scope of the tests where necessary and also to subject to test those parts for which testing is not expressly prescribed in the Rules.

1.4 Parts subject to approval are to be replaced with tested parts. The same also applies to spare parts.

1.5 Where submersibles are equipped with a diver's lockout, the components and equipment concerned are also to be subjected to the tests prescribed in Diving Systems and Diving Simulators, Chapter 52.

1.6 A summary of the test pressures, as well as of the design and layout pressures is contained in Section 4, Table 4.2.

2. Total system

On completion, the submersible is to be subjected to a functional and acceptance test in accordance with the trial programme approved by **TL**. This shall include at least the following individual tests:

- Inspection of assembly (where not already performed during supervision of manufacture)
- Measurement of weight and buoyancy and checking of stability under normal and emergency conditions
- Inspection of internal equipment, partition bulkheads with doors, floors and ladders
- Testing of all safety devices
- Functional testing of diving and trimming equipment
- Functional testing of mechanical, electrical and optical equipment
- Functional test of the working devices related to the effects on the submersible
- Statical diving test under controlled conditions
- Heeling test submerged and surfaced
- Trimming test submerged and surfaced
- Testing of emergency release equipment
- Trial trip on surface with verification of buoyancy
- Trial trip submerged
- Testing of mating system
- Functional testing of life support systems
- Verification of the accuracy of all essential instrument readings
- High voltage test and insulation test on the electrical equipment

The tests of the total system under water are to be performed with diving depths up to nominal diving depth **NDD**, see Section 4, B.

3. Pressure hull

3.1 On completion of the machining work and any necessary heat treatment, pressure hulls are to be subjected to a hydraulic external pressure test. This test may be performed either on the raw hull in a compression chamber or as part of a submersion test carried out on the completed submersible. The test pressure is to be determined in accordance with Table 4.1 in Section 4.

Pressure hull compartments (tanks) in which an internal overpressure may occur are to be subjected to a hydraulic internal pressure test at 1,5 times the maximum allowable working pressure.

After the pressure tests, the pressure hull is to be examined for leaks, permanent deformations and cracks.

3.2 Pressure hull penetrations and closing appliances are to be tested for tightness by the application of an underpressure of at least 0,2 bar below atmosphere pressure.

In addition pressure hull penetrations and hatch covers are to be tested with an internal pressure of 1,3 bar absolute.

3.3 All pressure hull windows are to be subjected to a hydraulic pressure test. The test may be performed after installation together with the pressure hull or individually in a testing device. The test pressure is to be determined in accordance with 3.1. For the pressure test it has to be observed that the test pressure is not higher than 1,5 times the design pressure of the window.

After the pressure test, windows may exhibit no scratches, cracks or permanent deformation.

3.4 At the pressure test of the submersible the tightness of pressure-tight hatch covers is to be verified with test diving pressure **TDP**.

3.5 Doors in pressure-tight bulkheads are, if not possible otherwise, to be tested at the manufacturer's works with test diving pressure **TDP**. In installed condition a tightness test with 0,2 bar underpressure has to be performed.

3.6 For pressure-tight bulkheads a tightness test with 0,2 bar underpressure is to be performed.

4. Exostructure

4.1 A check is to be carried out on the arrangement, mounting and fastening of such equipment items as stairways, gratings, handrails, bitts, masts, navigating lights, towing devices and draught marks.

4.2 External structural components such as anchoring equipment, rudders, etc. are to be subjected to a functional test.

4.3 The lifting points at the submersible are to be tested statically with 2,2 times the safe working load **SWL** (= weight and payload **NL** of the submersible)

4.4 The fixing point of the umbilical at the submersible is to be tested statically with 2,2 times the maximum permissible tension load of the umbilical.

5. Diving, compensating and trimming tanks, as well as ballast systems

5.1 Lockable diving tanks are to be subjected to a tightness test using air at a test pressure of about 0,2 bar respectively for open diving tanks a tightness test of the ventilation valves has to be performed.

5.2 Compensating tanks, which vary their filling level by compressed air, are to be subjected to a hydraulic pressure test at 1,5 times the maximum allowable operating pressure, but at least at test diving pressure **TDP**.

5.3 Trimming tanks, which are internally in the pressure hull and which change their filling level by pumps are to be considered as gravity tanks, but if the filling level is varied by compressed air , they are to be subjected to an internal

hydraulic pressure test with 1,5 times the maximum allowable working pressure.
Trimming tanks, which are arranged outside the pressure hull in the exostructure and which are varying their filling level by pumps are to be subjected to a test at external test diving pressure **TDP**, for the case of varying the filling level with compressed air, an additional internal test at 1,5 times maximum allowable working pressure will be required.

5.4 Diving, compensating and trimming systems are to be subjected to a functional test for normal and emergency operation.

The measuring system and the safety and alarm systems are to be checked.

5.5 The venting of the diving tanks and the elements for operation are to be subjected to a functional test.

6. Pressure vessels and apparatus

6.1 Pressure vessels are to undergo a hydraulic pressure test before being insulated or painted. The vessel walls shall not show permanent deformations or shall not leak.

6.2 The test pressure applied to vessels and apparatus with stress from internal pressure shall generally be equivalent to 1,5 times the maximum allowable working pressure PB.

6.3 Vessels and apparatus which may be subjected to external overpressure have to undergo an external pressure test. The test pressure shall be at least the test diving pressure **TDP** of the pressure hull.

6.4 If the strength against pressure of vessels and apparatus cannot be sufficiently proven by calculation, an alternative verification has to be agreed with **TL**.

7. Piping systems, umbilicals, pumps and compressors

7.1 Piping systems

7.1.1 On completion but before being insulated or painted, all piping systems are to undergo a hydraulic pressure test at 1,5 times the maximum allowable working pressure. Pipes under diving pressure are to be checked in addition with test diving pressure **TDP** (inside or outside according to the actual load case).

7.1.2 After installation on board, all pipes are to undergo a tightness test at the maximum allowable working pressure.

7.1.3 The safety devices are to be checked.

7.1.4 Pipes for breathing gas and oxygen are to be tested for cleanliness.

7.2 Pumps and compressors

7.2.1 Pump and compressor components subjected to pressure are to undergo a hydraulic pressure test. For pumps the test pressure shall be 1,5 times the maximum allowable working pressure, for compressors 1,5 times the delivery pressure of the compressor stage concerned.

7.2.2 On completion, pumps and compressors are to be subjected to a tightness test at their maximum allowable working pressure. In addition, a performance test is to be carried out. With breathing gas compressors, the final moisture content and any possible contamination of the compressed gas are also to be determined. The safety devices are also to be checked.

7.3 Umbilicals/supply lines

Umbilicals/supply lines of non-autonomous submersibles have to meet special requirements. The required tests are to be divided in a type test for the prototype and a routine test of each end product.

All aspects for the tests and trials of umbilicals are defined in Annex E, D.

7.4 Hose lines

As far as the requirements in 7.3 are applicable for hose lines they shall be used.

8. Propulsion and manoeuvring equipment

The entire propulsion plant is to be subjected to a functional test within a trial trip under water and surfaced.

9. Positioning system

The positioning system is to be checked.

10. Working devices

(Compare also Chapter 54.)

10.1 The effect of the working devices on the total system is to be tested.

10.2 The working devices have at least to be checked with reference to:

– Ability to function according to the specified task at relevant capacity of the device

– Control and monitoring

– Functioning of safety devices

– Avoiding dangers for divers and the submersible

10.3 The fixing system is to be subjected to a function test where at least the following individual tests are to be performed with reference to:

– Specified holding power of the fixing system

– The power and way limitations of the fixing system as well as the directing of the vehicle

– Simulation of an energy failure

11. Electrical equipment

11.1 Electrical machines, components, including steering and control positions, cables and lines are to be tested in the manufacturer's works in accordance with the **TL** Rules Electrical Installations, Chapter 5.

11.2 All electrical systems and equipment are to be inspected and tested before the submersible is put into service.

11.3 Electrical protective devices are to be checked; in addition, an insulation test is to be performed on the electrical equipment.

11.4 Electrical cables under external pressure are to be checked according to the electrical requirements for umbilicals defined in 7.3.

11.5 All electrical equipment which is exposed to diving pressure shall be checked additionally for isolation after the first diving.

12. Automation, communication, navigation and locating equipment

12.1 Indicating and monitoring instruments are to be tested for the accuracy of their readings and their limit value settings according to the **TL** Rules Automation, Chapter 4-1.

12.2 Automation systems are to be checked for satisfactory performance under service conditions.

12.3 Communication systems for normal and emergency operation are to be subjected to a functional test.

13. Life support systems

13.1 A functional test is to be carried out to verify the satisfactory functioning of the life support system under normal and emergency conditions.

13.2 The arrangement of the O_2, CO_2 and H_2 measuring devices is to be inspected, and they are to be checked for the accuracy of their readings and their limit value settings.

13.3 The sanitary facilities are to be checked for proper functioning.

13.4 The installation of the ventilation system is to be inspected and the operation of the fans and fire flaps is to be checked.

14. Fire protection and fire extinguishing systems

14.1 The fire behaviour of the internal fittings and equipment is to be checked by reference to the relevant test certificates and symbols.

14.2 A check is to be made as to whether the electrical heating systems and heaters are fitted with protection against overheating.

14.3 Fire alarm, detection and extinguishing appliances are to be subjected to a functional test.

15. Rescue systems

Elements of the rescue system arranged outside the pressure hull are to be tested at test diving pressure **TDP**. In addition it shall be proven that the rescue systems function properly even with the submersible at the maximum permissible inclination and that sufficient stability of the vehicle is maintained.

16. Mating systems

16.1 A test is to be performed to ensure that mating respectively release of the submersible proceed smoothly and safely under normal and emergency operating conditions.

16.2 Where a mating device is provided, it is to be checked that release can only take place when the connecting trunk is not under pressure.

16.3 The safety devices are to be checked.

H. Marking

1. Fittings, indicators and warning devices

All valves, fittings, controls, indicators and warning devices are to be provided with permanent and seawater resistant markings.

2. Pressure vessels, gas cylinders and pipe systems

2.1 All pressure vessels and gas cylinders are to be permanently marked at an easily visible position with the following details:

- Name or company designation of manufacturer
- Year of construction and serial number (pressure vessels)
- Serial number (gas cylinders)
- Type of gas
- Maximum allowable working pressure [bar]
- Maximum allowable working temperature (for > 50 °C and < -10 °C)
- Capacity [ℓ]
- Test pressure [bar]
- Empty weight (of gas cylinders) [kg]
- Date of test
- Test stamp

2.2 Permanently installed gas cylinders, gas containers and gas piping systems are, in addition, to be marked with a permanent colour code in accordance with Table 2.2 and with the chemical symbol designating the type of gas concerned. The marking of pressure vessels and gas cylinders has to be visible from the valve side.

Systems for other media are also to be marked in suitable way.
The distances of the markings are to be chosen for pipe systems according to function and safety.

Table 2.2 Marking of gas systems

Type of gas	Chemical symbol	Colour code
Oxygen	O_2	white
Nitrogen	N_2	black
Air	-	white and black
Helium	H_e	brown
Oxygen/Helium gas	O_2/H_e	white and brown

I. Spare Parts

1. Independent submersibles are to be provided with spare parts.

1.1 In order to restore machinery operation and manoeuvring capability of the submersible in the event of a damage at sea, spare parts for the main propulsion plant and the essential equipment shall be carried on board together with the necessary tools.

1.2 For batteries arranged within the pressure hull a sufficient set of cables with adequate cross section to bridge parts of the batteries or single cells has to be on board.

1.3 The scope of spare parts is to be documented and a relevant listing has to be on board.

2. Deviating requirements are possible in the case of submersibles which can only operate in conjunction with, or are supplied by, accompanying surface vessels.

SECTION 3

STABILITY AND BUOYANCY

A. **GENERAL**.......... **3-**2

B. **INTACT STABILITY**.......... **3-**3

C. **STABILITY IN DAMAGED CONDITION**.......... **3-**11

D. **DIVING, TRIMMING AND HEELING TESTS**.......... **3-**12

A. General

1. Classification

1.1 Submersibles will be assigned Class only after it has been demonstrated that their buoyancy and their static and dynamic stability in intact condition is adequate for the service intended. The level of intact stability for submersibles shall generally meet the standard defined in the following, unless special operational restrictions reflected in the Class Notation allow a lower level.

The manufacturer of the submersible may apply for judgement according to other existing standards regarding intact stability, if **TL** is accepting such standards as equivalent.

1.2 For the stability in damaged condition of the submersibles relevant here, it is assumed that the pressure hull is undamaged but an important tank in the exostructure is not functioning because of damage. For this case sufficient stability has still to remain, see C.

2. Documents for approval

The documents to be submitted are summarized in Section 2, E.2.5.

3. Definitions

In addition to the general definitions given in Section 2, C., the following specific definitions are valid for this Section.

3.1 Watertight

Watertight, in relation to an element of the structure means that it is capable of preventing the passage of water under the head of water for which the element and its surroundings are designed.

3.2 Weathertight

Weathertight in relation to an opening and its cover means, that water will not penetrate into the surfaced submersible in any thinkable seaway condition.

3.3 Centre of buoyancy

The centre of buoyancy has the designation **B**↓ for the submerged submersible is related to the submerged displacement Δ↓.

The centre of buoyancy with the designation **B**↑ for the surfaced submarine is related to the surfaced displacement Δ↑.

3.4 Centre of gravity

The centre of gravity for the relevant load condition has the designation **G**.

3.5 Metacentre

The metacentre with the designation **M** is the point of intersection between the buoyancy resultant through the centre of buoyancy and the middle axis for heeling angles $0° < \phi \leq 5°$. For bigger heeling angles ϕ the metacentre is to be evaluated adequately.

4. Stability documentation

Concerning the required stability documentation see Section 2, E.2.5.

B. Intact Stability

1. Buoyancy in surfaced condition

1.1 Depending on the type of submersible and the operation area the distance between the waterline in fully surfaced condition and the upper edge of entrance openings, air pipes, etc. which may be open for surfaced operation, has to be approved by **TL**.

If there are bulwarks/hatchway coamings which are open at the upper side, adequate bilge systems are to be provided.

1.2 All submersibles shall have a sufficient reserve of buoyancy in surfaced condition to meet the stability requirements of this Section. This buoyancy reserve shall be proven by calculation.

1.3 The buoyancy reserve shall be at least 10 % of the pressure tight volume.

1.4 For open diving tanks it is to be proven for all intended seaway conditions that sufficient buoyancy is available at the heeling and trimming conditions to be expected.

2. Load cases for stability

2.1 General

In general the following stability load cases have to be investigated. If these load cases are not to be applied for the actual case, other or additional load cases are to be agreed with **TL**.

All load cases are to be investigated with the lowest as well as the highest defined water densities, compare Section 2, D.3.

Even keel of the submersible is to be assumed for dived condition.

Tanks with great breadth resp. great length shall be protected against the influence of free liquid surfaces by separating/baffle plates.

A summary of the different load cases is given in Table 3.1.

2.2 Load case 1a: Surfaced, start of the journey with 100 % stocks, no payload NL

The submersible is fully equipped and manned, diving tanks are empty, trimming tanks 50 % full, Buoyancy tanks empty, stocks and fuel tanks (if existing)

100 % full, any working gears drawn out, no payload **NL** (means no passengers and/or no picked up materials, additional equipment, etc.)

2.3 Load case 1b: Surfaced, end of the journey with 10 % stocks, no payload NL

The submersible is fully equipped and manned, diving tanks are empty, trimming tanks 50 % full, buoyancy tanks empty, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % and oxygen 10 % full, any working gears drawn out, no payload **NL**. For submersibles with sole electro drive and relatively little quantities of compressed air and oxygen it has to be investigated, if this load case is essentially different from load case 1a and has to be checked separately.

2.4 Load case 1c: Surfaced, end of the journey with 10 % stocks, no payload NL, release of solid ballast

The submersible is fully equipped and manned, diving tanks are empty, trimming tanks empty, buoyancy tanks empty, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % and oxygen 10 % full, any working gears drawn out, no payload **NL**. The solid ballast is released as aid for surfacing.

2.5 Load case 2a: Surfaced, start of the journey with 100 % stocks, with payload NL

The submersible is fully equipped and manned, diving tanks are empty, trimming tanks are 50 % full, buoyancy tanks empty, stocks and fuel tanks (if existing) 100 % full, any working gears drawn out, with payload **NL** (means with passengers and/or picked up materials, additional equipment, etc.)

2.6 Load case 2b: Surfaced, end of the journey with 10 % stocks, with payload NL

The submersible is fully equipped and manned, diving tanks are empty, trimming tanks 50 % full, buoyancy tanks empty, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % and oxygen 10 % full, any working gears drawn out, with payload **NL**.

For submersibles with sole electro drive and relatively little quantities of compressed air and oxygen it has to be investigated, if this load case is essentially different from load case 2a and has to be checked separately.

2.7 Load case 2c: Surfaced, end of the journey with 10 % stocks, with payload NL, release of solid ballast

The submersible is fully equipped and manned, diving tanks and trimming tanks are empty, buoyancy tanks empty, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % and oxygen 10 % full, any working gears drawn out, with payload **NL**. The solid ballast is released as aid for surfacing.

2.8 Load case 3a: Dived, start of the journey with 100 % stocks, no payload NL

The submersible is fully equipped and manned, diving tanks are flooded, trimming tanks 50 % full, buoyancy tanks 20 % full, stocks and fuel tanks (if existing) 100 % full, any working gears drawn in, no payload **NL**.

2.9 Load case 3b: Dived, end of the journey with 10 % stocks, no payload NL

The submersible is fully equipped and manned, diving tanks are flooded, trimming tanks 50 % full, buoyancy tanks 80 % full, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % and oxygen 10 % full, any working gears drawn in, no payload **NL**

2.10 Load case 4a: Dived, start of the journey with 100 % stocks, with payload NL

The submersible is fully equipped and manned, diving tanks are flooded, trimming tanks 50 % full, buoyancy tanks 10 % full, stocks and fuel tanks (if existing) 100 % full, any working gears drawn in, with payload **NL**.

2.11 Load case 4b: Dived, end of journey with 10 % stocks, with payload NL

The submersible is fully equipped and manned, diving tanks are flooded, trimming tanks 50 % full, buoyancy tanks 70 % full, stocks and fuel tanks (if existing) 10 % full, compressed air 50 % full, any working gears drawn in, with payload **NL**.

2.12 Further load cases

If required, further load cases have to be investigated in agreement between operator of the submersible and **TL**.

Table 3.1 Summary of stability cases

Load cases / Loads	1a	1b	1c	2a	2b	2c	3a	3b	4a	4b
	Surfaced						Submerged			
	Without payload		Ballast released	With payload		Ballast released	Without payload		With payload	
	All values are percentages of the maximum possible load [%]									
Submersible 1	100	100	100	100	100	100	100	100	100	100
Crew	100	100	100	100	100	100	100	100	100	100
Diving tanks	0	0	0	0	0	0	100	100	100	100
Trimming tanks	50	50	0 **(3)**	50	50	0 **(3)**	50	50	50	50
Compensating tanks 2	2	2	2	2	2	2	20 **(4)**	80 **(4)**	10 **(4)**	70 **(4)**
Air	100	50	50	100	50	50	100	50	100	50
Oxygen	100	10	10	100	10	10	100	10	100	10
Stocks	100	10	10	100	10	10	100	10	100	10
Fuel	100	10	10	100	10	10	100	10	100	10
Lube oil, operating agents	100	10	10	100	10	10	100	10	100	10
Releasable ballast	100	100	0	100	100	0	100	100	100	100
Passengers	0	0	0	100	100	100	0	0	100	100
Other loads	0	0	0	100	100	100	0	0	100	100

(1) *Submersible fully equipped*
(2) *Depending on the geometrical arrangement of the buoyancy tanks the percentage for the most unfavourable stability case shall be applied.*
(3) *For the case that the trimming tanks are drainable*
(4) *Exact percentage depending on ambient conditions, e.g. seawater density*

3. Assumptions for the calculation

For unification and comparability between different projects the following assumptions shall be observed for the calculations submitted to **TL**:

- The displacement shall be computed in metric tons (1000 kg).

- The range of the salt content for which the submersible shall be used is to be defined clearly.

- The weight of the crew resp. of the passengers is normally assumed with 75 kg/person, depending on area of operation and the duty of operation this assumption may be too low and has to be agreed with the manufacturer.

- The density of all liquids used in tanks and bunkers is to be agreed with the manufacturer.

4. Righting levers

4.1 Definition

A righting lever h is defined as follows:

$$h = \frac{\text{righting moment } [\text{mt}]}{\text{displacement } \Delta\uparrow \text{ or } \Delta\downarrow [\text{t}]} \quad [\text{m}]$$

4.2 Surfaced submersible

The righting levers h_{sw} of the surfaced submarine in still water have to be evaluated for the load cases defined in 2. and for the following conditions:

The levers in still water have to be evaluated for the heeling angles φ = 10°, 20°, 30°, 45°, 60° and 75° and are to be presented as lever arm curves. For operation in a seaway see 6.5.

4.3 Submerged submersible

The righting levers of the submerged submersible are following from the fact that the centre of gravity has to be situated below the centre of buoyancy:

A righting lever h is defined as follows:

$$h_{Sub} = \overline{B\downarrow G} \cdot \sin\varphi$$

5. Heeling levers

5.1 Definition

A heeling lever k is defined as follows:

$$k = \frac{\text{heeling moment } [\text{mt}]}{\text{displacement } \Delta\uparrow \text{ or } \Delta\downarrow [\text{t}]} \quad [\text{m}]$$

The heeling levers are to be determined for heeling angles ϕ = 10°, 20°, 30°, 45°, 60° and 75°.

5.2 Surfaced submersible

The following heeling influences are to be considered:

5.2.1 Free liquid surfaces

In partially filled tanks and bunkers the liquids have free surfaces which contribute to the heeling moment by a heeling lever k_F as follows:

$$k_F = \frac{1}{\Delta \uparrow} \cdot \Sigma\left(p_i \cdot b_{\varphi i}\right)[m]$$

p_i = mass of liquids in tank/bunker i with free liquid surface [t]

$b_{\phi i}$ = change of the centre of gravity in relation to the upright submarine, measured parallel to the design water line [m]

5.2.2 Turning circle

As far as necessary the motion in the turning circle with heeling lever k_D is to be considered. See also Section 4, C.6.

5.2.3 Wind

The calculation of the wind forces at the elements above the waterline has to be done according to Section 4, C.1. This results in a heeling lever kW.

According to the area of operation the values for the wind velocity to be used are to be agreed with **TL**.

5.2.4 Ice loads

If the planned area of operation of the submersible requires it, the calculation of the ice loads at the elements above the waterline has to be done according to Section 4, C.4. This results in a heeling lever k_E.

5.2.5 Load-handling loads

During the transfer of equipment, provisions and persons from land or the support ship to the one side of the submersible a heeling lever k_P may to be considered.

5.2.6 Tow-rope pull

During towing of the submersible a heeling lever k_T may be created by the tow-rope pull.

5.2.7 Payload NL

If the payload respectively the working devices are able to change their position in transverse direction, a heeling lever k_N is to be considered.

5.2.8 Supply lines/umbilicals

For non-autonomous submersibles transverse pull forces may occur – depending on the arrangement - because of the supply lines from the support ship. This has to be considered as heeling lever k_V.

5.2.9 Jettisoning of ballast

If the ballast is released as surfacing aid, the centre of gravity is shifted upwards, thus reducing the distance GM.

5.3 Submerged submersible

For the submerged submersible the following influences which lead to heeling levers are to be considered:

- Free liquid surfaces in tanks and bunkers, compare 5.2.1 with heeling lever k_F. Δ↓ is to be inserted instead of Δ↑.

- Motions of the vehicle in the three dimensional space with heeling lever k_D , compare 5.2.2 and Section 4, C.6.

- Influence of payload with heeling lever k_N, compare 5.2.7

- Tension forces from the supply line for non- autonomous levers with heeling lever k_V, compare 5.2.8

- Jettisoning of ballast

6. Criteria for intact stability

6.1 Summary of influences

The righting and the heeling levers are summarized in Table 3.2.

6.2 Proof of stability

6.2.1 Lever arm curves

The proof of sufficient stability shall be done by comparison of the curves of the righting levers h and the heeling levers k. It has to be considered as far heeling levers may act simultaneously. Decisive for the evaluation is the size of the remaining righting lever and of the static angle of heel. As remaining lever h_{rem} the remaining lever above the curve of the heeling levers is designated, see Fig. 3.1.

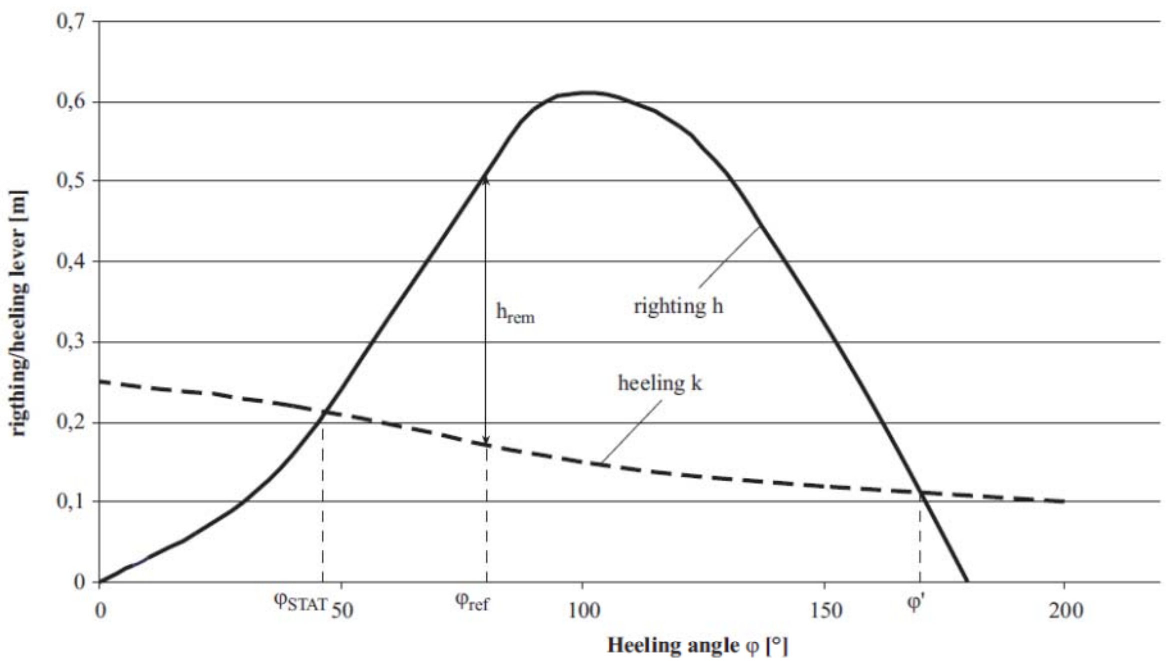

Fig. 3.1 Lever arm curves

6.2.2 Minimum values of stability

Between the angle of the static balance φ_{stat} and the angle of immersion of the first unprotected opening φ_{ref} or the angle φ' of the second intersection of the curves of the heeling and righting levers or the intersection of the righting lever with the abscissa, whereas the smallest angle has to be considered, positive remaining levers h_{rem} have to exist. Generally the remaining lever h_{rem} should be in dived condition at least 0,05 m and in surfaced condition at least 0,1 m, in an actual case this value has to be agreed with **TL**.

Decisive for the proof of initial stability is the size of the value $\overline{\mathbf{GM}}$ (= vertical distance between centre of gravity and metacentre) for the surfaced submersible respectively the distance $\overline{\mathbf{B \downarrow G}}$ (= vertical distance between centre of buoyancy and centre of gravity) for the submerged submersible. The minimum values to be kept are defined in Table 3.3.

Table 3.2 Summary of the righting and heeling lever arms

Load cases		**Surfaced / without seaway**		**Submerged**	
No.	**Designation**	**righting**	**heeling**	**righting**	**heeling**
1a	100 % stocks no payload	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V	–	–
1b	10 % stocks no payload	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V	–	–
1c	10 % stocks no payload no ballast	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V	–	–
2a	100 % stocks with payload	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V, k_N	–	–

Table 3.2 Summary of the righting and heeling lever arms *(continued)*

Load cases		**Surfaced / without seaway**		**Submerged**	
No.	**Designation**	**righting**	**heeling**	**righting**	**heeling**
2b	10 % stocks with payload	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V, k_N	–	–
2c	10 % stocks with payload no ballast	h_{sw}	k_F, k_D, k_W, k_E, k_P, k_T, k_V, k_N	–	–
3a	100 % stocks no payload	–	–	h_{sub}	k_F, k_D, k_V
3b	10 % stocks no payload	–	–	h_{sub}	k_F, k_D, k_V
4a	100 % stocks with payload	–	–	h_{sub}	k_F, k_D, k_V, k_N
4b	10 % stocks with payload	–	–	h_{sub}	k_F, k_D, k_V, k_N

Table 3.3 Minimum values for sufficient stability

Operating Condition	**Stability criteria [m]**	**Distance [m]**
Surfaced	Distance $\overline{\mathbf{GM}}$ **(1)**	0,10 **(1)**
Submerged	Distance $\overline{\mathbf{B \downarrow G}}$ **(1)**	0,05 **(1)**
(1) *this value is to be agreed with **TL** for an actual case*		

6.3 Draught

The draught of the surfaced submersible is the permissible draught which is possible because of buoyancy and stability. In general it will be achieved by load case 2a.

The draught has to be clearly marked in an unchangeable way on both sides of the submarine admidships as usual for vehicles classified by **TL**.

6.4 Trimming diagram

The trimming diagram serves as graphic presentation of the region of mass and trimming moments in longitudinal direction of the submersible, which can be reached by the control of the water in compensating and trimming tanks as well as in special spaces (e.g. diver's lock-out).

These possibilities are to be shown in the trimming diagram in form of a polygon line. It has to be proven that the displacement due to additional loads (e.g. because of taking up of payloads) can be compensated by changing the filling of the compensating tanks as well as the trim by filling the trimming tanks. If the points representing the different load cases are lying within the polygon line, compensation is possible with operational measures on board.

6.5 Dynamic intact stability

6.5.1 This possible stability case for the surfaced submersible in a seaway has to be investigated in addition to 4.2 if longer journeys in a certain sea area with predominated wind direction and certain required courses of the submersible are planned.

In this case it is advisable to perform such investigations already in the design stage:

- For the submersible in the seaway in wave crest condition: h_C

- For the submersible in the seaway in wave trough condition: h_T

- For the submersible in the seaway, average value of wave crest and wave trough conditions: h_{WV}

In the seaway especially the length of the submersible in relation to the critical wave lengths and heights in the operation area have to be considered. Thus a reduction of the above conditions may occur.

6.5.2 For independent submersibles the dynamic stability is to be investigated in any case.

TL is able to offer for such a case special advice and relevant computation procedures.

6.6 Special construction types

For special types of construction of submersibles the criteria defined above may not be directly applicable. In this case special agreements have to be made with **TL**.

C. Stability in Damaged Condition

1. Degree of damage

According to A.1.2 for the stability in damaged condition it will be assumed for the submersibles relevant here, that:

- The pressure hull is undamaged,

- The exostructure is distorted,

- One important tank (e.g. a diving tank) within the exostructure fails because of damage,

- An emergency operation of the submersible is possible without endangering the crew.

2. Surfaced submersible

2.1 Righting levers

Buoyancy and righting levers may be reduced in relation to B.4.2 by the changed centre of gravity of the exostructure and the loss of buoyancy of the damaged tank.

2.2 Heeling levers

The lever k_F for free surfaces according to B.5.2.1 has to be checked. Concerning the lever k_W for the wind load according to B.5.2.3 it has especially to be proven as far as the area of wind pressure and its centre of gravity are changed because of the new floating conditions.

2.3 Criteria for buoyancy and stability

The following assumptions have to be met after damage:

- Openings to the pressure hull are to have sufficient freeboard to avoid ingress of water into the pressure hull with hatches open.

- The heel of the vehicle shall not exceed φ = 22,5°. At the same time the trim forward and sternward shall remain below 10°.

- A positive remaining lever h_{rem} shall be guaranteed. Its value is to be agreed with **TL** according to the type of construction.

3. Submerged submersible

3.1 It is to be checked how the centre of buoyancy is changed and if therefore more critical conditions arise.

3.2 Criteria for diving capability and stability

The following assumptions have to be met also after damage:

- The submersible has still to be able to surface in a safe way.

- The centre of weight has still to be below the centre of buoyancy.

D. Diving, Trimming and Heeling Tests

1. General

1.1 Practical tests with the fully equipped submersible intended for normal operation are to be performed for a new building or after essential conversions.

1.2 If an identical series of submersibles is built on a yard, the following tests are to be performed for the first submersible only. If identical submersibles are built in different yards, the tests have to be performed with the first vehicle of each yard.

1.3 The tests are to be performed in presence of a **TL** Surveyor.

1.4 The tests defined in 2. to 5. are to be performed in the given sequence.

2. Diving test

The following steps are to be performed:

- An adequate depth of the water has to be chosen.

- The density of the water is to be evaluated.

- The diving tanks are to be filled completely with water, entrapped air is to be avoided.

- By adequate filling of the compensating tank(s) the weight condition of the vehicle in the hovering condition of the submersible submerged is to be evaluated.

- By adequate distribution of the water between the trimming tanks the submersible is to be brought to even keel and the required filling of the buoyancy and trimming tanks is to be evaluated.

3. Heeling test submerged

The heeling test with the submerged vehicle serves to evaluate the centre of gravity under water as basis for the stability considerations described in B.2.

The condition of the submersible is according to the diving test in 2.

For the preparation of the test the following has to be considered:

- The influence of free surfaces in tanks, pipes, etc. is to be kept to a minimum.

- Starting angles of heel of more than 1° are to be avoided using weights/ballast.

The following steps are to be performed:

- The heeling/trimming of the submersible is to be started by a displacement of delivered test weights to the sides resp. forward and astern.
- These weights are to be chosen in such a way, that a heeling of 1,5 to 3,0 degrees to each direction occurs.
- The heeling angle is to be measured with two suitable devices, one of which shall be at least a damped pendulum with a reticule plate.
- The test is to be repeated at least 2 times to each side resp. forward and astern with different heeling moments, the average of the measurements is to be determined.
- At the end of the test the starting condition of the loads is to be re-established and the floating condition is to be checked for conformity with the starting position.

4. Heeling test surfaced

The heeling test with the surfaced vehicle with 100 % empty diving tanks serves to evaluate the centre of gravity surfaced as basis for the stability considerations described in B.2.

For the preparation of the test the following has to be considered:

- The test has to be performed in calm water with only slight wind.
- The draught forward, midships and astern is to be evaluated at port and starboard.
- All tanks shall be completely empty to avoid for certain the influence of free surfaces, the valves of the piping systems have to be closed.
- Starting angles of heel resp. starting trimming angles of more than 1° are to be prevented using additional ballast.

The same steps are to be performed as for the heeling test submerged (3.).

5. Trimming test

For the fully surfaced submersible with 100 % empty diving tanks it has to be investigated by variation of the filling of the forward and aft trimming tanks if a floating condition on even keel can be reached and which trimming conditions can be reached forward and aft.

For the evaluation of the trimming status suitable measuring devices have to be used or the draught marks forward and astern have to be read.

SECTION 4

DESIGN LOADS

A. **GENERAL**.. ..... **4-**2
B. **PRESSURE DEFINITIONS** **4-**2
C. **OTHER EXTERNAL LOADS** **4-**4
D. **INTERNAL LOADS**. **4-**8
E. **LOAD CASES FOR THE PRESSURE HULL**. **4-**10
F. **SUMMARY OF PRESSURES FOR THE ELEMENTS OF SUBMERSIBLES**. **4-**11

A. General

1. Scope

This Section summarizes all loads to be considered for the design of a manned submersible.

2. Use of actual loads

The following rules do not release the designer and the construction yard from the proof of the actual loads in each special case. If it becomes known during the design procedure that the actual loads are higher than in these rules, the effective loads have to be considered in the calculation and the causes for it are to be defined.

3. Load plan

All relevant loads for a submersible shall be summarised in a load plan. From the loads defined in the following only the loads relevant for the actual case have to be considered.

B. Pressure Definitions

1. Pressure load plan

As part of the load plan a plan has to be established which contains all pressures to be considered for the different parts of the construction.

It has to be defined in which way the pressure tests have to be carried out.

It has to be defined for which components (e.g. diving/ ballasting tanks, battery spaces, pressure hull, etc.) underpressure tests respectively overpressure tests have to be carried out.

2. Pressures for the pressure hull

Reference points for the pressure heads are the water surface and the lower edge of the pressure hull respectively of a constructional element. The following pressure heads are to be considered.

2.1 Pressure for nominal diving depth

The nominal diving depth **NDD** [m] is the diving depth for unrestricted operation of the submersible. The nominal diving pressure **NDP** [bar] for this depth follows by multiplying the **NDD** value by 0,101 [bar/m], if not otherwise agreed with **TL** for special operations.

2.2 Pressure for test diving depth

The test diving depth **TDD** [m] is the diving depth to which pressure hull resp. equipment are exposed to external pressure under testing condition after completion or after main repairs and modifications. The test diving pressure **TDP** [bar], which has also to be included in the pressure load plan, is the pressure used for testing pressure hull resp. equipment for its strength, tightness and function. The test diving pressure **TDP** is defined in Table 4.1.

2.3 Pressure for collapse diving depth

The collapse diving depth **CDD** [bar] is the diving depth decisive for the design of the pressure hull. The collapse diving pressure **CDP** is the pressure for which the pressure hull will collapse under load without consideration of the creeping behaviour and the creep rupture strength of the material.

In general the collapse diving pressure can be chosen according to Table 4.1. Deviating factors for the collapse diving pressure may be agreed with **TL** case by case.

2.4 Safety factors

2.4.1 The safety factor S_1 of the pressure hull is the relation test diving pressure **TDP** according to 2.2 to nominal diving pressure **NDP** according to 2.1.

2.4.2 The safety factor S_2 of the pressure hull is the relation collapse diving pressure **CDP** according to 2.3 to nominal diving pressure **NDP** according to 2.1.

The factor S_2 shall cover the following uncertainties:

- Influences which cannot be covered by the calculation procedure

- Influences as consequence of manufacturing mistakes (material failures, manufacturing inaccuracies, welding mistakes, residual stresses from manufacturing), compare also Appendix B.

- Negative influences during operation (corrosion deficiencies, unobserved buckling, alternating stressing)

- Time dependent characteristics of the material

Table 4.1 Test diving pressure and collapse diving pressure depending on nominal diving pressure

Nominal diving pressure NDP [bar]	**5 (1)**	**10**	**20**	**30**	**40**	**50**	**≥ 60**
Test diving pressure / nominal diving pressure S_1 = **TDP /NDP (3,4)**	1,70	1,40	1,25	1,20	1,20	1,20	1,20
Collapse diving pressure / nominal diving pressure S_2 = **CDP** / **NDP**	3,20	2,40	2,00	1,87 **(2)**	1,80 **(2)**	1,76 **(2)**	1,73 **(2)**

(1) *Minimum nominal diving pressure 5 bar*

(2) *Minimum value S_2 = 2 for operations in water depth > nominal diving depth*

(3) *In the range **NDP** = 5 ……… 30 bar is valid S_1 = 3 / **NDP** + 1,1*

(4) *For pressure tests with the factor > 1,5 it has to be observed, that all parts of the system, like acrylic windows, are designed for **TDP***

(5) *In the range **NDP** = 5 ……… 60 bar is valid S_2 = 8 / **NDP** + 1,6*

3. Pressures for vessels and apparatus

3.1 Pressures for calculation

3.1.1 For vessels and apparatus which are not exposed to the diving pressure, the design pressure is equal to the maximum allowable working pressure PB.

3.1.2 The additional layout pressure for vessels and apparatus which are exposed to the diving pressure is 1,1 times the collapse diving pressure **CDP**.

3.1.3 Design and layout pressure are not decisive for the fatigue strength**,** decisive is the maximum pressure occurring during operation which means the nominal diving pressure **NDP**.

3.2 Test pressure

3.2.1 The test pressure is the pressure for the proof of strength. The functional test shall be performed after the tightness test.

3.2.2 The test pressures are defined in Section 2, F.6. and also summarized in Table 4.2.

C. Other External Loads

1. Wind loads

1.1 General

Wind loads are to be considered for strength analysis of exposed parts of the surfaced submarine, such as tower, if applicable masts, periscopes, etc.

In addition they have to be considered for stability considerations.

Maximum wind speeds, air density, etc. have to be agreed with the operator for the operation area of the submersible. In the following standard values are used.

1.2 Wind forces

$F_w = q_w \cdot c_f \cdot A_w$ [kN]

q_w = wind pressure

= $0{,}5 \cdot \rho_L \cdot v_w^2$ [kN/m²]

ρ_L = density of the air [t/m³]

v_w = wind speed [m/s]

c_f = form coefficient [-]

A_w = projected area exposed to wind [m²]

Note:

For plane areas the form coefficient may be assumed with $c_f = 1{,}0$, for rounded areas the form coefficient may be assumed with $c_f = 0{,}6$.

The water content in the air may increase the air density ρ_L by about 30 %.

Table 4.2 Summary of pressures

Element group/ Element	**Reference: Section or Appendix/ A-Z/No.**	**Layout/Design**		**Tightness test pressure TTP**	**Test pressure PP**	**Further conditions**
		External pressure	**Internal pressure**			
Pressure hull and related elements:						
Pressure hull totally	2/F.3.1 4/B.2.2+B.2.3	PA = **CDP**	–	–	**TDP**	–
Fatigue strength	4/B.2.1 A/B.	PA = **NDP**	–	–	–	–
Bulkheads	5/C.7.	PA = **CDP**	–	0,2 bar underpressure	–	–
Bulkhead doors	2/F.3.5 5/C.6.4	PA = 1,1 x **CDP**	–	0,2 bar underpressure	**TDP**	–
Compartments under internal overpressure	2/F.3.1	–	PR = PB	–	1,5 x PB	–
Penetrations and closures	2/F.3.2 5/C.6.2 5/C.6.4	PA = 1,1 x **CDP**	–	0,2 bar underpressure	–	–
Pressure tight hatch covers	2/F.3.4 5/C.6.4	PA = 1,1 x **CDP**	–	**TDP**	–	–
Acrylic plastic windows	2/F.3.3 4/Tab. 4.1 5/G.5. C/D.1.	PR = **NDP**	–	–	**TDP** PP < 1,5 x PR	PB ≤ 1380 bar For **TDP** > 1,5 x **NDP**: PR = **TDP**/1,5
Tanks:						
Diving tanks	2/F.5.1 7/C.2.2	wash of the sea	static pressure	–	0,2 bar	–
Compensating tanks exposed to diving pressure/pumps	7/D.2.2	PA = 1,1 x **CDP**	PA = gravity	–	**TDP**	–
Compensating tanks exposed to diving pressure/compressed air	2/F.5.2 7/D.2.2	PA = 1,1 x **CDP**	PR = PB	–	**TDP** 1,5 x PB	–
Compensating tanks inside pressure hull/pumps	7/D.2.3	–	PA = gravity	–	–	minimum thickness
Compensating tanks inside pressure hull/compressed air	7/D.2.3	–	PR = PB	–	1,5 x PB	–
Trimming tanks exposed to diving pressure/pumps	2/F.5.3 7/E.2.2	PA = 1,1 x **CDP**	PA = gravity	–	**TDP**	–
Trimming tanks exposed to diving pressure/sompressed air	2/F.5.3 7/E.2.2	PA = 1,1 x **CDP**	PR = PB	–	**TDP** 1,5 x PB	–

Table 4.2 Summary of pressures *(continued)*

Element group/ Element	Reference: Section or Appendix/ A-Z/No.	Layout/Design		Tightness test pressure TTP	Test pressure PP	Further conditions
		External pressure	Internal pressure			
Trimming tanks inside pressure hull/pumps	2/F.5.3 7/E.2.3	–	PA = gravity	–	–	–
Trimming tanks inside pressure hull/compres-sed air	2/F.5.3 7/E.2.3	–	PR = PB	–	1,5 x PB	–
Vessels and apparatus:						
Exposed to diving pressure	2/F.6.3 4/B.3.1.2	PA = 1,1 x **CDP**	–	–	**TDP**	–
Exposed to diving pressure/fatigue strength	4/B.3.1.3	PA = **NDP**	–	–	–	–
Exposed to internal pressure	2/F.6.2 4/B.3.1.1	–	PR = PB	–	1,5 x PB	–
Piping systems, pumps and compressors:						
Systems exposed to diving pressure	2/F.7.1.1 2/F.7.1.2 9/B.1.1	1,1 x **CDP**	PR = PB	PB	**TDP** 1,5 x PB	–
Systems exposed to internal pressure/ pumps	2/F.7.1.1 2/F.7.2 9/B.1.1	–			1,5 x PB	–
Compressors	2/F.7.2	–	PR = PB		1,5 x PB	test pressure related to each stage
Hose lines and umbilicals/cables:						
Type test for liquids	E/B.2.4 E/D.2.1	PA = 1,1 x **CDP**	PR = PB	PB	4 x PB	for external pressure: PP = 1,5 Δp
Type test for gases					5 x PB	
Type test for electric cables	E/B.3.3	PA = 1,1 x **CDP**	–	–	2 x P_N (cyclic)	–
Routine test for electric cables	E/D.3.2	–	–	–	1,5 x P_N (cyclic)	–
Routine test for metallic hoses	E/D.3.1	–	–	–	1,5 x PB	–
Routine test for non-metallic hoses	E/D.3.1	–	–	–	2,0 x PB	–
Routine test for umbilical completely installed	E/D.3.1	–	–	PB with original media	**TDP**	–
Drives and electrical equipment:						
Housings exposed to diving pressure	2/F.8. 10/B.1.2 11/D.3.2	PA = 1,1 x **CDP**	–	–	test pressure without mathematical proof: **CDP**	
Electric pressure hull penetrations and plug-in connections/type test	11/D.8.1 11/D.8.2	PA = 1,1 x **CDP**	–	with air: 2x P_N with helium: 1,5 x P_N	hydrostatic (cyclic)	–
Electric pressure hull penetrations and plug-in connections/routine test	11/D.8.3	–	–	–	hydrostatic1,5 x P_N (cyclic)	S_1 = **TDP/NDP** ≥ 1,5

Table 4.2 Summary of pressures *(continued)*

Element group/ Element	Reference: Section or Appendix/ A-Z/No.	Layout/Design		Tightness test pressure TTP	Test pressure PP	Further conditions
		External pressure	Internal pressure			
Rescue systems:						
Detachable rescue vessel	2/F.15. 15/B.5.2	PA = 1,1 x **CDP**	–	–	**TDP**	–
Marker buoy	2/F.15. 15/B.6.1.1	PA = 1,1 x **CDP**	–	–	**TDP**	–

2. Flow resistance

If not the local hydrodynamic pressure is decisive but the resultant of the hydrodynamic forces, the maximum flow resistance for possible speeds is to be calculated using resistance coefficients or is to be evaluated by adequate tests.

For all parts of the shell area the local hydrodynamic pressure for maximum speed is to be considered.

3. Wash of the sea

The load from wash of the sea is defined for all parts of the outside areas which are emerging from the water by a static substitutive pressure of:

$p = 50 \text{ kN/m}^2$

All emerging parts such as tower, upper deck, etc. need in general only be considered up to 1 m above water surface.

For convex areas the substitutive pressure may be multiplied with cos α. The angle α is the angle between the line normal to the area and the assumed direction of the wash of the sea. It has to be proven that the wash of the sea can be locally borne, always under the assumption of normal loading. In addition it has to be proven that the resulting forces are absorbed by the relevant elements of the construction. This has to be proven for the most unfavourable direction of the wash of the sea and the maximum speed relations. If a more detailed investigation results in different loads, these are to be used.

4. Ice accretion

On the parts of the submersible above the waterline ice may accrete during a mission in cold operating areas.

If there is no other data available, the following loads may be used:

- 0,30 kN/m^2 on upper deck and other horizontal areas

- 0,075 kN/m^2 for the projected side area of the superstructure on both sides

- For other little constructional elements, such as guard rails, the projected areas of the superstructure should be increased by 5 %, the statical moment by 10 %

5. Loads at emerging

If additional loads are occurring at normal emerging or at emerging in an emergency, e.g. by temporary water in the exostructure, these loads are to be considered.

6. Accelerations from vehicle movements and seaway

The accelerations from the movement of the submarine depend very much on the type of mission and the mode of operation of the submersible. They have to be agreed with the operator.

Note

As guiding values accelerations of 2 g rms vertically down, 1 g rms vertically up and 1 g rms sideward and in longitudinal direction may be assumed (g = 9,81 m/s²).

7. Accelerations from collisions

In longitudinal direction an acceleration from collision of 3 g has to be taken into account ($g = 9{,}81\ m/s^2$).

8. Loads from towing, anchoring, manoeuvring, and lifting/lowering

The rupture load of the chosen anchor chains and the wire ropes are to be taken as design load for the relevant elements of the vehicle structure.

If a winch is provided, the maximum load of the winch is to be considered for local loads.

9. Load on the propeller shaft

For bigger submersibles where the propeller shaft penetrates the pressure hull, an additional load has to be considered. To the propeller thrust gained from calculations and/or model tests, the diving pressure, which acts on the propeller shaft at nominal diving depth **NDD**, is to be added to evaluate the total force on the propeller shaft respectively the thrust bearing.

10. Forces on rudders, fins and propulsion drives

The forces on rudders and fins are to be considered according to the **TL** Rules Chapter 1 - Hull, Section 18. Thrusts and moments from the (mostly rotatable) propulsion drives are to be determined case by case.

D. Internal Loads

1. Loads on watertight and non-watertight subdivisions

1.1 Bulkheads and decks under external pressure

The static load on watertight bulkheads or decks is:

$$p_{WTstat} = g \cdot \rho \cdot DD \ [kN/m^2]$$

g = acceleration due to gravity

= 9,81 [m/s^2]

ρ = density of water [t/m^3]

DD = for load case I as per E.1: nominal diving depth **NDD** according to B.2.1 [m]

= for load case II as per E.2: collapse diving depth **CDD** according to B.2.3 [m]

In single cases the diving depth for the design of the bulkheads may be agreed between manufacturer and **TL**.

1.2 Non-watertight subdivisions

1.2.1 The static load p_{NWT} is to be defined by the manufacturer of the submersible, but shall not be less than:

p_{NWT} = 2 kN/m^2

1.2.2 Additionally the static and dynamic loads from devices and equipment installed on bulkheads and walls are to be considered.

2. Loads on internal decks

2.1 Single point loads

The total weight of devices, systems, etc. is to be assumed as single point load P_E depending on the type of their foundation. As first approach for single static point loads may be assumed:

P_{Estat} = 1,5 kN

2.2 Uniform loads

The effective loads are to be evaluated in an actual case. As first approach for static uniform loads can be assumed:

p_{Lstat} = 3 kN/m^2

3. Loads on tanks not subjected to additional internal pressure

The static pressure is:

$p_{T1} = g \cdot h_1 \cdot \rho + 100 \cdot \Delta p$ [kN/m^2]

h_1 = distance of load centre from tank top [m]

ρ = density of liquid in tank [t/m^3]

Δp = adjusted pressure of the safety valve (if existing) respectively additional pressure component created by an overflow system [bar]

E. Load Cases for the Pressure Hull

The environmental conditions according to Section 2, D. are the basis for the calculations.

1. Load case I

The load case I is determined by the operation loads:

- Nominal diving pressure **NDP** according to B.2.1
- Wind loads according to C.1.
- Flow resistance according to C.2.
- Wash of the sea according to C.3.
- Ice accretion according to C.4.
- Loads at emerging according to C.5.
- Acelerations from vehicle movements and seaway according to C.6.
- Acceleration from collision according to C.7.
- Loads from towing, etc. according to C.8.
- Load on the propeller shaft according to C.9.
- Forces on rudders, fins and propulsion drives according to C.10.
- Loads on subdivisions of the pressure hull according to D.1.
- Loads on internal decks according to D.2.
- Loads on tanks not subjected to additional internal pressure according to D.3.
- Additional local loads for lifting points and supports

The fatigue strength for at least 5000 operation cycles (recommendation: 10000) at rectangular spectrum has to be proven in dependence on the **TL** Rules Chapter 1 - Hull, Section 3, D.

2. Load case II

The load case II is determined by the loads at collapse diving depth **CDD** according to B.2.3:

- For the pressure hull the collapse diving pressure **CDP** is to be used as maximum load, though for single components themselves 1,1 times collapse diving pressure **CDP** is the criterion for dimensioning.
- Other loads are not to be considered.

3. Load case III

The load case III is determined by the test loads:

- Test diving pressure **TDP** according to B.2.2
- Loads from strength, tightness and functional tests of different areas or of the vehicle as a whole
- Pressure loads on the different elements as defined in the pressure load plan according to B.1.
- Additionally loads from load case I, which may occur at the tests (e.g. flow resistance, propeller thrust, rudder forces, etc.) are to be superposed.

F. Summary of Pressures for the Elements of Submersibles

Table 4.2 presents a summary of the pressures which are defined in the different Sections of these Rules.

The following pressures are defined:

- Design pressure PR: pressure as input in a calculation procedure, which includes certain safety requirements according to the respective professional field
- Lay out pressure PA: limit value of the pressure equal to or in relation to the collapse diving pressure **CDP**, which can be barely endured without consideration of the creeping behaviour and the creep rupture strength of the material
- Test pressure PP: pressure to be used for practical tests
- Pressure PB: maximum allowable internal working pressure, usually limited by safety equipment
- Nominal pressure of components PN: the nominal pressure defined by the manufacturer
- Tightness test pressure TTP: test to be applied for tightness tests

SECTION 5

PRESSURE HULL

A. **GENERAL**.. .... **5-**2

B. **MATERIALS**.. **5-**2

C. **PRINCIPLES OF MANUFACTURE AND CONSTRUCTION**........................ **5-**5

D. **CALCULATIONS**. **5-**9

E. **PROOF OF STRENGTH USING NUMERICAL METHODS**........................ **5-**11

F. **CREEP RUPTURE STRENGTH**. **5-**12

G. **EQUIPMENT AND INTERIOR FACILITIES**. **5-**12

A. General

1. The following Rules apply to pressure hulls of submersibles in which the vehicle crew can be accommodated at atmospheric pressure.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, F. and G.

B. Materials

1. General

1.1 Materials are to be suitable for the purpose intended and for the processes applied, e.g. welding. Principally the requirements of the **TL** Rules Chapter 2 - Material are valid.

1.2 Furthermore the materials have to meet the special requirements defined in 3.

1.3 Viewports constituting part of the pressure hull are to be made of acrylic plastic and shall meet the requirements stated in Annex C.

2. Approved materials

2.1 Rolled or forged steels and steel castings with guaranteed ductility and toughness according to Table 5.2 are normally to be used for pressure hull fabrication. Steel plates, profiles and bars are to be made of fine-grained special steels with sufficient share of fine grain creating elements, e.g. Al, Nb, V or Ti according to the **TL** Rules Chapter 2 - Material and shall be produced keeping the requirements in 3.

2.2 Materials other than those mentioned in 2.1 may be used provided they have been proved to be suitable for the intended application. If no recognized standards are available, the relevant specifications are to be submitted to **TL** for examination and approval.

3. Special requirements applicable to materials for pressure hulls

3.1 Ductility

All metals shall possess sufficient ductility (in terms of the elongation measured by tensile test). The elongation at fracture (A) shall conform to the values stated in the standard or material specification and shall not be less than 16 % for steel. For screws an elongation of fracture A ≥ 14 % is required.

3.2 Impact energy

Steel grades shall conform to the impact energy values measured by notched bar impact test stated in the standard or material specification. In addition there is valid:

– Plates shall possess an impact energy of at least 30 J measured on ISO V-notch transverse specimens at a test temperature corresponding to the plate thickness in accordance with Table 5.1.

– Pipes shall possess an impact energy of at least 27 J measured on ISO V-notch transverse specimens resp. 41 J on longitudinal specimens at 0 °C.

– Cast iron shall possess an impact energy of at least 31 J measured on ISO V-notch specimens at 20 °C.

– Forgings and steel profiles and bars which are load bearing and are welded directly to the pressure hull, e.g. reinforcing rings, stiffeners, shall possess an impact energy of at least 27 J measured in ISO V-notch longitudinal specimens at a test temperature of 0 °C.

– Screws shall possess an impact energy of at least 52 J for tempered steels resp. at least 40 J for untempered steels measured on ISO V- notch specimens at a test temperature of 20 °C.

Table 5.1 Test temperatures for notched bar impact tests

Plate thickness [mm]	Test temperature [°C]
≤ 20	0
> 20 ≤ 40	- 20
> 40 ≤ 60	- 40
> 60	by agreement

Table 5.2 Approved materials for pressure hulls

Product type	Grade of material	TL Rules, Chapter 2 - Material, standard or specification
Plates	Normalized and heat treated fine grained steels and pressure vessel steels with characteristics according to B.3.	Chapter 2, Section 3, B., C., D., E. EN 10028-3, -6
Ends	Normalized and heat treated fine grained steels and pressure vessel steels with characteristics according to B.3.	Chapter 2, Section 4, A.
Profiles and bars	General-purpose shipbuilding and structural steels, provided these are killed, also fine- grained structural steels with characteristics according to B.3.	Chapter 2, Section 3, B. and I., EN 10025-2, -3, -4, -6, EN 10028-3, -5, -6
Pipes	Seamless and welded ferritic steel pipes with characteristics according to B.3.	for wall thickness ≤ 20 mm: Chapter 2, Section 4, B., 20 mm < wall thickness ≤ 40 mm: Chapter 2, Section 4, D.
Forgings	Forgings, pressure vessels and piping with characteristics according to B.3.	Chapter 2, Section 5, E.
Steel castings	Steel castings, pressure vessels and piping with characteristics according to B.3.	Chapter 2, Section 6, D. and E. EN 10213
Bolts and nuts	Unalloyed or alloy steel bars with characteristics defined in B.3.	Chapter 2, Section 4, ISO 898: Strength class 5.6, 8.8, ISO 3506-1 and -2
Viewports	Acryl glass panes	Annex C to these Rules

3.3 Non-destructive tests

3.3.1 Plates with a thickness above 8 mm shall with regard to their internal defects as a minimum satisfy the requirements for Class 2, Table 1 of Stahl- Eisen-Lieferbedingungen (SEL) 072 **(1)** or S_2/E_3 of the standard EN 10160 or comparable standards.

Zones for longitudinal, round and socket seams with a width equivalent to the plate thickness, but at least 50 mm, shall satisfy the requirements according to Class 1, Table 2 according to SEL 072 respectively of quality class E_3 according to EN 10160.

Areas for the connection of lifting eyes, elements of the exostructure and other plates, which may also be stressed in thickness direction, shall satisfy the requirements according to Class 0, Table 1 according to SEL 072 respectively of quality class S_3 according to EN 10160.

3.3.2 For forgings greater DN 250 the material quality is to be checked by the producer using suitable test procedures according to the **TL** Rules Chapter 2 - Material, Section 5, G. The tolerance boundaries are to be agreed with **TL** depending on the type of the component.

3.3.3 The producer has to submit to **TL** the proof for the non-destructive tests.

4. Proof of quality characteristics

4.1 Proof of the quality characteristics of materials used for pressure hulls is to be supplied in the form of material test certificates according to the **TL** Rules Chapter 2 - Material, Section 1, F. The type of Certificate required for the product concerned is indicated in Table 5.3. Unless otherwise specified, the testing authority for acceptance tests for the **TL** Material Certificate is **TL**.

4.2 The evidence to be supplied in respect of the characteristics of products made of steel not included in Table 5.3 shall be agreed with **TL**.

4.3 For small parts, like e.g. supports for consoles, welding lugs or other, not load-bearing and not pressure loaded elements approval Certificates of the manufacturer are to proven.

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(1) *Stahl-Eisen-Lieferbedingungen (Steel-Iron-Purchasing Conditions) are standard-type technical purchasing conditions for different groups of steel which are issued by Verein Deutscher Eisenhüttenleute (VDEh).*

Table 5.3 Proof of quality characteristics

Product type	Type of Certificate (1)		
	A	**B**	**C**
Plates for the pressure hull	X	–	Not applicable for pressure hull materials
Steel profiles and bars (load-bearing elements)	X	–	
Pipes and sockets > DN 50 ≤ DN 50	 X –	 – X	
Forgings, forged flanges > DN 250 ≤ DN 250	 X –	 – X	
Steel castings	X	–	
Bolts ≥ M 30 ≥ M 16 alloyed and tempered steel other not here defined bolts	 X X – 	 – – X	
Nuts ≥ M 30 other	 X –	 – X	
Acrylic plastic	X **(2)**	–	

(1) *Test Certificates are to be issued in accordance with* ***TL*** *Rules Chapter 2 - Material, Section 1, F. with the following abbreviations:*
A: ***TL*** *Material Certificate, B: Manufacturer Inspection Certificate, C: Manufacturer Test Report*

(2) *Proof by independent institution may be recognized.*

C. Principles of Manufacture and Construction

1. Treatment

1.1 Treatments applied to materials are to be professionally carried out. Materials whose characteristics have been impaired by hot or cold forming shall subsequently be suitably heat-treated, compare **TL** Rules Chapter 2 - Material, Section 4, A.

Concerning the criteria for adequate workmanship see also Section 1, H.

1.2 Materials are to be so marked as to enable them to be identified and correlated with their respective test Certificates even during and after the fabrication of the pressure hull.

1.3 The requirements of Annex C are to be complied with in the manufacture and machining of acrylic windows.

2. Welding

2.1 Approval

Companies wishing to undertake the fabrication of pressure hulls for submersibles have to be approved by **TL** with regard to their facilities, welding personnel and professional supervision.

2.2 Procedure tests

Before welding work is commenced, the properties of the joints to be welded are to be proven to **TL** by welding procedure tests at the manufacturer's works.

2.3 Butt welds

All butt welds in the pressure hull are to be performed as full-penetration, multi-pass welds executed from both sides. In addition, the work is to be performed in such a way that it can be assigned a weld factor v = 1,0 in accordance with **TL** Rules, Chapter 3 - Welding.

2.4 Fillet welds

The proof of the fillet welds is to be performed according to the **TL** Rules Chapter 1 - Section 20, B. and C. If no detailed proof by computation is required, the dimensioning shall follow Table 5.4.

Depending on accessibility a suitable test procedure is to be applied and to be agreed with **TL**.

3. Cutouts and viewports

3.1 Cutouts causing a weakening of the pressure hull wall are to be suitably strengthened (see Annex A, F.7.). The reinforcement shall form an integral part of the pressure hull or nozzle. Set-on reinforcing rings are not permitted.

Openings and cutouts, e.g. pipe, cable and mechanical linkage penetrations in bulkheads and web frames, are to be rounded with a radius according to their load and are normally to be flanged.

3.2 In the design and construction of viewport flanges, account is to be taken of the fact that the acrylic windows make no contribution to reinforcing the cutout in the shell of the pressure hull. Where the inside diameter of viewport flanges is greater than 350 mm, more stringent requirements are to be applied to the permissible radial deformation and angular deformation of the window seats, and these are to be agreed with **TL** in each case.

3.3 The window seat in the viewport flange is to be designed to give the window sufficient support at the maximum operating pressure. The seat dimensions for various standard windows are indicated in Annex C.

3.4 For flat windows having a right-angled edge and an O-ring seal, the seat diameter in the viewport flange shall be within + 0,25/ - 0,00 mm of the nominal value, or within + 0,75/ - 0,00 mm where flat gasket seals are used.

3.5 For spherical windows with a conical bearing surface, the major diameter of the conical seat in the viewport flange shall be within + 0,002 D_o/– 0,000 mm of the nominal value.

The included conical angle of the window seat in the viewport flange shall be within + 0,000/ - 0,25 degrees of the nominal value.

Table 5.4 Thickness of seams for double sided full-penetration fillet welds and double-bevel welds

Construction elements depending on the load	Seam thickness a / t_{min}
Pressure hull (PH):	
- Web of frame with shell of PH	0,35
- Web of frame with flange	0,35
- Web frame with PH	0,50
- Bulkhead (Exception pressure tight bulkhead) with shell of PH	0,50
- Bulkhead (Exception pressure tight bulkhead) with flange of web of PH	0,35
- Deck with shell of PH	0,40
- Pressure tight bulkhead with shell of PH	1
Pressure tight bulkhead:	
- Stiffeners on bulkhead	0,50
- Flange of web with web	0,50
- Penetrations in bulkhead	0,50
- Supporting deck with bulkhead	0,50
Compensating tanks:	
- Connection to the main structure	0,50
Walls/decks/bulkheads of tanks:	
- Plating together	0,40
- Plating with shell of PH	0,40
- Stiffeners with plating	0,25
- Girders with plating	0,30
Exostructure:	
- Plating together	0,35
- Frames with shell	0,25
- Web frames	0,30
- Bulkheads	0,30
- Frame connections to shell of PH	0,40
- Plating to the shell of PH	0,35
- Keel plates with web	0,50
- Brackets	0,45
Foundations:	
- Longitudinal and transverse girders	0,50
- Stiffeners and brackets	0,40
Decks and walls:	
- Plating together	0,30
- Plating with shell of PH	0,30
- Stiffeners with plating	0,15

t_{min} = smaller thickness of the plates to be connected
Tension and bending loaded cruciform joints are to be connected with a/t = 0,7

$$a = \sqrt{t_{min}} - 0{,}5 [mm]$$

t_{max} = the bigger thickness of the plates to be connected

3.6 The surface roughness of the window seat shall not exceed 1,5 µm.

3.7 The window seat is to be permanently protected against corrosion (e.g. by overlay welding using corrosion-resistant filler metals).

3.8 A soft gasket material can be used for the primary seal of standard windows in accordance with Annex C, Tables C.2 to C.4. This seal shall be sufficiently thick to enable it to absorb a reasonable degree of deformation without experiencing permanent setting.

3.9 In the case of flat windows with a right angled edge, a secondary seal is required which is normally bonded to the flange seat with contact cement. This seal also acts as a supporting gasket for the window and may not be more than 3 mm thick.

3.10 Sealing ring grooves are not allowed in the window bearing surface or the metal flange seat.

3.11 Retaining rings shall be able to provide the necessary initial compression of the window seals.

3.12 When fitting acryl glass pane windows, care is to be taken to ensure that all bearing surfaces are thoroughly cleaned. Where cleaning agents, window seat greases or adhesives for the window seals are used, these are to be tested for compatibility with acrylic plastic prior to use.

4. Ends

Knuckles of dished ends shall not be inadmissibly restricted in their movement by mechanical restraints of any kind, e.g. retaining plates, stiffeners, etc.

5. Pipe nozzles and flanges

5.1 The wall thickness of pipe nozzles is to be so dimensioned that they are fully able to withstand additional external loads. The wall thickness of socket-welded nozzles shall be compatible with the wall thickness of the part into which they are welded. Pipe nozzles and flanges are to be socket-welded in such a way that the weld configuration includes the whole wall thickness of the pressure hull.

5.2 Pipe connections in accordance with the **TL** Rules Chapter 4 – Machinery, Section 16 are to be provided for the connection of pipes.

6. Penetrations through the pressure hull

6.1 Hatches, doors, access ways

6.1.1 Submersibles are in general to be provided with an access and exit hatch which can be operated from both sides by one person. The access exit is to be so designed that a safe passage and leaving of the submersible is possible without water entering in the internal space of the vehicle. The hatch covers shall open to outside and it shall be possible to secure them in the open position.

6.1.2 The access and exit hatches are to be provided with a closing mechanism which makes it possible to create, even when the submersible is surfaced, a sufficient contact force on the hatch sealing. In addition the closing mechanism is to be designed in a way that opening of the hatch is only possible after pressure equalization has happened, see also Section 13, F.

Two measures are to be provided to guarantee that the hatches are closed and secured before diving, one of the measures shall be visibly noticeable.

6.1.3 Arrangements are to be provided that doors can be opened from both sides. A banging of doors or hatches is to be prevented safely by suitable mechanical measures.
Doors at casings and locks are to be equipped with pressure equalization valves.

6.1.4 Doors and passages for persons shall have at minimum a net width of 500 mm, diver's accesses and exits are to have at least 600 mm.

6.2 Penetrations for supply lines

Penetrations through the walls of the pressure hull for umbilicals/supply lines and other piping, hoses and cables are to be protected, as far as possible, against mechanical damage by appendages or covers to the pressure hull

6.3 Propeller shafts

For the penetration of all propeller shafts from the exostructure into the pressure hull it is to be avoided that elastic deformations and vibrations are transferred into the pressure hull.

6.4 Lay out

The lay out of the penetrations through the pressure hull according to 6.1 to 6.3 has to be done at least for 1,1 times the collapse diving pressure **CDP**.

In addition the lay out is to be done for an internal pressure of 1,3 bar absolute.

7. Pressure tight bulkheads

The lay out of pressure tight bulkheads for division of the internal space has to be based on the collapse diving pressure **CDP.** The lay out of doors in these bulkheads is to be done according to 6.4.

8. Mating arrangements

8.1 If at a submersible with diver's lockout arrangements are provided for mating with a deck decompression chamber (pressure chamber) the requirements of Chapter 52 – Diving Systems, Section 2, J. are valid for these arrangements.

8.2 If submersibles are equipped with systems for transfer of persons under atmospheric pressure, the conditions for design and construction of the mating arrangement are to be agreed with **TL**.

D. Calculations

1. General

1.1 Pressure hulls, hatches, windows, suspensions, etc. are to be calculated in accordance with the relevant Rules of **TL** or other equivalent codes of engineering practice.

Pressure hulls and pressure vessels subjected to external overpressure may be calculated in accordance with Annex A, windows in accordance with Annex C.

1.2 The calculations on which the design is based are to be submitted to **TL**. Where the calculations are to be performed with the aid of computers, proof of the suitability of the programs is to be furnished to **TL**.

1.3 The loads have to be evaluated from the load cases I to III according to Section 4, E.

1.4 For the weld factor of welds see C.2.3.

1.5 The allowance for corrosion and wear shall normally be c = 1 mm. The allowance may be dispensed with in the case of plates ≥ 30 mm thick, stainless steels or other corrosion resistant materials and where special corrosion protection measures are applied.

1.6 The wall thickness of shells and ends of seamless or welded pressure hulls shall generally not be less than 6 mm.

2. Design criteria for the pressure hull

The following design criteria are to be applied to the calculation of components subjected to external overpressure:

– Tensile, compressive and bending stresses at nominal and test diving pressures shall not exceed the permissible values stated in 3.

– Components critical to stability are to be designed to withstand buckling, bulging and lateral buckling at collapse diving pressure **CDP** in conformity with the safety factors stated in 4. For cylindrical shells, proof is to be provided of resistance to both asymmetrical and symmetrical buckling.

– The possibilities of failure critical to stability and of plastic failure are to be analyzed. Allowance is to be made for the reduction in the modulus of elasticity between the limit of proportionality and the yield point resp. 0,2 % proof stress. Generally, the material shall be assumed to behave elastically and plastically (e.g. as specified in DIN 4114, sheet 2) without strain hardening. Where the compressive load/- deformation curve for the material has been determined in the presence of **TL**, this curve may be used as the basis for calculations.

– The collapse pressure/nominal diving pressure ratio indicated in Section 4, Table 4.1 shall not be undercut.

Table 5.5 Safety factors

Material	Nominal diving pressure NDP		Test diving pressure TDP		Collapse diving pressure CDP	
	A	B	A'	B'	A"	B"
Ferritic materials	2,7	1,7	–	1,1	–	1,0
Austenitic materials	2,7	1,7	–	1,1	–	1,0
Titan	2,7	1,7	–	1,1	–	1,0

3. Permissible stresses

For the nominal diving pressure is valid:

$$\sigma_{zul,NDP} = \min\left\{\frac{R_{m,20°}}{A};\frac{R_{eH,t}}{B}\right\}$$

For the test diving pressure is valid:

$$\sigma_{zul,TDP} = \min\left\{\frac{R_{m,20^\circ}}{A'};\frac{R_{eH,t}}{B'}\right\}$$

For the collapse diving pressure is valid:

$$\sigma_{zul,CDP} = \min\left\{\frac{R_{m,20^\circ}}{A''};\frac{R_{eH,t}}{B''}\right\}$$

$R_{m,20^\circ}$ = guaranteed minimum tensile strength [N/mm²] at room temperature (may be disregarded in the case of established fine-grained steels with R_{eH} ≤ 360 N/mm^2 or where external overpressure exerts a compressive load)

$R_{eH,t}$ = guaranteed yield point or minimum value of 0,2 % proof stress at design temperature

The safety factors A, A', A" resp. B, B', B" are shown in Table 5.5.

4. Safety factors against buckling and tripping

Cylindrical and spherical shells are to be designed at collapse diving pressure to withstand elastic-plastic buckling under consideration of manufacturing influences. The adequate reduction factors are defined in Annex A, F.2.5, F.3.3, F.6.6.

For frames a proof of stability against tripping on the basis of a stress calculation is to be performed, which meets the balance in deformed condition. The relevant limit values for stresses are defined in Annex A, F.4.2, F.5.1, F.5.3 and F.5.4.

5. Allowance for manufacturing tolerances

5.1 In design calculations relating to pressure hulls, allowance is to be made for deviations from the ideal shape, e.g. with regard to the roundness of the shell configuration or the positioning of the stiffening rings, see Annex B.

5.2 If the manufacturing tolerances according to Annex B on which calculations have been based are exceeded, the deviations observed shall be used to carry out a mathematical verification of the maximum permissible pressure.

E. Proof of Strength Using Numerical Methods

1. For areas for which a numerical stress proof is required (see Annex A) the ultimate strength limit has to be numerically proven. In general the same computation model can be used for it. Should in exceptional cases a numeric proof for convex dished ends be required, than the critical area has to be modelled with the actually measured or the maximum permissible radius of curvature.

2. The computation has to consider the deformations in the balance and the elastic-plastic material behaviour as defined in F.3. of Annex A.

3. The suitability of the method and the choice of the element type have to be demonstrated with a computation model evaluating the failure pressures for the symmetrical and asymmetrical buckling in the area of the regularly stiffened cylinder. The numerically evaluated values should be 2 % to 4 % lower than the values analytically evaluated in F.2. and F.3. of Annex A.

4. The numerically evaluated failure pressure for cylindrical and conical pressure hulls shall in areas where a numerical computation has been applied, show a safety factor of 1,07 related to the collapse diving pressure **CDP**. For spherical shells the safety factor has to be agreed separately with **TL**.

F. Creep Rupture Strength

For pressure hulls made of creeping materials it has to be proven by model tests or by computations that the pressure hull can withstand for the duration of 104 minutes 80 % of the collapse diving pressure. The performance for such a proof has to be agreed with **TL**.

G. Equipment and Interior Facilities

1. Interior facilities of the pressure hull

1.1 For equipment, fittings, insulation, paintwork and preservative coatings inside pressure hulls, use may only be made of those materials and media which do not release any toxic or severe irritant gases under the atmospheric conditions mentioned in Section 2, D. Wherever possible, this also applies to the effects of heat.

If gases which are not mentioned in these Rules may occur because of special missions and requirements, these are to be monitored.

1.2 Wherever possible, only non-combustible or at least flame-retardant materials and media shall be used inside the pressure hull.

1.3 Battery spaces are to be so designed that they can accommodate the equipment needed for ventilation, air circulation, acid measurement and cooling.

1.4 Tanks and bunkers located within the pressure hull are to be functionally designed and provided with sufficient ventilation and drainage facilities in each case. All tanks and bunkers are to be provided with manholes.

2. Allocation of space

As far as possible, the space occupied by the crew is to be separated from that in which machinery and equipment is installed and is to be acoustically and thermically insulated.

3. Equipment

3.1 At least one seating facility is to be provided for each crew member.

3.2 In independent submersibles and those designed for periods of service exceeding 12 h, the pressure hull is to be provided with a suitable accommodation area with sleeping facilities and separate sanitary arrangements.

4. Lighting

Each pressure hull compartment is to be adequately lighted, see Section 11, E.2.

5. Windows for the pressure hull

5.1 The requirements for the acrylic plastic windows to be used are defined in Annex C.

5.2 View ports are, as far as necessary, to be protected internally and externally against mechanical damage.

6. Miscellaneous

6.1 Pressure hulls are to be adequately provided with eye plates, welding lugs, or similar for the attachment of supports.

6.2 Sealing systems for hatch covers are to be approved by **TL**. Pressure hull penetrations of shafts are to be provided with double sealing.

SECTION 6

EXOSTRUCTURE AND EQUIPMENT

A. GENERAL **6-**2
B. DESIGN PRINCIPLES FOR THE EXOSTRUCTURE **6-**2
C. EQUIPMENT **6-**4
D. CORROSION PROTECTION **6-**6

A. General

1. The following Rules apply to the entire freeflooded exostructure of the submersible including cladding, supporting structures and pressure hull fixtures as well as for the equipment in the range of the exostructure.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, F. and G.

B. Design Principles for the Exostructure

1. Computation

Recognized mathematical procedures are to be followed in performing calculations relating to components of the exostructure. The dimensional design of the exostructure shall be such that, at the anticipated loads for normal operation, the calculated stress is not greater than 0,6 times the yield strength.

According to the type of the configuration of the exostructure and with the relevant openings it has to be secured that structural elements which are not pressuretight do not get remarkable loads from the diving pressure and that no air bubbles remain in the exostructure after preparing the diving procedure.

The external loads which may effect the exostructure and which have to be considered for the computation, where applicable, are summarized in Section 4, C.

2. Materials

2.1 Materials shall be suitable for the intended application and manufacturing process and have to be approved by **TL**.

Materials for the exostructure shall be compatible with the material for the pressure hull, but the strength parameters may be different. If the electromechanical characteristics of the materials are different, corrosion protection may become necessary.

2.2 The manufacture, processing and testing of steels are subject to **TL** Rules Chapter 2 - Material.

2.3 For the manufacture and processing of fibre reinforced plastics (FRP) materials Annex D to these Rules is to be considered.

2.4 All other materials are to be manufactured and processed in accordance with recognized standards or to material manufacturer's specifications which have been examined and approved by **TL**.

2.5 Materials for rigid buoyancy bodies are to be suitable for the proposed pressure and temperature ranges, shall have a low absorption factor and shall not suffer appreciable crushing under pressure.

2.6 Suitable proof is to be furnished of the quality characteristics of materials, e.g. by a Manufacturer Inspection Certificate, compare Table 5.3.

3. Form of the exostructure

3.1 If the submersible shall achieve a speed worth mentioning, the exostructure is to be provided with a streamlined and smooth surface. Stepwise connections of structural elements shall be equalized if the flow will be influenced in a negative way.

3.2 The exostructure of a submersible is to be so designed that parts of it can be crushed without damaging the pressure hull. In addition it shall be excluded as far as possible that the vehicle is being caught up by parts of its exostructure. Anchors are to be so arranged that, when stowed, they are flush with the exostructure.

3.3 The exostructure is to be stiffened and supported by transverse and longitudinal frames and as far as necessary by web frames, middle and side stringers according to the design and strength requirements.

3.4 The shell is to be reinforced in the area of the diving and ballast tanks. In the area of the tanks screwed connections of elements of the shell are not permissible.

4. Tower

If a tower is provided to enable an access into the pressure hull also at higher seaways and/or to secure the bearings of periscopes and masts for electronics and navigation lights, additional forces have to be absorbed by the exostructure. The supporting structural members of the tower's structure are to be situated in line with web frames, frames and if necessary bulkheads of the pressure hull. Outside of the pressuretight entrance pipe a good accessibility of the exostructure is to be rendered possible.

5. Keel

If a keel is provided, it has to be designed for the attachment of fixed ballast and for the transfer of forces occurring during docking.

6. Supports and runners

Submersibles with a diver's lockout are to be fitted with supports or runners which ensure a sufficient clearance between the seabed and the vehicle.

7. Ram frames

As far as necessary, submersibles are to be equipped with ram frames or similar to protect the pressure hull as well as attached parts and working devices.

8. Flooding and venting

All free-flooding parts of submersibles are to be designed and provided with openings in such a way that the spaces concerned can be fully flooded and vented and no remarkable loads caused by the diving pressure are built up.

9. Fixtures to the pressure hull

When welding pressure hull fixtures such as diving tank mountings, working devices, stabilizing fins, rudders or similar, care is to be taken to minimize the resulting internal stresses in the pressure hull. The ability to inspect and preserve even those areas of the pressure hull adjoining fixtures shall be secured.

10. Buoyancy appliances

Buoyancy appliances mounted externally on the vehicle are to be properly secured and protected.

11. Lifting points

Submersibles which are operated from support ships are to be provided with lifting points suitable for lifting the submersible on board. The lifting point on the submersible is to be so designed and located that the vehicle can be hoisted and retrieved under the maximum permissible seaway conditions.

In addition submersibles are to be equipped with alternative lifting points on which in case of emergency lifting devices for the salvage of the vehicle can be fastened. These alternative lifting points are to be so designed and arranged that the submersible can be brought to the water surface even if the interior space is flooded.

The lifting points shall have a safety against rupture of 8 times the safe working load and are to be clearly signed and marked with their safe working load.

12. Towing point

An element to fasten towing lines at the submersible is to be provided. This towing point is to be so designed and located that the submersible can be towed surfaced with the maximum planned towing speed and the access opening is not flooded even under the most adverse operating conditions.

13. Upper deck

13.1 The exostructure of submersibles and especially the upper deck is to be so designed and, where necessary fitted with gratings, to enable safe access to the vehicle.

13.2 All flaps have to be provided flush in the deck and shall be secured against vibrations.

13.3 The upper deck has to protect all devices and equipment situated in free spaces below, like rescue equipment, boatsman's equipment (fenders, ropes, etc.)

13.4 Mooring equipment like bollards, cleats, hawses, lifting and towing points, fenders, rudders, propulsion devices and other elements of the exostructure and of the equipment have to be so designed that the danger of getting trapped in nets, marking or anchoring ropes, etc. is avoided as far as possible. In addition the flow on the submersible shall not be hindered.

C. Equipment

According to the area of operation and the mission of the submersible the required elements for the hull equipment are to be provided.

1. Anchoring equipment

Independent submersibles are to be equipped according to their area of operation with adequate anchors including the measures for bringing the anchor out and in. The gear shall be jettisonable in an emergency.

Concerning the size of anchors and their composition see Chapter 1 - Hull, Section 17, A.–E.

Anchors, anchor chain cables/ropes and mooring ropes/hawsers are to be manufactured and tested in accordance with the **TL** Rules Chapter 2 - Material, Section 10.

2. Warping gear

Submersibles are to be equipped with bollards, cleats or similar to enable a mooring of the vehicle. The arrangement shall be chosen in a way to disturb the flow during underwater travel to a minimum.

Concerning the number and dimension of the mooring ropes see Chapter 1 - Hull, Section 17, F.

3. Guard rails

3.1 Depending on the size, the form and the accessibility of the upper deck it may be safety relevant, especially for works in the harbour or at the preparation of a diving mission, to provide guard rails at the upper deck. If the upper deck is rounded the stanchions are to be placed on the flat part on the deck.

3.2 The height is to be at least 1,0 m from the deck. The height below the lowest course is not to exceed 230 mm, The other courses are not to be spaced more than 380 mm apart. The guard rail is to be constructed according to DIN 81702, equivalent designs may be agreed by **TL**.

3.3 If guard rails are disturbing during diving missions, it shall be possible to turn them down or draw them back.

3.4 As an alternative or as addition it may be recommendable to provide on upper deck a steel wire, a rail or a slot where the members of the crew can hang in their rescue belt during the work on deck.

4. Retractable masts

4.1 Masts for signal purposes, radar and sensor equipment respectively air pipes are normally retracted into the exostructure or turned down during diving journeys and are to be lifted/turned up for surface journeys. The required height and the scope of the devices to be mounted are to be agreed with **TL** case by case.

4.2 For utilization of the mast for surface journeys the following loads are to be considered:

– Wind forces according to Section 4, C.1.

– Accelerations through movements of the vehicle according to Section 4, C.6.

4.3 The flow resistance of the part of the mast in the water outside the exostructure may be considered according to the **TL** Rules Chapter 62 – Offshore Technology – Structural Design, Section 2, B.3 and B.4.

4.4 For the used material the limitation of deflection is in general the decisive criterion to secure a faultless and precise functioning of the devices.

4.5 If the bearings of the retractable masts are water lubricated, only materials which are completely corrosion-resistant against seawater are to be utilized.

4.6 For the lifting mechanism see **TL** Chapter 50 – Lifting Appliances.

5. Umbilicals

5.1 Umbilicals as the connection element between support ship and submersible may contain control and communication cables, hydraulic and pneumatic lines as well as energy supply lines and a lifting cable in a joint cover.

5.2 The umbilical connection at the submersible has to be designed to transfer the maximum permissible tension load of the umbilical to the exostructure.

5.3 All aspects for the design of umbilicals are defined in Annex E.

6. Further equipment (working devices)

The further equipment of submersibles, e.g. manipulators, TV-systems, search lights, tools and working devices depends on the type of submersible, the intended purpose of the mission and is to be agreed with **TL** case by case. Requirements for working equipment are defined in the **TL** Rules Chapter 54 – Underwater Equipment.

7. Jettisoning of equipment

7.1 Manipulators, claws, anchors and other items of gear which may be used to keep the submerged vehicle in position are to be so designed that they can be released or jettisoned in an emergency. Towing lines are to be designed jettisonable.

7.2 Jettisoning gear shall be operable even if the main power source fails. It is also to be designed to preclude accidental release or jettisoning. Jettisoning shall not cause any inadmissible heeling or trim conditions.

D. Corrosion Protection

1. Protection outside

1.1 The exostructure and the equipment as well the belonging components are to be protected effectively against corrosion. The principle requirements of the **TL** Rules Chapter 1 - Hull, Section 22 are to be observed.

1.2 Locations which are because of constructional reasons not accessible later on are to be provided with a durable corrosion protection already during construction.

1.3 An active corrosion protection is to be secured e.g. by mounting of sacrificial anodes in sufficient number and composition.

2. Internal protection

Corrosion protection painting in the internal space of the pressure hull has to meet the requirements defined in Section 5, G.

SECTION 7

ARRANGEMENTS FOR DIVING/BALLASTING, CONTROL/COMPENSATING AND TRIMMING

A. GENERAL.. .... **7-**2
B. PRINCIPLES OF DESIGN AND CONSTRUCTION. **7-**2
C. DIVING TANKS.......... **7-**3
D. COMPENSATING TANKS. **7-**4
E. TRIMMING DEVICES.......... **7-**5
F. BALLAST SYSTEMS.......... **7-**6

A. General

1. The following Rules apply to the arrangements for diving/ballasting, control/compensating and trimming of submersibles and their associated components.

It has to be secured, that these arrangements are working under all specified conditions of heel and trim inclusive of those, which may occur at an accident, where the pressure hull is not damaged,

Pipes and pumps for these systems are treated in Section 9. The requirements for depth rudders and other manoeuvring systems are defined in Section 10.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, F. and G.

B. Principles of Design and Construction

1. General Principles

1.1 Diving, compensating and trimming tanks are to be so designed and arranged that the following conditions are satisfied:

- The submersible shall be stable in every phase of operation, compare Section 3.
- It shall be possible to operate the submersible safely on the surface under the maximum permissible seaway conditions.
- It has to be possible before initiating the diving procedure to check the necessary technical systems (Check “Ready for diving”).
- When submerged, it shall be possible to balance and trim the submersible at any depth less than or equal to its nominal diving depth **NDD**.
- The submersible shall at all times be capable of returning safely to the surface.
- In the event of failure of the compensating tank system the submersible shall be capable of surfacing by jettisoning of ballast and/or emergency blowing of the diving tanks and has to float on the surface in an upright stable position.

1.2 For diving/surfacing may serve:

- Diving tanks
- Compensating tanks
- Trimming tanks as dynamic diving/surfacing assistance, see E.

– Depth rudders/side rudders as dynamic diving/surfacing assistance, see Section 10

– Release of ballast, see Section 15, B.3.

– Propulsion systems as dynamic diving/surfacing assistance, see Section 10

1.3 For non-autonomous submersibles, which are connected to the support ship via an umbilical with lifting cable a surfacing independent of the lifting cable shall be possible.

1.4 A combination of compensating and trimming systems is possible, compare Section 9, B.2.

1.5 Flooding and bilge openings are to be protected against obstruction respectively entrance of foreign matters by installation of e.g. suitable grids, filters, strum boxes.

2. Control of the systems

2.1 All the operating units for controlling positive and negative buoyancy are to be grouped together and clearly marked, either on the control console or, in bigger submersibles, at the diving control stand.

2.2 The control console resp. the diving control stand is to be equipped with indicating instruments which show continuously the position of the submersible and the state of the depth and trim.

2.3 Control operating units and indicating instruments are subject to the Rules set out in Section 12. For dynamic depth control see Section 10.

C. Diving Tanks

1. Purpose

Diving tanks shall serve for the diving of the submersible by filling with water and for surfacing by eliminating the water and filling with air.

2. Computation and Materials

2.1 The materials, manufacture, design and calculation of diving tanks are to comply with the Rules set out in Sections 5 and 6, as far as applicable.

2.2 Diving tanks are to be designed and fabricated to withstand the impact of waves and the internal static pressure.

3. Arrangement

The diving tanks are arranged normally outside of the pressure hull inside the exostructure.

4. Filling and emptying

4.1 The volume of the diving tanks has to be chosen in a way, that the submersible has enough freeboard in surfaced condition as well as that it owns enough reserve buoyancy, compare Section 3, B.1.

4.2 The filling shall normally be done by suitable flooding openings for water near the bottom of the tank, the venting at the same time through valves at the ceiling of the tank.

The emptying has to be done with closed venting valves by blowing of compressed air or by pumping. For the layout of the air storage Section 9, B.3.1 applies.

For other concepts of diving tanks eventual other deviating conditions are to be approved with **TL**.

4.3 Diving tanks are to be provided with vents enabling them to be completely flooded with water. The venting system shall be provided with a separate shut-off device for each individual tank. The vent valves are to be designed such as to prevent unintentional opening.

4.4 Where diving tanks have flooding holes without means of closure, double shut-off devices may be stipulated for the vent pipe.

4.5 Where diving tanks are evacuated by compressed air, the blowing line for each tank has to be shut-off separately in case of emergency. It is necessary to ensure that blowing the tanks cannot cause an excessive overpressure.

4.6 Where the diving tanks are to be pumped out, the flooding holes are to be fitted with means of closure and steps shall be taken to ensure that the freeing of the tanks cannot cause an excessive underpressure. If freeing water is only possible with pumps, a standby bilge pump is to be provided.

4.7 If several diving tanks are provided which shall be applied for dynamic assistance of the diving/surfacing manoeuvres, each tank is to be controlled separately.

D. Compensating Tanks

1. Purpose

Normally compensating tanks are to be provided for a fine adjustment of the wanted depth and for balancing of changes of buoyancy because of consumption of provisions and supplies during the underwater voyage, changes of the density of seawater, taking-on or taking-off of payloads as well as effects of buoyancy/loss of buoyancy.

2. Computation and Materials

2.1 The materials, manufacture, design and calculation of compensating tanks arranged outside the pressure hull are to comply with the **TL** Rules Chapter 4 - Machinery, Section 14.

2.2 Compensating tanks outside the pressure hull are to be designed for 1,1 times the collapse diving pressure **CDP**. If they change their filling condition with assistance of compressed air, a design pressure according to the maximum allowable working pressure of the compressed air system is to be considered.

2.3 Compensating tanks located within the pressure hull may be designed as gravity tanks provided that freeing is effected by pumps only. If they change their degree of filling by compressed air, a design pressure PR according to the maximum allowable working pressure of the compressed air system is to be considered.

3. Arrangement

The location of the compensating tanks should be chosen in a way that the floating condition of the submersible does not change very much during filling and emptying.

4. Filling and emptying

4.1 The capacity of compensating tanks has to be big enough to compensate for all the changes in buoyancy expected to arise during the planned diving duties plus a reserve capacity of at least 10 %.

4.2 Compensating tanks may be freed by compressed air or by pumping. The quantity of water admitted during flooding and expelled during freeing has to be indicated. For that purpose compensating tanks are to be fitted with content gauges giving a continuous reading.

4.3 The vent pipes of compensating tanks are to be designed and arranged in such a way that water cannot penetrate inside the vehicle unnoticed. The section of the venting pipes is to be in accordance with the maximum rate of inflow/outflow.

4.4 The compensating tanks are to be safeguarded against excessive over and underpressure.

E. Trimming Devices

1. Purpose

1.1 Trimming devices serve for producing a horizontal position of the submersible during a voyage at the same depth.

1.2 On the other hand an inclined position forward or astern can be adjusted with full intention to facilitate diving or surfacing.

2. Computation and materials

2.1 The materials, design and calculation of trimming tanks arranged outside of the pressure hull are to comply with the **TL** Rules Chapter 4 - Machinery, Section 14.

2.2 Trimming tanks located on the outside of the pressure hull in the exostructure of the submersible are to be designed to withstand an external load according to 1,1 times the collaps diving pressure **CDP**. It they change their filling condition with assistance of compressed air, a design pressure according to the maximum allowable working pressure of the compressed air system is to be considered.

2.3 Trimming tanks which are located inside the pressure hull and where the water is transferred by pumping may be designed as gravity tanks. If they change their degree of filling with the assistance of compressed air a design pressure according to the maximum allowable working pressure of the compressed air system is to be considered.

3. Arrangement of trimming tanks

To achieve a big leverage trimming tanks are to be arranged as far as possible forward and aft on the submersible.

4. Filling and emptying of trimming tanks

4.1 The volume of the trimming tanks has to be chosen in a way that all planned trimming positions of the submersible can be adjusted by combined filling and emptying of the different tanks.

4.2 The transfer of water may be by pumping or by compressed air. A constraint circuitry shall ensure that the transfer always takes place in the desired direction. The quantities of water used for trimming are to be indicated.

4.3 If trimming tanks are arranged directly drainable for the emergency case, miss-switching in normal operation is to be avoided by suitable measures.

4.4 For trimming tanks outside the pressure hull ventilation into the pressure hull is to be provided with double shut-off devices. For combined compensating and trimming systems the overall system is to be agreed with **TL**.

5. Trimming weights

5.1 If longitudinally movable weights are provided for trimming, steps are to be taken to ensure that the weights cannot accidentally slip out of position.

5.2 If trimming weights for a certain operation area or mission are arranged outside of the pressure hull and cannot be shifted during operation, they may be used additionally to the rigid ballast as release weight, compare Section 15, B. If the weights cannot be controlled visually, an indication of their position is to be shown at the control stand.

F. Ballast Systems

1. Ballast systems for equalization of weight changes, like e.g. by payloads, change of number of persons on board, etc., may be operated with

- Fixed ballast, as well as
- Liquid ballast.

2. For liquid ballast compensating and trimming tanks or separate ballast tanks may be used.

3. If fixed ballast is used and payload shall be taken up during the mission, the ballast is to be connected to the submersible with the ability of jettisoning.

If fixed ballast is required during the complete mission to achieve neutral buoyancy, it may consist of safely stored, non-jettisoning ballast weights.

4. At maximum ballast condition it shall be possible to create sufficient remaining positive buoyancy even in case of a failure.

SECTION 8

VESSELS AND APPARATUS UNDER PRESSURE

A. GENERAL.......... **8-**2
B. PRESSURE VESSELS, GAS CYLINDERS AND APPARATUS UNDER PRESSURE.......... **8-**2
C. COMPRESSION AND DIVING CHAMBERS.......... **8-**3

A. General

1. The documents to be submitted to **TL** for approval are stated in Section 2, E.

2. The necessary tests and markings are as stated in Section 2, F. and G.

3. The pressures on which the layout is to be based are to be taken from the relevant Sections.

B. Pressure Vessels, Gas Cylinders and Apparatus under Pressure

1. Vessels

Vessels under internal and mainly external pressure are required in submersibles among others for:

– Pressure vessels for the operation

– Compensating tanks

– Trimming tanks

– Fuel bunkers (if existing)

– Battery boxes

– Equipment containers/housings, e.g. for rescue equipment, cameras, searchlights, etc.

– Pressure storages for hydraulic systems

– Compression and diving chambers (see C.)

2. Gas cylinders

2.1 Gas cylinders for the purpose of these Rules are bottles with a capacity ≤ 150 l, an outside diameter ≤ 420 mm and a length ≤ 2000 mm, which are charged
with gases in filling stations.

2.2 On board of submersibles gas cylinders are amongst other utilized for:

– Compressed air for blowing tanks and bunkers

– Breathing gases for the crew

– Gases for drives, e.g. cyclic motors as well as fuel cell drives

3. Apparatus

Apparatus under pressure in the sense of these Rules are devices and aggregates, which have a closed volume and are exposed to internal or external pressure.

4. Lay out

4.1 Vessels and apparatus are to be designed under consideration of Section 4, B.3. and to be tested according to Section 2, F.

4.2 For vessels and apparatus under internal pressure the requirements set out in the **TL** Rules Chapter 4 - Machinery, Section 8, A. – F. respectively for gas cylinders in Section 8, G.

4.3 For vessels and apparatus under external pressure normally Section 5 has to be applied analogously and for the computation Annex A is to be considered. The application of other recognized rules can be approved by **TL** in individual cases. For this the requirements for products made of steel and titanium are to be considered according to Section 5, B.3. and for fibre reinforced plastics (FRP) the requirements according to Annex D. are to be considered.

4.4 For vessels and apparatus located outside the pressure hull, the strength of which cannot be proven sufficiently by computation, a pressure test with a design pressure 1,1 x collapse diving pressure **CDP** has to be performed within a type test. Kind and scope of such a type test is to be agreed with **TL**.

If it is guaranteed by suitable technical measures that at any time a defined internal pressure is existing, the test may be performed only with the differential pressure.

C. Compression and Diving Chambers

1. Compression and diving chambers in submersibles are to be built and equipped in accordance with Chapter 52 – Diving Systems.

2. Submersibles which have a diver's lock-out or a diving chamber are to be equipped - depending on their mission - with the possibility of the connection to a decompression chamber on board of the support ship.

SECTION 9

PIPING SYSTEMS, PUMPS AND COMPRESSORS

A. **GENERAL**.......... **9-**2

B. **PRINCIPLES OF DESIGN AND CONSTRUCTION**.......... **9-**2

C. **MATERIALS, MANUFACTURE AND CALCULATIONS**.......... **9-**5

D. **OPERATIONAL MEDIA**.......... **9-**5

A. General

1. The following Rules apply to all piping systems, including valves, fittings, hose assemblies pumps and compressors, which are needed to operate the submersible. In addition, the **TL** Rules Chapter 4 - Machinery, Section 16 are to be observed, wherever applicable.

The technical requirements for hose lines and umbilicals are defined in Annex E.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, F. and G.

B. Principles of Design and Construction

1. Pipes, valves, fittings, hoses and pumps

1.1 All pipes, valves, fittings and pumps are to be dimensioned for a design pressure PR equal to the maximum allowable working pressure PB.

All pipes, valves, fittings and pumps which can be loaded with the diving pressure are to be designed additionally for 1,1 times the collapse diving pressure **CDP** (according to the load case from outside or inside).

1.2 Pipes which are led through the pressure hull wall are to be fitted with two shut-off devices, one of which is to be located immediately at the hull wall.

1.3 Gas pipes and electric cable conduits are to be routed separately wherever possible. Piping which may be susceptible to mechanical damage shall be adequately protected.

Piping passing through spaces inaccessible for maintenance shall consist of one piece.

1.4 Shut-off devices shall conform to a recognized standard. Valves and fittings with screw-down covers or spindles are to be safeguarded against unintentional unscrewing of the cover.

1.5 Manual shut-off devices are to be closed by turning in the clockwise direction.

1.6 The open and closed positions of all sea valves and essential shut-off valves are to be clearly indicated. If this is not practicable, equivalent procedures may be accepted.

1.7 All valves acting as sea connections are to be so designed that the tapered plug opens against the external pressure. Taper cocks shall not be used.

1.8 For the design of hoses is to be observed:

– Each hose is to be designed for the burst pressure, the minimum burst pressure is for liquids 4 times, for gases 5 times the maximum allowable working pressure.

– Hoses of umbilicals are to be computed for an external design pressure according to Annex E, B.

2. Bilge, compensating and trimming equipment

2.1 Generally submersibles are to be equipped with a bilge system capable of freeing all the spaces inside the vehicle from water due to condensation and leakage.

2.2 To prevent water from penetrating inside the vehicle through the bilge system, two non-return valves are to be mounted in front of the freeing connections. One of these non-return valves is to be placed in the pipe in front of each suction.

2.3 Where the bilge, compensating and trimming systems are interconnected, the connecting pipes are to be fitted with valves in such a way that seawater is reliably prevented from penetrating inside the vehicle through the bilge system even in the event of faulty switching of the valves or when the valves are in intermediate positions.

2.4 Bilge pumps are to be of the self-priming type.

2.5 The bilge system shall be provided with at least one standby pump. In case of interconnection of bilge, compensating and trimming systems the standby pump shall be able to serve all systems.

2.6 Where diving tanks are freed only by pumps, the standby pump is to be connected to the emergency power supply.

3. Compressed air systems

3.1 Where air is used to blow diving, compensating and trimming tanks, the supply of air carried on board shall be sufficient according to the purpose of the mission, to blow the diving tanks at the surface at least 4 times resp. at nominal diving depth **NDD** 1,5 times and to blow the compensating tanks at least 3 times completely at the nominal diving depth **NDD**. In normal operation, the compressed air receivers providing this supply may not be used for other purposes. In special cases deviation of this rule may be possible after agreement with **TL**.

3.2 If air receivers are not changed, a compressor respectively a transfer system shall be provided for charging the compressed air receivers.

3.3 The compressed air supply is to be carried in at least 2 separate banks of receivers with the same total volume.

3.4 The compressed air systems are to be fitted with valves in such a way that no unintentional pressure equalization can occur between different systems.

3.5 Where pressure-reducing valves are fitted, these are to be redundant. In single cases provision can be made for bypassing with manual control. In addition, a safety valve is to be fitted on the low-pressure side of the pressure-reducing valve or an equal safety device is to be provided.

3.6 Compressed air systems are to be equipped with a sufficient number of pressure indicators.

3.7 Compressed air systems which come into connection with seawater are to be designed adequately and to be separated from other systems. In addition measures are to be taken which as far as possible rule out the penetration of seawater into the compressed air system.

4. Hydraulic systems

4.1 Wherever necessary, the possibility of a pressure rise due to the penetration of seawater into the system is to be observed.

To protect the hydraulic system from overpressurization, a closed circuit safety valve shall be fitted and the discharged oil shall be returned into the system.

4.2 Hydraulic systems essential to the safety of the vehicle are to be equipped with at least one power driven pump and one hand-operated emergency pump. Independent submersibles are to be equipped with two power-driven pumps.

4.3 In individual cases, hydraulic systems not designed for continuous operation may also be equipped with hand-operated pumps.

4.4 All valves and fittings, including hydraulic accumulators, which are fitted in submersibles are to be designed in accordance with 1.1. Valves and fittings are to be placed in easily accessible positions.

4.5 Hydraulic systems are to be fitted with filters to keep hydraulic fluid clean. In addition, provision is to be made for venting and dewatering the system. Hydraulic fluid tanks are to be fitted with level indicators. Wherever necessary, hydraulic systems are to be equipped with means of cooling the hydraulic fluid.

4.6 Hydraulic lines should not be routed close to oxygen systems.

4.7 When selecting the hydraulic oil, allowance is to be made not only for the service conditions but also for the temperatures occurring during the commissioning or repair of the submersible, compare C.3.

4.8 Hydraulic systems are to be equipped with all the indicating devices necessary for the functioning of the system.

5. Oxygen systems

For oxygen systems the following special requirements are to be considered:

5.1 Pipelines for mixed gases containing more than 25 % oxygen are to be treated as pure oxygen lines.

5.2 All components and materials included in the system are to be suitable for oxygen in relation to their type and application and are to be carefully cleaned and degreased before putting into operation.

5.3 Manometers for oxygen and/or Nitrox are to be marked as free of oil and grease.

5.4 In piping systems containing oxygen only spindle valves are permissible. As emergency shut-off quick-closing valves, like e.g. ball valves, may be provided at a suitable location, if these are adequately marked and secured against unintentional activation.

5.5 Wherever possible, the pressure in oxygen lines is to be reduced at the gas storage facility to a pressure which is still compatible with an adequate gas supply to the diving system.

5.6 Oxygen pipes are to be routed separately from to oil pipes. Pipelines carrying oxygen under high pressureshall not be routed through accommodation spaces, engine rooms or similar compartments.

5.7 For oxygen lines with operating pressures above 40 bar high-alloyed Cr-Ni-steels with a content of Cr and Ni of together at least 22 % or Cr-Si-steels with a Cr content of at least 22 % are to be used.

5.8 Connection pieces for oxygen are to be de- signed to avoid burnout or are to be so arranged resp. to be protected that the personnel cannot be injured in case of burnout.

5.9 Spindle valves for oxygen are to be so designed for nominal diameters above 15 mm and operating pressures of more than 40 bar, that the spindle gear is outside the gas space.

5.10 Sealing materials which contain flammable elements and which come into contact with gases under pressure and oxygen influence, may only be approved for connection parts if their suitability for pressures, temperature and type of mounting is proven.

5.11 For valves, fittings and connections for oxygen only lubricants are permissible, which are approved for the operating conditions.

5.12 Hoses are to be suitable for oxygen.

5.13 Concerning the requirements for oxygen plants in life support systems see Section 13, C.2.1.

C. Materials, Manufacture and Calculations

With regard to materials, manufacture and calculations are valid for:

1. Pipes, valves, fittings and pumps

TL Rules Chapter 4 - Machinery, Section 16. All pipes which are passing the wall of the pressure hull shall be at least adequate to pipe class I.

2. Compressors

TL Rules Chapter 4 - Machinery, Section 2.

3. Hydraulic systems

TL Rules Chapter 4 - Machinery, Section 10.

D. Operational Media

1. Media such as hydraulic fluids, lubricants, etc. are to be selected in accordance with the proposed ambient conditions. They shall not tend to congeal or evaporate over the whole temperature range.

2. Hydraulic fluids, lubricants, etc. are to be so selected that water penetration or intermixture with seawater does not seriously impair the serviceability of the submersible.

3. Operational media shall not contain toxic ingredients which are liable to be hazardous to health through skin contact or when given off in fumes.

4. Operational media shall not be corrosive or attack other operating equipment (e.g. seals, hose lines, etc.).

SECTION 10

PROPULSION AND MANOEUVRING EQUIPMENT

A. GENERAL.......... **10-**2
B. PRINCIPLES OF DESIGN AND CONSTRUCTION.......... **10-**2

A. General

1. The following Rules apply to all equipment for the propulsion and dynamic positioning of submersibles and to all steering gears, including dynamic depth control. In addition, propulsion units and steering gears are subject to the **TL** Rules Chapter 4 - Machinery, vertical and horizontal rudders to the **TL** Rules Chapter 1 - Hull, Section 18.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, F. and G.

B. Principles of Design and Construction

1. Propulsion equipment

1.1 With regard to their type, number, size and arrangement, propulsion units are to be designed in accordance with the intended purpose and type of the mission of the submersible.

1.2 Externally mounted propulsion units are either to be designed for 1,1 times the collapse diving pressure **CDP** of the submersible or they are to be pressure-equalized.

1.3 Propulsion engines for submersibles are to be designed for intermittent and continuous service.

1.4 When travelling on the surface, the air supply to internal combustion engines shall pass through an air mast. For the requirements to be met by the air mast, see Section 13, C. as well as Section 6, C. Exhaust lines are to be led out through the pressure hull via a double, pressure-tight shut-off device.

The requirements to be met by closed-circuit propulsion systems are to be agreed with **TL** in each individual case.

For propulsion systems, e.g. internal combustion engines, it has to be secured at any time that no gases of the combustion process get into the atmosphere of the submersible.

1.5 Electric propulsion motors are to be designed in accordance with the requirements stated in Section 11.

1.6 If the propulsion engine is located inside the pressure hull, the thrust block should also be located in the same space.

1.7 Concerning shaft penetrations through pressure hull walls see Section 5, C.6.3.

1.8 Where necessary, propellers are to be shielded to avoid endangering divers and to prevent fouling of the submersible.

1.9 Devices for controlling the engine speed and/or the direction of rotation are to be so designed that the propulsion engine can be stopped should they fail. The propulsion engines of independent submersibles shall also be capable of manual control.

1.10 The propulsion equipment is to be fitted with a sufficient number of indicators and alarms to guarantee safe operation.

1.11 Because of the restricted space conditions in a submersible an optimized arrangement of the devices has to be observed to guarantee the minimum required accessibility. It has to be aimed at as possible that all devices can be mounted and dismounted via the existing hatches without opening of the pressure hull.

2. Manoeuvring equipment

2.1 Submersibles are to be equipped with suitable devices to ensure that the vehicle possesses the necessary manoeuvrability both on the surface and when submerged.

Especially propeller thrust for sternway has to be provided, which enables an effective braking of the vehicle.

2.2 Horizontal and vertical rudders are to be designed to withstand the maximum loads generated by the pitching motions of the submersible and the wash of the sea when surfaced and by the steering forces experienced when submerged. The effective stress in the rudder stock shall not exceed 0,5 times the yield stress.

2.3 Independent submersibles are to be equipped with at least one main and one auxiliary steering gear. With the vehicle travelling at full speed, the main steering gear shall be capable of putting the side rudder from 35° on one side to 30° on the other within 28 seconds.

2.4 Horizontal rudders are to be so designed, that for sufficient incoming flow the buoyancy neutral submersible is assisted concerning positive and negative buoyancy.

2.5 If horizontal rudders are definitely necessary for a submersible, those rudder systems are to be equipped with an alternative power supply. It shall be possible to switch from the main to the alternative power supply from the control stand.

2.6 The slewing mechanisms of propulsion units which are also used for manoeuvring are subject to the same requirements as rudders.

2.7 The main and emergency control stands of independent submersibles are to be fitted with indicators showing the positions of vertical and horizontal rudders. All other submersibles are to be equipped with at least one position indicator each for the vertical and horizontal rudders. In addition, suitable indicators are to be fitted which signal any malfunction or failure of the steering gear.

3. Dynamic positioning

Dynamic positioning may be necessary for certain operating duties, whereby for non-autonomous submersibles a combined action with the support ship may be required, compare Section 17, C.4.

3.1 General

3.1.1 Dynamic positioning means that a vehicle keeps automatically its position at the water surface or in the underwater space (within the accuracy of the system defined for the mission duty) or that it moves on a predefined track under consideration of the depth, using solely the effect of propulsors.

3.1.2 Systems for dynamic positioning have to include the following subsystems:

– As far as required for safe operation, redundant source of energy with switchgear and energy distribution

– A number of drives/propulsors with motor, if applicable gear and propeller as well as slewing gear. The controllability of the positioning systems shall be adequate to the functional specification of the submersible.

– Suitable sensors for determination of the location/position

– Control system including a computer system with software, sensor system, monitoring display at the control stand and reference system for the position

– Further details concerning the requirements for such systems are defined in the **TL** Rules Chapter 22 – Dynamic Positioning Systems.

3.2 Submersible

For submersibles the use of dynamic positioning and the required equipment for this duty has to be agreed with **TL** case by case.

SECTION 11

ELECTRICAL EQUIPMENT

A.	**GENERAL**	**11-**2
B.	**DESIGN PRINCIPLES**	**11-**2
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A. General

1. The following Rules define the specialities for all electrical equipment on board of submersibles and have priority against the **TL** Rules Chapter 5 – Electrical Installation which are to be applied for further detailed problems. Where appropriate, these Rules may be applied to equipment for the launching and recovery of submersibles. In submersibles with a diver's lockout, the electrical equipment in the area of the diver's lockout is also required to comply with the provisions of the Chapter 52 – Diving Systems, Section 2, H.

2. The documents to be submitted to **TL** for approval are listed in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, G. and H.

B. Design Principles

1. General principles

1.1 All electrical systems and equipment are to be constructed and installed in such a way that they are serviceable and perform satisfactorily under the design conditions specified for the submersible to minimize for crew and passengers the risk of fire, explosion, electric shock and emissions of toxic gases. The operating parameters of electrical equipment are to conform to the requirements stated in the **TL** Rules Chapter 5 – Electrical Installation, Section 1, F.

1.2 Besides the essential consumers listed in the **TL** Rules Chapter 5 – Electrical Installation, Section 1, B. the following items of electrical equipment on submersibles also count as essential consumers:

- Battery charging equipment for autonomous and independent submersibles with own charging device, e.g. generator
- Battery room ventilators
- Acid circulation and cooling system
- H_2 measuring device
- Essential equipment for monitoring and treating breathing air
- Bilge and emergency bilge system
- Electrical installations for diving and buoyancy tanks, e.g. magnetic valves

2. Materials and insulation

2.1 The materials used in the construction of electrical machines, cables and apparatus are to be resistant to moist and salty sea air, seawater and oil vapours. They shall not be hygroscopic and have to be flame-retardant and self-extinguishing.

2.2 Materials with high tracking resistance are to be used for the supports of live parts.

2.3 The creepage and clearance distances are to be dimensioned as appropriate for the appliance in accordance with IEC. Generator circuit-breakers, pressure hull wall penetrations, under water plug connectors and appliances directly connected to the busbars are to be designed for the next higher nominal insulation rating.

2.4 Materials and insulations for electrical equipment used in water are to be agreed with **TL** in each single case.

3. Supply systems

3.1 Approved supply systems are:

– Direct current and single-phase alternating current:

2 conductors insulated from the vehicle hull

– Three-phase alternating current:

3 conductors insulated from the vehicle hull

3.2 Networks with an earthed neutral are not permitted in submersibles.

4. Voltages and frequencies

The use of standard voltages and frequencies is recommended. The maximum permissible voltages are the following, but deviating voltages for propulsion drives may be agreed with **TL**:

500 V:

– For permanently installed power systems

– For power systems connected by socket outlets

– For heating and galley equipment

250 V:

– For lighting systems and sockets for direct current and single-phase alternating current

– Mobile appliances with protective insulation and/or protective isolating transformers

– Machinery control and monitoring systems, vehicle control systems and vehicle safety systems

50 V:

– For mobile appliances used in confined space conditions and in damp spaces, where appropriate using protective isolating transformers

5. Protective measures

5.1 All electrical equipment is to be protected in accordance with the **TL** Rules Chapter 5 – Electrical Installation, Section 1 unless otherwise stated in the following.

5.2 The minimum classes of protection stated in Table 11.1 are to be applied in submersibles. The class of protection is to be maintained for the equipment as installed, even when in operation (heeling position). In this context, the provision of shielding at the point of installation is deemed to be a protective measure.

5.3 Protective conductors

For the use of protective conductors is to be observed:

a) The protective conductors shall have the form of an additional cable, additional conductor or additional core in the connecting cable. The use of cable shields or sheaths as protective conductors has to be checked in every single case and is to be approved by **TL**.

b) The cross-section of the protective conductor is to be at least half that of the principal conductors/outer conductors. However, with cross-sections up to 16 mm^2, its cross-section shall be equal to that of the principal conductors/outer conductors. The minimum cross-section of separately laid protective conductors is 4 mm². The cross-section of the protective conductor shall at least comply with the factors shown in Table 11.2.

In the vehicle's propulsion network, the dimensional design of the protective conductors is to be based on the maximum possible short-circuit currents of the equipment concerned, the maximum break times of the relevant protective elements and a maximum temperature rise of the protective conductor of 90 °C.

c) Machines and appliances mounted on insulated vibration dampers are to be earthed with mobile cables, conductors or braided copper leads.

d) The protective conductor is to be connected to the hull of the support ship in a position where it can easily be checked.

e) The connections of the protective conductors to the submersible are to be installed at locations which are easily to check.

Table 11.1 Minimum degree of protection against foreign bodies and water (in conformity with IEC 60529)

Type of equipment / Where installed	Safety and measuring equipment	Generators, motors, tranformers	Switchgear, eletronic units, recording equipment	Telecommuni-cations equipment, input units, signalling equipment, switches, Sockets, junction boxes, Actuators	Heating equipment, heaters, cooking equipment	Light fittings
Control rooms and accommodation	–	IP 23	IP 23	IP 23	IP 44	IP 23
Machinery spaces and sanitary spaces	IP 55	IP 44	IP 44	IP 55	IP 44	IP 44
Pipe tunnels, bilges	IP 56	–	–	IP 56	–	IP 56
Outside pressure hull	Watertightness under pressure in accordance with the submersible’s design criteria					

Table 11.2 Cross-sections for protective conductors

Cross-section of outer conductor	Minimum cross-section of earthing conductor	
	in insulated cables [mm^2]	Separately laid [mm^2]
0,5 to 4	equal to cross-section of outer conductor	4
> 4 to 16	equal to cross-section of outer conductor	equal to cross-section of outer conductor
> 16 to 35	16	16
> 35 to < 120	equal to half the cross-section of the outer conductor	equal to half the cross-section of the outer conductor
≥ 120	70	70

f) At the superstructure resp. at the hull of the vehicle a possibility for connection in the form of a connecting plate with stud bolt, preferably M 12, to which protective conductors can be connected without the use of tools is to be provided at an easily accessible position.

This connection shall serve as compensation of potential between the recovered submersible and the support ship.

C. Power Supply

1. Power demand

1.1 Proof of adequate rating of the units for generation and storage of electrical power has to be furnished by a power balance.

1.2 The power demand is to be determined for the following operating conditions:

– Normal operation (surface/diving operation)

– Emergency operation.

1.3 In the power balance all consumers installed, including their power inputs, are to be considered according to the general operation conditions.

2. Equipment for power supply

All electrical equipment essential for the safety of the submersible and its crew is to be connected to an independent main and emergency power supply system.

2.1 Main electrical power supply

2.1.1 Each submersible is to be equipped with a main power source of sufficient capacity, such as to ensure:

– That normal operation and the conditions of life as intended to prevail on board can be maintained, without having to take recourse to the emergency power supply

– A sufficient supply of electric power for the envisaged periods of service is to be guaranteed in operation independent from outside air supply as well as in operation depending on outside air supply

2.1.2 The main power source has to consist of at least two mutually independent, redundant power generating systems, such as

– Generator sets,

– Batteries,

– Fuel cell systems.

Exceptions may be permitted for vehicles with restricted range of service and/or accompanied by support ships.

2.1.3 In the case of non-autonomous submersibles the main power supply may be followed directly from the switchboard of the diving support ship resp. from the main power source of the diving system.

2.1.4 If started electrically, generating sets are to be equipped with a starting device as per **TL** Rules Chapter 5 – Electrical Installation, Section 3.

2.2 Emergency power supply

2.2.1 An independent emergency power source is to be provided in all submersibles.

The location and electrical connection of the emergency power supply shall be in a form that in the event of failure or damage of the main power supply because of fire or other influences, the function of the emergency power supply is secured.

2.2.2 The emergency power source is to be capable of supplying the submersible with the energy required in emergencies.

All electrical equipment required for surfacing the vessel are to be adequately supplied with power; apart from this, simultaneous supply of electrical power to at least the equipment listed below is to be ensured according to an emergency power balance:

– Emergency lighting inside the vehicle

– Emergency communications equipment

– Equipment for maintaining a breathable atmosphere

– Essential monitoring and alarm equipment, e.g. leakage monitoring system, fire alarm system, breathing air monitoring, H_2 monitoring

– Locating equipment, signal lamps

3. Charging and shore connection

3.1 Where socket connections are provided for charging and shore connection with a nominal current more than 16 A these are to be blocked such as to preclude both insertion and withdrawal of the plug, with the contact sleeves of the sockets being alive.

3.2 On the main switchboard an indicator is to be fitted showing whether the shore connection line is alive.

4. Storage batteries and battery chargers

4.1 Storage batteries, general

4.1.1 Storage batteries are to be rated such as to be capable of supplying the consumers during the period specified in accordance with the power balance, when charged to 80 % of their rated capacity.

4.1.2 At the end of the supply period the voltage in the storage battery resp. in the consumers shall at least reach the values quoted in the **TL** Rules Chapter 5 – Electrical Installation, Section 1, F. and Section 3, C.

4.1.3 Approved storage batteries are lead-acid storage batteries with diluted sulphuric acid as electrolyte and steel storage batteries with nickel-cadmium cells and diluted potassium hydroxide as electrolyte.

4.1.4 Further types of batteries may be approved under consideration and test of the following points:

– Resistance to short circuits

– Fuse elements at occurring short circuits

– Electrical monitoring elements

– Fire risk/fire behaviour including consequences on adjacent cells or components

– Special requirements for the installation location

– Suitability of the used belonging electrical components

– Integration in the electrical plant including switch gears

– Charging devices and automation system for charging

4.1.5 Storage batteries are to be designed such as to retain their undisturbed function at inclinations of up to 22,5° and such that for inclinations of up to 45° electrolyte will not leak. Cells without covers are not admissible.

4.1.6 The casing is to be resistant to electrolytes, mineral oils and cleaning agents, as well as to corrosion due to saline mist. Glass and readily flammable materials are not approved as materials for casings.

4.1.7 In the case of storage batteries containing liquid electrolyte it shall be possible to check the electrolyte level. The maximum admissible electrolyte level is to be marked.

4.1.8 Lead and alkaline storage batteries may not be accommodated in the same space or be placed in direct proximity to each other.

4.1.9 Where the installed battery capacity is 1000 Ah or more, the battery is to be divided into smaller battery units so that restricted operation of the submersible is still possible in the event of a fault.

4.1.10 It shall be possible to bridge damaged cells with measures on board if they are located within the pressure hull. The use of rigid interconnection links between batteries shall be avoided.

4.1.11 The weight of the biggest transportable unit shall not exceed 100 kg.

4.1.12 The rating data of the storage batteries are to be indicated on rating plates.

Storage batteries are to be serviced and operated in accordance with manufacturers' instructions.

4.1.13 Storage batteries providing a power source for electric propeller drives and/or the vehicle's power network shall be accommodated in special battery spaces or containers. It is necessary to ensure that the storage batteries are accessible for cell replacement, repairs and maintenance.

4.1.14 Measures are to be taken to ensure that neither the crew nor the operational equipment can be endangered by emissions of electrolyte fumes.

4.1.15 A sign is to be mounted at the entrance of battery spaces pointing out that only insulated tools are to be used inside and conductive objects like keys, ballpoint pens, watches with conductive watch straps have to be taken off.

Explosion hazard shall be pointed out.

4.1.16 Storage batteries are to be installed in such a way that mechanical damage is as far as possible excluded. Safe operation under the environmental conditions stated in Section 2, D. is to be ensured and the discharge of electrolyte is to be prevented.

Suitable measures, e.g. provision of plastic trays or flexible rubber bags, are to be taken to prevent electrolyte from entering the battery space bilges in the event of mechanical damage to individual battery cells.

4.2 Special requirements for lead batteries

4.2.1 Battery spaces shall be arranged and ventilated to prevent the accumulation of ignitable gas mixtures.

4.2.2 The quantity of air to be aspirated and exhausted during charging shall be so calculated, that the lower explosion limit for a hydrogen air mixture will not be exceeded. H_2-monitors permanently mounted at suitable points have to measure the gas concentration in the battery space, the exhaust system and, where necessary, in other spaces within the vehicle.

If the H_2 concentration reaches and exceeds a level equivalent to 35 % of the lower explosion limit (LEL), this shall automatically release a visual and audible alarm at a central monitoring station. Equipment for monitoring the H_2-concentration shall be type approved.

4.2.3 Battery spaces shall contain no other electrical appliances apart from the storage batteries themselves. Lights, fuses (single voltage measuring device) and measuring devices for H_2 concentration may be installed if they are in accordance with the requirements for an atmosphere containing H_2 (see recommendation IEC 60079).

4.3 Battery chargers

4.3.1 Battery chargers are to be rated such that the maximum admissible charging currents cannot be exceeded.

4.3.2 The power demand of the consumers is to be taken into account when selecting the battery chargers.

4.3.3 The battery chargers are to be rated such that the tolerances of the limited characteristics and constant characteristics respectively are adhered to irrespective of external disturbance effects.

4.3.4 Battery chargers have to cut out automatically in case of:

– Failure of the battery space ventilation (if an ignitable gas mixture may be created)

– Excessive temperature of charging generator/battery charger

– Over temperature of the electrolyte (if a temperature control of the single cells is provided)

4.3.5 For lead batteries is to be considered additionally:

– If during charging simultaneously consumers are fed, the maximum charging voltage shall not exceed 120 % of the rated voltage.

– Preferably chargers with IU or IUI resp. IUW characteristics shall be employed.

– Charging devices have to cut off automatically, if the H_2 concentration is too high, e.g. 60 % LEL.

D. Power Distribution

1. Distribution and switchgear

1.1 Electrical distribution systems are to be so designed that a fault or failure in one circuit cannot impair the operation of other circuits or the power supply.

1.2 In normal operation, the emergency power distribution system may be supplied via a transfer line from the main power distribution system.

1.3 Switchboards are to be so placed as to minimize the length of the cables from the batteries to the switchboard. These cables are to be laid as far as their respective circuit breakers in separate cable runs and are to be protected against mechanical damage.

1.4 Effective measures are to be taken to prevent the occurrence of vagabond voltages inside switchgear. Circuits at protective low voltage are not to be routed with circuits at higher voltage in a joint conductor bundle or cable duct.

Terminals for different voltage levels are to be arranged separately and are to be clearly identified.

1.5 Switches and fuses for different voltage systems are to be spatially separated inside the switchboard.

2. Switching and protective devices

2.1 Each circuit is to be protected against over-load and short-circuit.

2.2 All consumer circuits are to be fitted with switches. The switching action shall be on all poles.

2.3 Fuses may be used for overload protection on submersibles up to a rated current of 63 A.

2.4 A continuously operating insulation monitoring system is to be installed.

An alarm is to be tripped at the control stand if the insulation value drops below a preset limit (in general: 50 Ω for 1 V).

3. Enclosures for electrical equipment

3.1 The enclosures of electrical equipment installed outside the pressure hull or operated in water are to be approved by **TL**.

3.2 Pressure tight enclosures which are arranged outside the pressure hull and are exposed to diving pressure are to be designed according to Section 4, B.3. and are to be tested according to Section 2, G.

Where the strength of enclosures and electrical components situated outside of the pressure hull cannot sufficiently be proven by computation, a pressure test with a layout pressure equal to 1,1 x collapse diving pressure **CDP** has to be performed as a type test.

4. Earthing

4.1 The earthing of electrical systems and equipment on autonomous and independent submersibles is subject to the requirements stated in Chapter 5 – Electrical Installation.

4.2 Earthing arrangements on non-autonomous submersibles are subject to the requirements of Chapter 52 – Diving Systems, Section 2, H.

5. Cables and lines

5.1 Cables and lines for submersibles are to be suitable for the proposed application. Their use is subject to approval by **TL**.

5.2 The selection, dimensioning and installation of cables and lines shall comply with the **TL** Rules Chapter 5 – Electrical Installation, Section 12 and Section 20, F.

5.3 Only halogen-free materials shall be used as insulating sleeves, protective coverings, sheaths and fillers of cables used in submersibles.

5.4 Underwater cables and lines are to be radially watertight and designed for an external hydrostatic pressure equal to 1,1 times the collapse diving pressure **CDP**.

For further requirements concerning design and testing see Annex E.

6. Umbilicals/supply lines

Umbilicals as a connection between support ship and submersible may contain control and communication cables as well power supply lines.

All aspects of design and testing are defined in Annex E.

7. Busbars bare or painted

7.1 General

7.1.1 Busbars shall be made of copper, aluminium with copper sheathing or corrosion resistant aluminium. Further busbar materials are to be agreed with **TL** and have to be checked for the load case.

7.1.2 Main collecting and field distribution bars made of copper are to be designed for the permitted current load according to the **TL** Rules Chapter 5 – Electrical Installation.

The loading of busbars is to be designed according to DIN 43671. On continuous load, the busbar temperature shall not exceed 100 °C.

7.1.3 Parallel-run busbars of the same phase are to be installed not less than one bar thickness apart. Earth conductors, neutral conductors of three-phase mains and equalization lines between compound-wound generators shall have at least the half cross section of the phase conductor.

7.2 Connections to equipment

Cross-sections of connection bars and wires to equipment shall be of such size as to avoid thermal overloading of the equipment at rated load as well as in the event of a short circuit

7.3 Busbar carriers

Busbars are to be mounted in such a way that they withstand the dynamic loads caused by short-circuit currents and maintain the required clearance and creepage distances relative to other voltage carrying or earthed components.

7.4 Clearance and creepage distances

Clearance and creepage distances are to be designed for the specific equipment according to IEC.

7.4.1 Where busbars are used for connecting equipment, only sealed or insulated systems may be employed.

Exceptions to this rule are switchboards and enclosed electrical service spaces.

7.4.2 The busbar system is to be so constructed that neither the connected neighbouring equipment nor the busbar system itself can be damaged by movement of the busbars, temperature rises or external mechanical influences.

It is recommended that expansion links are to be fitted.

Prior to the installation of busbar systems, proof is required of mechanical strength under short-circuit conditions considering the effects of the electrical heating produced by the short-circuit current.

8. Electrical penetrations in pressure hull walls, underwater plug connections

8.1 Lay out

For the lay out the following is to be considered:

– The lay out has to be done for 1,1 times the collapse diving pressure **CDP**.

– Pressure hull penetrations are to be gas and watertight. Their tightness shall be guaranteed even should the connected cables be damaged or shorn off.

– They are not to be used for the passage of other systems.

– The positive and the negative conductors from a power source are not to pass through the same penetrating device at the pressure hull wall.

– Electrical conductors within the penetrating device shall be of solid material

8.2 Type approvals

Electrical pressure hull penetrations and underwater plug connections are to be type approved.

Type-testing is performed, on application, at the manufacturer's works and comprises at least the following individual tests:

– Hydraulic pressure test, in which the test pressure shall be equal to twice the nominal pressure PN. The test is to be conducted in accordance with the test pressure/time curve shown in Fig. 11.1, the changes in pressure are to be applied as quickly as possible.

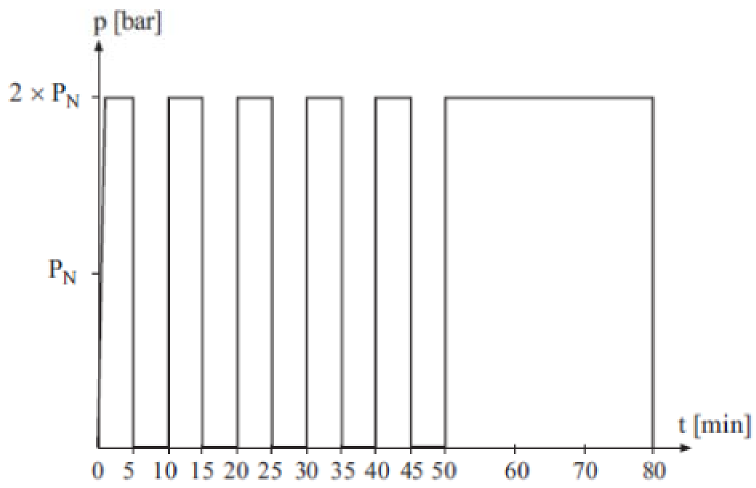

Fig. 11.1 Test pressure/time curve for type approval

– Gas tightness test with shorn, open cable ends. This test may be performed under air or alternatively under Helium. The test pressure is to be 2 times the nominal pressure of the component PN for air and 1,5 times the nominal pressure of the component PN for helium. The leakage rate is to be specified by the manufacturer and to be approved by **TL**.

In all pressure and tightness tests on pressure hull wall penetrations, the pressure is to be applied in each case from the pressure side of the wall penetration.

During the pressure and tightness test, the penetration is to be loaded with the rated current in all conductors.

– High voltage test at an AC voltage of 1000 V plus twice the rated voltage. This test is performed at the rated frequency and is to be carried out for 1 minute in each case between all the conductors mutually and between the conductors and the casing. The test is performed in the disconnected state. The sealing of the connector shells and the like is permitted to the degree stipulated by the manufacturer in the relevant data sheet.

– Measurement of insulation resistance:

  The minimum value of the insulation resistance between the conductors mutually and between the conductors and the casing shall be 5 MOhm for the type test, for periodic Classification surveys the minimum value shall be 2 MOhm.

  The insulation resistance is to be measured with an instrument using 500 V DC.

  With wet plug connections, the minimum insulation resistance is also to be measured after the connection has been made once in saltwater.

– Visual check against manufacturer's documentation.

8.3 Individual test after the manufacturing (Routine Test)

Each manufactured electrical pressure hull wall penetration and each plug connection are to be subjected to routine inspection after manufacturing by the manufacturer.

This inspection comprises the following tests:

– Hydraulic pressure test at the manufacturer in accordance with Fig. 11.2 at 1,5 times the nominal pressure of the component PN and at the overall test with test diving pressure **TDP**, if applicable.

– High-voltage test

– Measurement of insulation resistance

A Manufacturer Inspection Certificate is to be issued covering the inspection.

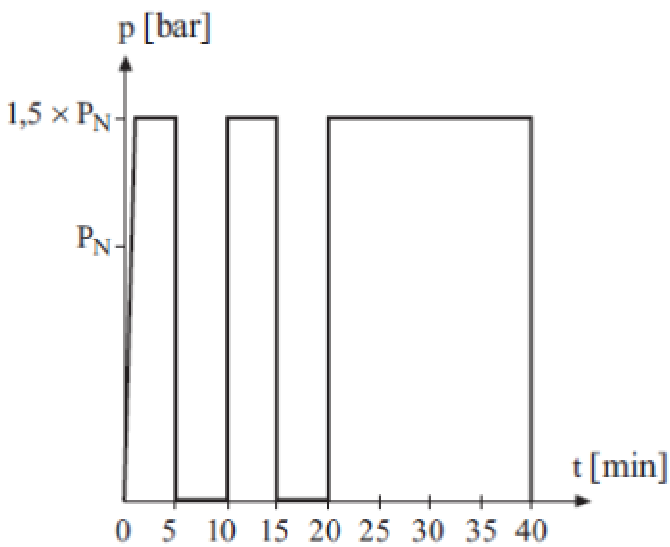

Fig. 11.2 Test pressure/time curve for routine tests

E. Electrical Equipment

1. Electrical machines

1.1 Electrical machines shall conform to the **TL** Rules Chapter 5 – Electrical Installation, Section 20, A.

1.2 Generators and all electric propeller motors should to be equipped with a standstill heating system.

1.3 Machines for electric propeller drives rated at more than 100 kW are to be equipped with monitoring devices in accordance with the **TL** Rules Chapter 5 – Electrical Installation, Section 13.

If direct current motors are used, energizing current circuits where the failure may endanger the operation are only to be protected against short circuit.

1.4 For the windings of electrical machines in submersibles at least isolation class F is to be provided.

1.5 An automatic limitation of the performance of the driving motors has to secure that the board main is not overloaded.

The reverse power for reversing, reduction and shut-off is to be considered and shall be limited to permissible maximum values.

1.6 In addition to the tests stipulated in the **TL** Rules Chapter 5 – Electrical Installation, Section 20, A.4 the following electrical machines are to be tested in the presence of a **TL** Surveyor:

– Generators and motors for electric propeller drives

– Motors for steering gear drives and windlasses

– All other motors driving machines and equipment necessary to the safety and manoeuvrability of the submersible

2. Interior lighting

2.1 Service and work spaces, safety and control stations as well accommodation areas are to be equipped with normal and emergency lighting. Emergency lights are to be marked as such to facilitate easy identification.

2.2 The lighting is to be so designed and arranged that all important instruments and markings can be read and any necessary operations can be safely performed.

As far as possible the interior lighting shall be arranged glare-free.

2.3 All lighting fixtures shall be so mounted that combustible parts are not ignited by the generated heat, and they themselves are not exposed to damage.

2.4 The emergency lighting is to be independent from the main lighting. This concerns the power generation as well as the distribution and cable network.

The emergency lighting has to be automatically switched on in case of failure of the main lighting. Switches for emergency lighting shall switch-off only partial areas, e.g. in the control stand.

SECTION 12

AUTOMATION, COMMUNICATION, NAVIGATING AND LOCATING EQUIPMENT

A. **GENERAL**.. **12-**2
B. **AUTOMATION EQUIPMENT**. **12-**2
C. **COMMUNICATION EQUIPMENT** **12-**8
D. **NAVIGATING AND LOCATING EQUIPMENT**. **12-**9

A. General

1. The following Rules supplement the **TL** Rules Chapter 5 – Electrical Installation and Chapter 4-1 - Automation and are to be applied to the construction and use of monitoring, open and closed loop control and communications equipment in submersibles as well as to that of wireless, navigating and locating equipment in submersibles built under the survey and in accordance with the Rules of **TL**.

In submersibles with a diver's lockout, for automation, control, monitoring and communications equipment in the area of the diver's lockout the requirements of Chapter 52 – Diving Systems are to be considered.

2. The documents to be submitted to **TL** are listed in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, G. and H.

B. Automation Equipment

1. Design principles

1.1 General principles

1.1.1 All equipment for the automatic monitoring and open and closed loop control of a submersible's operating parameters is to be designed and constructed so that it works properly under the design and environmental conditions specified for the submersible.

1.1.2 Computer-aided operating systems for the submersible are allowed.

Details of the scope and redundancy requirements of these systems are to be agreed with **TL**.

The systems are to be approved by **TL** and type-tested components should be used. Such testing includes both the equipment to be used (hardware) and the corresponding computer programs.

1.1.3 The automation equipment on submersibles is to be constructed in accordance with Chapter 4-1 - Automation. Apart from this, the following is to be observed:

1.1.4 All items of monitoring and open and closed loop control equipment are to be clearly inscribed and marked.

1.1.5 Indicating instruments and synoptic displays are to be designed and inscribed in such a way that they can be read quickly and clearly.

1.1.6 Any fault or failure which may occur in the automation system shall not provoke a critical operating condition.

1.1.7 As far as possible, automation equipment is to be safeguarded against faulty operation.

1.1.8 Automation equipment shall be capable of maintaining the submersible's assigned operating parameters.

1.1.9 Any inadmissible variations in the operating parameters shall actuate an automatic (visual and audible) alarm at the control stand. The same shall also occur in the event of automatic switching operations in the power supply systems or faults in the open and closed loop control and monitoring system. An additional alarm is to be provided for the monitoring of the vehicle atmosphere. Acknowledging of the acoustic alarms is only permissible for this actual failure case. A general suppression of alarms is not allowed.

1.1.10 In addition to electronic open and closed loop control and monitoring equipment, independent safety devices are to be fitted which prevent a fault in one system from provoking an improper response in another system.

1.1.11 Automatic monitoring and open and closed loop control equipment is to be capable of being switched to manual operation at all times.

1.1.12 The response values of automation equipment have to be so coordinated with each other that, when a threshold is reached, a warning is initiated, followed, after a certain warning period or if the process variable continues to change at a preset speed, by the actuation of safety devices. The limit value for the warning is to be defined in a way that for reaching this limit value still no actual endangerment occurs.

1.1.13 The integral operation of automation systems is to be designed to take account of the lags and time constants of the units and elements making up the system (e.g. by allowing for the length and cross-section of piping systems and the response time of gas analyzers).

1.1.14 The criterion for the freedom from interference of electronic systems shall be IEC 60533 (Electromagnetic compatibility of electric and electronic installations in ships).

1.1.15 The functioning of essential indicating lamps has to be checkable during operation

1.2 Construction

1.2.1 Electronic automation systems shall comprise easily replaceable assemblies, preferably of the plug-in type. The construction groups are to be standardized as far as possible. Because of spare parts inventory the number of assembly types is to be kept small.

1.2.2 Plug-in cards are to be clearly marked or coded to prevent inadvertent confusion.

1.2.3 Measures are to be taken to prevent condensation inside electronic units, even when switched off. Shutdown heating is recommended.

1.2.4 Wherever possible, automation equipment shall be capable of operation without forced ventilation. The function of any cooling system used is to be monitored.

1.2.5 Components are to be effectively secured. Any mechanical loading of wires and soldered connections due to vibration or jolting is to be reduced to a minimum.

1.2.6 The construction of systems and units is to be simple and straightforward. Good accessibility is to be ensured to facilitate measurements and repairs.

1.2.7 Input equipment such as limit switches, transducers, transformers and reading-in machines, as well as control elements, fire alarm systems, remote control devices for propulsion systems, engine alarm systems and combined equipment for the recording of measurement data and interferences are to be tested according to 1.5.

1.3 Circuitry

1.3.1 Equipment for monitoring and open and closed loop control systems with a safety function are to be designed on the failsafe principle, i.e. faults due to short-circuit, earthing or circuit breaks shall not be capable of provoking situations hazardous to personnel and/or the system. In this respect, it is to be assumed that faults occur singly.

The failure of one unit, e.g. due to short-circuit, shall not result in damage to other units.

1.3.2 In stored-program control systems, the electrical characteristics of the signal transmitters shall conform to the safety requirements for instruction and control devices. This means principally:

– Activation at H level, i.e. by energization across NO contacts

– Deactivation at L level, i.e. by deenergization across NC contacts

The requirements of 1.3.1 are unaffected.

1.3.3 Instruction and control units for safety functions, e.g. emergency stop buttons, shall be independent of stored-program control systems and shall act directly on the output unit, e.g. the STOP solenoid. They are to be safeguarded against unintended operation.

1.3.4 Stored-program control systems shall be non-reactive and, in case of fault, shall cause no malfunctions in program-independent safety interlocks or stepped safety circuits for fixed subroutines.

1.3.5 Freely accessible potentiometers and other units for equipment trimming or operating point settings are to be capable of being locked in the operating position.

1.3.6 Interfaces with mechanical switchgear are to be so designed that the operation of the system is not adversely affected by contact chatter.

1.3.7 Printed conductors forming part of circuits extending outside the enclosure containing the printed circuit boards are to be conditionally short-circuit proof, i.e. in the event of an extreme short-circuit only the protective devices provided may respond without destroying the printed conductors.

1.3.8 The equipment shall not be damaged by brief voltage surges in the vehicle's power supply which may be caused by switching operations. If not more detailed otherwise, at the feeding of non-autonomous submersibles interference voltages and quick transient interference factors according to IEC 61000 4-5, severity level 3 are to be considered.

Where systems are supplied by static converters, it may be necessary to make allowance for periodic voltage pulses. The size of the pulse amplitude depends on the converter type and is to be investigated in each case.

An overvoltage protection adjusted to the system is recommended.

1.4 Power supply

Regarding the power supply to control, monitoring and ship safety equipment the requirements as per Chapter 5 – Electrical Installation, Section 9 are to be observed.

1.4.1 Power supply units for automation equipment shall at least have short circuit and overload protection, if no unsafe operation conditions of the vehicle may be created.

1.4.2 The energy supply is to be monitored and failure is to be alarmed.

1.4.3 The automation equipment shall be capable of being safely operated in the event of voltage and frequency deviations referred to in Chapter 5 – Electrical Installation, Section 1 of the **TL** Rules.

1.5 Tests

Automation equipment shall be approved by **TL**. Preferably type-approved components are to be used.

The nature and scope of the test will be determined by **TL** in each single case, see also Section 2, F.12.

Type tests are to be in line with the **TL** Rules Regulations for the Performance of the Type Tests.

2. Navigation and manoeuvring

Principally the regulations of the flag state respectively of the competent authorities are to be considered.

2.1 Control stand

2.1.1 For the monitoring and control of the submersible a control stand is to be provided which shall be equipped with indicators displaying all essential information about the vehicle, its internal conditions and the operating states of the auxiliary systems and with all the regulating and control devices needed to operate the submersible including its wireless, TV and communications equipment.

2.1.2 At the control stand grouping and arrangement of the instruments for monitoring, open and closed loop control of the submersible shall conform to the principles of safety technology and ergonomics.

2.1.3 As far as feasible and rational, initiated control functions are to be indicated on the console or switchboards respectively.

2.1.4 No units or equipment liable to impede the monitoring and control of the submersible may be installed in the area of the control stand.

2.2 Control stand equipment

2.2.1 For each of the functions to be performed on the control stand of the submersible the following indicating instruments are to be provided:

2.2.2 Navigation and speed indicators

– Navigational radarscope

– Position indicator system (e.g. GPS)

– Obstruction signalling device (echo depth finder or sonar unit)

– TV camera

– External communication system (VHF)

– Internal communication system

– Gyro compass

– Depth indicators

2 depth indicators which work independently of each other and are not connected to the same pressure hull penetration. The scales of the depth indicators are to extend at least 20 % beyond the nominal diving depth **NDD**. The instruments shall give readings accurate to 1 % at maximum diving depth and shall not be significantly affected by pressure variations. The nominal diving depth **NDD** is to be clearly indicated on the scale.

One depth indicator is sufficient on non-autonomous submersibles attached by a lifting cable.

– Heeling and trim angle indicator

– Speed and distance indicator

– Rudder angle indicators (vertical and horizontal rudders)

– Indicator showing speed and direction of rotation of main driving propeller

– Thrust line indicator for propeller drives

– Navigating and signal lamp monitor

– Level indicators for compensating and trimming tanks

– Position indicator for weights to be shifted, if existing

– Chronometer

2.2.3 Vehicle atmosphere

– Indicators and alarms specified in Section 13 for monitoring the vehicle atmosphere

2.2.4 Electrical equipment

– Generator current and voltage indicators

– Battery current and voltage indicators

– If a capacity indication for the batteries has to be provided will be defined by **TL** in each single case.

– Current consumption indicators of propeller motors and essential electric drives

- Power supply/distribution indicators

- Insulation monitor displays

2.2.5 Safety equipment/indicators

- Machinery alarm systems

- Fire detection and fire alarm system

- Leakage alarm

- General alarm system

- Pressure gauge for all compressed-air receivers

- Pressure gauge for all oxygen storage tanks

- Pressure gauges for hydraulic systems

2.3 Steering and control systems

2.3.1 The control stand of the submersible is to be equipped at least with the following systems:

- Control of pressure, temperature and humidity of the vehicle atmosphere plus the oxygen metering and air renewal rates

- Control of the propulsion plant

- Control of the vertical and horizontal steering gears

- Control of the thrust propeller drives

- Control of blowing of diving and compensating tanks

- Control of trimming and ballast systems

- Control of bilge systems

- Emergency stopping systems

- Control of electricity supply

- control of auxiliary systems, e.g. hydraulic units and similar

2.3.2 Navigation and control functions are, wherever possible and expedient, to be indicated by displays on monitors and/or dead-front circuit diagrams on the control console.

3. Sensors and actuators

All devices for registering the operating conditions of submersibles as well as the belonging actuators are to be approved by **TL** and should be type approved.

4. Data transfer system

4.1 For the application of data cables it has to be guaranteed, that the specified data volume per time unit will be transmitted without disturbances at all operating conditions.

4.2 Navigation and control of the submersible has also to be possible if the data line fails.

4.3 If secondary “data for payloads” shall be transmitted on data lines, the transmission shall be independent from the data lines for the operation of the submersible.

C. Communication Equipment

1. General

1.1 Depending on their type, size and function or range of service, submersibles are to be equipped with various means of internal and external communication.

1.2 For submersibles with a diver's lockout, the means of communication between the diver in the water and the diver in the lockout and that between the diver's lockout and the submersible's control stand shall meet the requirements set out in Chapter 52 – Diving Systems, Section 2, G.

1.3 Antennae and transducers are to be permanently installed and so arranged as to preclude mutual interference.

2. Internal communications equipment

2.1 Submersibles with more than one room are to be equipped with a two-way communications system.

2.2 A telephone link independent of the vehicle's power supply system is to be provided between the control stand and the steering gear compartment and between the control stand and the propelling machinery space.

3. Surface communications

3.1 Autonomous submersibles are to be equipped with at least one two-channel transmitter/ receiver, one of the channels of which has to operate on safety channel 16-VHF, while the other is used as a "working channel" for communication between the submersible and its support ship.

3.2 Independent submersibles are also to be equipped with an additional radiotelephone.

3.3 On non-autonomous submersibles, a telephone link is to be provided between the submersible and the control position on the support ship. The telephone link is to be operated through loudspeakers and shall be permanently switched to "Receive" on the support ship's control console. It has also to be fitted with self-resetting switches for reversing the direction of communication.

4. Underwater communications

4.1 Autonomous submersibles are to be equipped with at least one single-channel side-band underwater telephone (UT) system. The UT system has as a minimum requirement to enable satisfactory communication to be maintained with the support ship when this is at a distance equivalent to twice the nominal diving depth of the submersible.

4.2 Independent submersibles are to be equipped with a two-channel side-band UT system.

4.3 For non-autonomous submersibles 3.3 is valid.

5. Emergency communications equipment

5.1 Independent submersibles are to be equipped with radiotelephones connected to the emergency power supply and capable of both surface and under- water operation. The emergency radiotelephone equipment shall include at least one VHF transmitter/ receiver operating on safety channel 16. The standby UT system should have a minimum range equivalent to twice the nominal diving depth of the submersible.

5.2 On autonomous submersibles, the UT system is to be fed from the emergency power supply and shall also be capable of acting as standby telephone system when the vehicle is on the surface.

5.3 On non-autonomous submersibles a telephone connection independent from the main power supply is to be provided in addition to the main telephone connection.

D. Navigating and Locating Equipment

1. General

1.1 Principally the regulations of the flag state respectively of the competent authorities are to be considered.

1.2 All electrically operated items of navigating and locating equipment necessary to the safety of the submersible and its crew are to be connected to the submersible's emergency power supply. The availability of the equipment for service and its current operating status are to be indicated at the control stand.

1.3 Reference is made to relevant equipment in Sections 6, C.4. and 15, B.6.

2. Lights, signal devices, acoustic signals

2.1 Submersibles are to be equipped with suitable signal systems (e.g. flashing light), which enable a quick detection of the surfaced submersible.

2.2 Independent and autonomous submersibles which are participating on ship/sea traffic are to be equipped with lights, signal devices and acoustic signals according to the International Regulations for Prevention of Collisions at Sea 1972 (**COLREGS 1972**).

3. Position indicators, radio direction finders, position finders

3.1 Submersibles are to be equipped with suitable systems for position finding when travelling at the water surface according to their type of operation and their mission.

3.2 For better visibility of the submersible at the water surface, submersibles should be provided with contrast colour painting or reflection material, applying preferably the colours orange, yellow or red.

SECTION 13

LIFE SUPPORT SYSTEMS

A. **GENERAL**.. .... **13-**2

B. **DESIGN PRINCIPLES**. **13-**2

C. **AIR SUPPLY**.. **13-**3

D. **MONITORING EQUIPMENT**. **13-**5

E. **EMERGENCY THERMAL AND FRIGIDITY PROTECTION**. **13-**5

F. **PRESSURE EQUALIZATION**. **13-**6

G. **WASTE DISPOSAL**. **13-**6

A. General

1. The following Rules apply to all those plant components and parts which are needed to ensure life support and a safe environment for the occupants of a submersible.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, G. and H.

B. Design Principles

1. Survival time

1.1 Manned submersibles are to be fitted with equipment for producing, maintaining and monitoring life support conditions inside the vehicle. The equipment is to be so designed that the necessary conditions can be maintained for the following survival times at least in excess of the maximum intended duty period of submersibles:

– Non-autonomous submersibles 72 h

– Autonomous submersibles 96 h

– Independent submersibles 168 h

Depending on the submitted and **TL** approved rescue concept the above defined survival times can be changed for non-autonomous submersibles.

If the assumptions according to Section 16, A.2. are met, **TL** may approve the survival times according to Section 16, B.4.2.

1.2 For submersibles equipped with a diver's lockout, the area of the lockout and any compression chambers provided are to comply with the requirements set out in Chapter 52 – Diving Systems.

2. Equipment is to be installed for the circulation and treatment of the atmosphere in the submersible such that the oxygen partial pressure can be maintained within the range 0,19 - 0,23 bar and the CO_2 partial pressure can be kept below 0,01 bar in the various spaces. In addition, air purifying and conditioning units are to be installed. The limit values for the permissible atmospheric impurities are to be agreed with **TL** in each case. The following note may be useful for design:

Note

Parameters for the design of life support systems (at 20 °C and 1013m bar):

– *O_2 demand: 15 l/h (resting); 40 l/h (working); 26 l/h (average); for tourist submersibles: 28,3 l/h (average)*

– *CO_2 production: 22 l/h (average); for tourist submersibles: 26,4 l/h (average)*

– *Humidity: 50 $\pm$20 %*

– *Heat production: 265 kJ/h*

Smoking, fire and open light have to be avoided by relevant notices and organisational measures.

3. Facilities are to be provided for supplying the whole crew with food and water and for disposing of waste and effluent during the periods stated in 1.

4. An emergency respirator or a breathing mask which can be connected to an emergency breathing air system is to be provided for each crew member. In addition at least one reserve device has to be on board.

5. Suitable equipment is to be fitted for monitoring the environmental conditions inside the vehicle. The crew is to be warned by an automatic alarm in the event of inadmissible deviations from the O_2 and CO_2 partial pressures stated in 2.

C. Air Supply

1. Air supply and exhaust system

1.1 When travelling on the surface, the vehicle is to be ventilated via an air mast which is to be designed and arranged to prevent the penetration of spray and swell water, compare Section 6, C.

1.2 A power-driven extractor fan is to be provided for expelling the battery gases during the charging of the batteries, as well as during the required time before and afterwards from the battery spaces in the pressure hull. An influence on the supply air is to be avoided by appropriate arrangement. The venting of battery spaces is to be separated from other ventilation systems.

For little battery plants also natural venting of the battery space may be possible after agreement with **TL**.

2. Air renewal

2.1 Oxygen system

2.1.1 An oxygen system is to be installed to replace the oxygen consumed from the atmosphere in the vehicle.

2.1.2 The oxygen system is to be designed on the basis of a consumption rate according to B.2.

2.1.3 The oxygen is to be stored in at least two separate banks of bottles, as possible outside the pressure hull. In this case the oxygen bottles are to be designed like outside vessels and apparatus.

For the arrangement outside as well as inside the pressure hull a design pressure PR equal to the maximum allowable working pressure PB has to be applied.

For the storage of the oxygen bottles within the pressure hull the volume of a bottle is to be restricted in such a way that the pressure does not exceed by 1 atmosphere and the O_2 content does not exceed 25 % by volume if the complete content escapes. If this cannot be achieved, the bottles are to be arranged outside the pressure hull.

2.1.4 Each bank of oxygen bottles is to be connected to the inside of the vehicle by a separate line.

2.1.5 Manually operated oxygen metering systems are to be equipped with a bottle shut-off valve and a device for controlling the flow rate with flow-rate indicator.

2.1.6 If the metering device is not provided in redundant form, it is to be equipped with a manually operated bypass.

2.2 CO_2 absorption

2.2.1 For regenerating the breathing air a CO_2 absorption unit is to be provided which shall be capable of keeping the CO_2 partial pressure in the range 0,005 - 0,010 bar. In addition, it shall be possible to maintain a CO_2 partial pressure within the vehicle of not more than 0,02 bar at the end of the survival time stated in B.1.

2.2.2 For the design of the CO_2 absorption unit the Note according B.2. is to be observed.

2.2.3 The CO_2 absorption unit is to be fitted with a dust filter of non-combustible material.

2.3 Humidity

The relative humidity of the air is to be kept during operation within boundaries comfortable for the crew by suitable measures, compare the note given in B.2.

3. Emergency breathing air supply

3.1 Emergency breathing air systems/appliances are to be designed to ensure that in an emergency all crew members have sufficient breathing air while the submersible is rising from nominal diving depth, or being brought to the surface, subject to a minimum time of one hour.

The emergency breathing air systems are to have a gastight eye protection.

3.2 The emergency breathing air appliances are to be so designed and arranged that in an emergency each crew member can very quickly reach a breathing appliance and can reach the exit from the submersible without first having to remove the breathing appliance.

3.3 The required number of spare breathing air appliances is to be agreed with **TL** depending on the number of persons on board.

3.4 If compressors are used for breathing air, the quality of the produced compressed air is to be proven according to EN 12021.

4. H_2 monitoring

4.1 If development of H_2 can be expected, the hydrogen content is to be monitored continuously in the battery spaces, the exhaust system and if applicable also in other spaces. The position of the measuring points is to be fixed in accordance with the local conditions.

4.2 If the gas concentration of 35 % of the lower explosion limit is exceeded, it is to be signalled optically and acoustically to the control stand.

If a value of 60 % of the lower explosion limit is reached, all charging or discharging processes have to be interrupted automatically.
If the H_2 concentration is still rising after the enforced switch-off, e.g. from finish gassing of the batteries, immediately surfacing is to be initiated and forced ventilation is to be applied.

4.3 The request for immediate surfacing is to be signalled optically and acoustically at the control stand. Acknowledgment of the optical signal shall be possible only after surfacing and after sufficient fresh air has been supplied.

4.4 The measuring and signalling equipment for monitoring of the H_2 concentration are to be type approved by **TL**.

4.5 The hydrogen measuring system is also to be supplied by emergency power.

D. Monitoring Equipment

1. The control stand of the submersible according to Section 12, B.2. is to be fitted at least with indicating instruments for monitoring the environmental conditions inside the vehicle for the following parameters:

– Pressure

– Temperature

– Humidity

– Oxygen partial pressure

– CO_2 partial pressure

– H_2 portion

– Pressure of connected breathing gas containers/bottles

– Outlet pressure of pressure-reducing valves

2. The readings of the pressure gauges are to be accurate to at least 1 % of the complete indicating range. The use of mercury pressure gauges and thermometers is not permitted.

3. Each space should be provided with facilities for measuring the room temperature and the O_2 and CO_2 partial pressures.

4. A permanent gauge and a standby indicator are to be provided for monitoring both the O_2 and CO_2 partial pressure. Test tubes may be recognized as standby indicators.

5. The system for the analysis of oxygen shall have a minimum indicating accuracy of ±0,015 bar for the oxygen partial pressure.

6. The CO_2 analysis system shall have a minimum indicating accuracy of ±0,001 bar for the CO_2 partial pressure.

7. A system of analysis is to be provided for determining possible atmospheric impurities such as e.g. CO, NO, NO_x and hydrocarbons. Test tubes may be approved for this purpose.

E. Emergency Thermal and Frigidity Protection

Submersibles are to be equipped to provide each crew member with sufficient thermal protection even in an emergency of the duration stated in B.1. (Thermal protection suits).

F. Pressure Equalization

Measures are to be provided to transfer in a controlled manner the higher or lower pressure eventually built up within the pressure hull to atmospheric pressure before the access hatches are opened.

G. Waste Disposal

Submersibles are to be equipped with devices or receptacles for disposal of waste produced during the survival period without substantially affecting especially the quality of breathing air.

SECTION 14

FIRE PROTECTION AND FIRE EXTINGUISHING

A. GENERAL.. **14-**2
B. STRUCTURAL FIRE PROTECTION.. **14-**2
C. FIRE SURVEILLANCE.. **14-**2
D. FIRE EXTINGUISHING SYSTEMS.. **14-**3

A. General

1. The Rules of this Section apply to structural fire protection, fire surveillance and the extinguishing systems of submersibles. In the following essential requirements for submersibles are defined. Details are to be taken from the **TL** Rules mentioned individually and have to be adjusted for the actual requirements of submersibles.

2. The documents to be submitted to **TL** for approval are stated in Section 2, E.

3. The necessary tests and markings are as stated in Section 2, G. and H.

B. Structural Fire Protection

1. As far as possible, only non-combustible materials or materials which are at least flame- retardant are to be used inside submersibles. All load-bearing components and insulations are to be made of non-combustible materials.

2. Sources of ignition are to be avoided wherever possible. Electrical heating appliances and heaters are to be fitted with protection against overheating.

3. Components and materials are to be selected with a view to minimizing the acquisition of static charges.

4. Where combustible materials are installed in closed cabinets, the latter are to be so designed that effective extinguishing action can be taken from outside.

5. Further detailed requirements are defined in Chapter 1 - Hull, Section 21.

C. Fire Surveillance

1. Principle requirements

1.1 For submersibles with several compartments manual fire alarm devices are to be provided.

1.2 Submersibles with not manned internal spaces (e.g. with engine rooms, battery rooms) have to be equipped for these rooms with an automatic fire alarm system.

1.3 For submersibles with only one compartment the fire surveillance is to be agreed with **TL**.

1.4 The fire alarm may be actuated manually from the control stand and the different spaces or automatically by the fire detection system.

1.5 The fire alarm system shall actuate visual and audible signals at least at the vehicle's control stand.

2. Constructural requirements

2.1 Fire detection and alarm systems including their wiring are to be type approved by **TL**.

2.2 Fire alarm systems are to be designed with self-control that means that occurring faults, like e.g. supply failure, short circuit or wire breakage in the detection loops, or the removal of a detector from its base, trigger a visual and audible signal at the control stand.

2.3 The operational readiness of the system has to be indicated at the control stand.

2.4 The fire alarm system is to be connected to the main as well as to the emergency power supply.

2.5 For the detailed design and arrangement of fire detection and alarm systems the **TL** Rules Chapter 5 – Electrical Installation, Section 9, D. and Chapter 4-1 - Automation, Section 4 are to be observed.

D. Fire Extinguishing Systems

1. Design

1.1 Each compartment of the pressure hull is to be equipped with suitable means for extinguishing a fire, which enable a quick and effective fire fighting. For fixed installed systems an even distribution of the extinguishing agent over all parts of the space has to be guaranteed.

1.2 The fire extinguishing systems are to be designed and constructed in such a way that they can safely deal with every conceivable outbreak of fire under the environmental conditions stated in Section 2, D.

2. Extinguishing agents

The following principle requirements are to be complied with for extinguishing agents:

2.1 Extinguishing agents with a toxic or narcotic effect are not permitted. Choking hazards of extinguishing agents are to be considered. For gas fire extinguishing systems an alarm circuit is to be provided in advance to their application.

2.2 Salt water is not permissible as extinguishing agent.

2.3 Actuation of a fire extinguishing system may not cause any unacceptable pressure change in the space concerned.

3. Types of fire extinguishing systems

As fire extinguishing systems portable fire extinguishers or fixed installed fire extinguishing systems are to be considered.

3.1 Portable fire extinguishers

3.1.1 As extinguishing agents may be utilized:

– Distilled water

– Dry powder

– Foam

– CO_2 for local application at electrical systems, switchboards, but not to be used as space protection, as the critical concentration to endanger human beings shall not be reached (net weight 2 kg maximum)

3.1.2 In each closed space of the pressure hull at least one portable fire extinguisher shall be available.

– Control stand: 1 portable fire extinguisher in the normal case

– Passenger compartment (if existing): number according to the size of the space

– Engine room: 1 portable fire extinguisher

– Battery spaces: 1 portable fire extinguisher at each access outside the battery space

– The total number and the distribution of the different extinguishers is to be agreed with **TL**

3.1.3 The portable fire extinguishers are to be positioned at easily reachable places.

3.2 Fixed installed systems

3.2.1 As extinguishing agents may be utilized:

– NOVEC-1230

– FM 200 or comparable gases

– Water fog

– Nitrogen or other inert gases/gas mixtures (e.g. Inergen)

3.2.2 The capacity of an extinguishing system with gas as extinguishing agent is to be so designed, that for a complete spray no toxic concentrations occur.

3.2.3 For submersibles with separate machinery spaces normally a permanently installed fire extinguishing system is to be provided.

3.2.4 Permanently installed extinguishing systems are to be actuated manually and shall be safeguarded against improper and accidental release. In case of several internal spaces the actuation has to be done from outside of the space to be protected and only to be released after an adequate alarm has been given in accessible spaces and the space has been evacuated by any persons.

3.2.5 Suitable means are to be provided to ensure that in any space the quantity of extinguishing agent ejected does not exceed that required to extinguish the fire.

4. Detailed design

For detailed design and arrangement see **TL** Rules Chapter 4 - Machinery, Section 18.

SECTION 15

RESCUE SYSTEMS

A. GENERAL.......... **15-**2
B. DESIGN PRINCIPLES.......... **15-**3

A. General

1. Scope

The rules of this Section are valid for the following equipment and systems, which are required for rescuing the submersible and its occupants:

– Emergency gas/air supply for (automatic) blowing the diving tanks

– Dead man's handle for the pilot of the vehicle to blow automatically, avoiding unintended action by suitable measures (optional)

– Jettisonable ballast

– Detachable elements of the equipment (e.g. manipulators, drive units, rudders, fixing devices, etc.)

– Detachment of umbilicals and lifting cables

– Detachable rescue vessel (optional)

– Marker buoy with and without recovery line

– Mating flange for rescue submersibles (optional) The emergency breathing air supply is defined in Section 13.

2. Life saving appliances on the surface

2.1 For the surfaced voyage of the submersible and surfaced crew members from the sunken submersible life saving appliances are to be provided.

2.2 The life saving appliances have to be in accordance with international and national regulations, see Section 2, B. Their design and testing is not part of the Classification of the vehicle by **TL**. In any way their storage, activation as well as resulting forces, if applicable, are to be considered within the frame work of the overall design.

Note:
Mostly these appliances will consist of inflatable life-rafts in sufficient numbers, which are unfolding after the actuation automatically at adequate outside pressure.

3. Personal life saving appliances

3.1 The equipment of the submersible concerning personal life saving appliances for the crew e.g. life rings, life jackets, immersion suits (thermal protection suits) is governed by the relevant international and national regulations, see Section 2, B.

3.2 A first aid kit is to be provided.

4. The documents to be submitted to **TL** for approval are stated in Section 2, E.

5. The necessary tests and markings are as stated in Section 2, G. and H.

B. Design Principles

1. Emergency gas/air supply

The supply to be carried for blowing the diving tanks is defined in Section 9, B.3.1.

2. Automatic blowing

As an option a device is to be fitted for the automatic blowing of the diving tanks. This shall be actuated automatically unless, at the expiry of a safety interval, a safety switch (dead man's handle) is actuated, or if the nominal diving depth is exceeded. This device is to be automatically rendered unoperational when the diver's lockout is open.

3. Jettisoning of solid ballast

3.1 Mathematical proof is to be furnished that, after release of the solid ballast, the submersible rises safely to the surface and floats there in a stable position, see Section 3.

For the design of the jettisonable ballast in general the biggest value of the following is to be assumed:

– Weight of the water volume of all compensating and trimming tanks, if these are designed for bilge pumping, reduced by the planned remaining water content

– Weight of the water volume of the biggest pressure vessel resp. apparatus arranged outside and subjected to external pressure, reduced by the internals

– Weight of the water volume of the largest diving tank

3.2 It shall be possible to jettison the solid ballast even if the main electricity supply fails.

The devices for jettison of ballast are to be so designed that two mutually independent actions have to be performed to initiate the release operation.

The release of ballast shall also be possible at the seabed.

3.3 Normally it shall be possible to release also equipment in addition; reference is made to Section 6, C.7.

4. Detachment of umbilicals and lifting cables

If required for the rescue of non-autonomous submersibles also umbilicals and lifting cables are to be designed detachable, referring to this see Section 6, C.5.

5. Detachable rescue vessels (optional)

5.1 The size of the rescue vessel has to be fitted to the number of the crew and has to be suitable for a safe and quick surfacing procedure.

5.2 The design has to be pressure tight for 1,1 times the collapse diving pressure **CDP**.

5.3 It shall only be possible to activate the release from inside the rescue vessel if the access hatch is closed.

5.4 In surfaced condition the rescue vessel shall float in a stable position with the access hatch at the top and with sufficient freeboard to the water surface.

5.5 The rescue vessel has to be provided with the necessary survival equipment, which is required for the stay of the crew over a time period to be agreed with **TL** depending on the rescue plan to be submitted.

6. Marker buoy

6.1 Independent and autonomous submersibles

6.1.1 Independent and autonomous submersibles are to be equipped with a marker buoy, which can be released in emergency from inside the vehicle. The buoy has to be pressure tight assuming a layout pressure of 1,1 times the collapse diving pressure **CDP**.

6.1.2 The marker buoy is to be equipped with an automatic emergency call transmitter.

6.1.3 For not too big diving depths, the marker buoy shall remain connected with the submersible by a rolling-off cable. If possible, the marker buoy shall also be usable as telephone connection with arrived rescue forces.

As the buoy and the related mechanism are in general arranged in the free flooded exostructure, all elements of the release system, the cable drum, etc. shall be made of stainless material to guarantee a faultless functioning under all circumstances.

6.1.4 If for big diving depths a connection of the marker buoy to the submersible is not possible anymore, it shall be equipped with a drag anchor, to remain as near as possible to the position of the submersible.

6.2 Non-autonomous submersibles

For non-autonomous submersibles a marker buoy according to 6.1 is recommended.

7. Mating flange (optional)

If a mating flange for docking of a rescue submersible is arranged on the submersible, the relevant design parameters and calculations are to be agreed with **TL** in each case, see also Section 5.

Concerning the number and arrangement of the mating flange respectively of the access hatches Section 16, B.3.5 is to be observed.

8. Emergency instructions

Near to the release points of the described rescue systems relevant operating instructions, warning signs, etc. are to be provided, which:

– Describe clearly the purpose of the release and the different procedures for operating,

– Are easily readable with emergency lighting and

– Utilize symbols in accordance with the international **SOLAS**, **LSA** and national regulations.

SECTION 16

ADDITIONAL REQUIREMENTS TO SUBMERSIBLES FOR TOURIST SERVICES

A. GENERAL **16-**2
B. DESIGN PRINCIPLES **16-**2

A. General

1. The following rules are defining which minimum requirements are to be met by submersibles intended for tourist services according to MSC/ Circ.981 of 29 January 2001.

2. The requirements relate to submersibles operating in already defined, explored diving areas at depths at any time accessible to surface divers and are able to transport more than 6 passengers. Also, it is provided that in order to avoid interferences between the surfacing submersible and vessels operating on the surface and with a view to assistant actions being initiated in an emergency at all times communication between the submersible and a control person on the surface and herewith also to other surface vehicles which are participating in sea/ship traffic is possible.

3. The operating conditions for which the submersible is designed are to be specified clearly to **TL**. **TL** reserve the right of adequately adapting design and equipment with a view to the respective operating conditions and, if necessary, in accordance with requirements of the Flag State.

Normally a submersible for tourist services shall not operate in waters with a water depth greater than the nominal diving depth **NDD**. Operations in waters with a greater depth may be applied for, if adequate, special safety measures are provided and these are approved as adequate by **TL**.

4. Any national regulations concerning operation, manning and safety equipment are to be ascertained, where existing, prior to commencement of construction and taken into account during construction, such as to prevent any later adaptations.

5. The particulars to be submitted to **TL** for approval are listed in Section 2, E. In addition an emergency plan for the evacuation of the passengers in case of fire, damage, etc. of the submersible is to be submitted.

6. The examination and markings stipulated can be taken from Section 2, G. and H.

7. For submersibles with less than 6 passengers the requirements have to agreed with **TL** case by case.

B. Design Principles

1. Stability and buoyancy

1.1 Submersibles for tourist services are with regard to their stability in the surfaced and submerged condition and in the transient conditions to be dimensioned such that persons moving on or below deck cannot cause any situations affecting their operational safety, compare Section 3.

1.2 The equipment (variable ballast) ensuring neutral buoyancy shall function independently of the diving depth and is to be designed for the maximum expected changes due to added loads and buoyancy (owing to differences in specific density).

The variable ballast may partly consist of removable solid ballast capable of being adequately secured. For the layout not pressure-proven diving tanks are not to be taken into consideration to achieve neutral buoyancy.

1.3 At least two facilities independent of each other – one of it without electric energy – are to be provided enabling the submersible to surface in a stable, upright floating condition.

1.4 The stability of the surfaced submersible, the arrangement of the access(es) and their height above the waterline have to be designed such, that also during evacuation of the submersible in an emergency and given the seaway conditions, for which the boat is designed, no water enters through the open hatch(es). In this context, the most unfavourable weight distribution of passengers on and below deck is to be assumed under consideration of the emergency plan.

1.5 For balancing an uneven weight distribution of passengers in the longitudinal direction of the submersible, the trimming tanks are to be appropriately subdivided, or else different trimming devices are to be available, permitting the vessel to be returned to horizontal trim at any time.

2. Surfacing in emergency

2.1 Basic requirements

The basic requirement to submersibles for tourist services is, that, as far as practicable, in the event of any single failure occurring, the vehicle is able to return to surface without external help. Appropriate backup systems and equipment shall be incorporated to meet this general design requirement. The vehicle shall be able to attain positive buoyancy at any time.

2.2 Emptying of tanks

2.2.1 The diving tanks are to be subdivided such that in the event of damage of the biggest tank the passengers will be able to evacuate the submersible safely and without the risk of water penetrating through the hatch(es), compare Section 3, C.

2.2.2 If tanks are emptied by compressed air, spare compressed air supplies, provided exclusively for this purpose, are to be available – in addition to the requirements of Section 9, B.3. - in sufficient quantities for blowing the tanks required for surfacing in the nominal diving depth **NDD** applying a safety factor of 1,5.

2.2.3 If other measures are provided, they are to be approved by **TL**.

2.3 Jettisoning of ballast

2.3.1 Ballast jettisoning equipment are to be capable of being operated without external power supply and shall be designed such as to preclude unintentional release. The handling of the ballast jettisoning device is to be demonstrated by appropriate markings. Jettisoning has to be possible also with the submersible being in the maximum conceivable inclined position, compare also Section 15, B.3. By these measures a surfacing speed comparable with normal operation has to be achieved.

2.3.2 The jettisoned ballast may consist instead of ballast weights designated only for this duty also of appendages or a combination of both. Alternatively the passenger compartment may be separated from all other parts of the submersible, provided the passenger compartment is positively buoyant when released.

2.4 External means

Measures have to be provided to bring the submersible with external means to the surface.

3. Equipment

3.1 The submersibles are to be provided with appropriate lifting and towing points. With the aid of the lifting points divers or remotely controlled underwater vehicles (ROVs) are to be in a position to easily connect lifting ropes or lifting balloons. The towing point is to be arranged such as to enable a towing across the distances expected in the operating area, without the safety of the vessel and its equipment being impaired, compare also Section 6, B.11. and B.12.

3.2 The submersibles are to be provided with appropriate warping gear, permitting safe mooring even under the most unfavourable expected weather conditions, compare also Section 6, C.2.

3.3 The submersibles are, in particular where intended to lie alongside a transfer boat or pontoon for changeover of passengers at sea, are to be equipped with solid fenders throughout, preventing damage to external diving tanks, propulsion units or other important equipment.

Means are to be provided that persons can board the submersible in a safe way, taking into account the relation of the heights of the submersible and of the transfer craft/pontoon, the influence of the seaway and, if applicable, also the protection of the appurtenances of the submersible.

3.4 The submersibles intended for transportation of passengers are to be provided with guard rails and hand rails in such a way that during embarkation and disembarkation the persons are protected against falling overboard and can at any time hold tight on and below deck, compare also Section 6, C.3.

3.5 Number and location of access hatches for passengers and crew are to be defined bearing in mind the total length of the submersible, the length of the pressure hull, number of passengers as well as conditions of operation and rescue facilities.

In addition for the design are to be considered:

– Accesses and exits are to be designed such as to ensure speedy and safe evacuation also in emergencies (e.g. fire, smoke, stability after uncontrolled passenger movement, down flooding through hatches due to adverse sea state, etc.). They are to be dimensioned and arranged such as to enable elderly or handicapped persons to be assisted by persons accompanying them; therefore it has to be checked, if the minimum net widths defined in Section 5, C.6. have to be increased.

– The number of the hatches shall not be increased beyond the necessary minimum.

3.6 For each passenger and each crew member adequately dimensioned seating space is to be provided.

3.7 Switchgear, valves and other equipment arranged in the passenger area are to be secured against unauthorized operation. Machinery spaces are to be provided with lockable doors. In order to prevent unauthorized access, the pilot area shall be capable of being separated from the passenger area.

3.8 It is to be safeguarded that the pilots can at any time intercommunicate with other crew members and that the pilot or some other crew member can at any time inform all passengers.

3.9 If the submersible is operating in areas where the water depth is greater than the nominal diving depth **NDD**, a depth alarm shall be triggered at **NDD**. This alarm shall only be acknowledgeable if the nominal diving depth is reached again.

3.10 If the surfaced submersible is not clearly visible on the radar screen of other craft, a radar transponder is to be provided.

For underwater voyages the submersible is to be equipped with a sonar reflector or an acoustic emergency pinger which shall be compatible with the support system at the surface.

3.11 The pilot's visibility has to be such that he will be able to safely manoeuvre the boat, in particular in the vicinity of obstacles as well as on the surface.

For extension of the visibility range TV systems may be installed.

4. Life support systems

4.1 The submersibles shall be equipped such that the passenger space can be sufficiently ventilated between two diving operations.

4.2 Submersibles under the operating conditions specified in A.2. are to be equipped with life support systems capable of maintaining the breathing air values as per Section 13, B.2. for the maximum times to be expected for rescue measures in emergency, but at least 24 hours beyond the envisaged normal operating period. The survival times defined in Section 13, B.1. for other types of submersibles are not to be applied here.

Where different operating conditions prevail, the required survival period is to be approved by **TL**.

4.3 Submersibles are to be equipped with devices or receptacles for disposal of the waste produced during the survival period without substantially affecting especially the quality of the breathing air.

4.4 For each passenger and each crew member a portable emergency respirator is to be provided, which in the event of an emergency (smoke, contaminated breathing air) will ensure breathing until surfacing and evacuation and protect the eyes as well. The capacity of the emergency breathing apparatus shall allow breathing air being available for 150 % of the time required for surfacing, but at least one hour. For special operating conditions this time may be reduced.

The required number of reserve apparatus is to be agreed with **TL** depending on the number of the persons aboard. The emergency breathing apparatus for the crew shall not obstruct them in performing their functions and make it possible for them to also operate the communication equipment.

4.5 For the emergency respirators and possibly also for the life jackets space is to be provided for stowage near the seats, enabling safe storage and immediate access. Relevant labels are to be affixed.

Notes:

– *Inflatable life jackets to facilitate the debarkation in emergency are recommended.*

– *Life buoys or equivalent rescue equipment shall be kept ready during embarkation and disembarkation, in case somebody stays on upper deck of the submersible.*

4.6 For operation of the submersible intended for tourist services in cold waters adequate low-temperature protection for passengers and crew during the survival period is to be ensured (Thermal protection suits).

SECTION 17

SUPPORTING SYSTEMS ABOARD THE SUPPORT SHIP

A. **GENERAL**.......... **17-**2
B. **CLASSIFICATION AND CERTIFICATION**.......... **17-**2
C. **SYSTEMS FOR CONTROL**.......... **17-**2
D. **SUPPLY SYSTEMS**.......... **17-**5
E. **LAUNCH AND RECOVERY SYSTEM**.......... **17-**7
F. **STOWAGE AND DECK TRANSPORT**.......... **17-**13
G. **MATING EQUIPMENT**.......... **17-**15

A. General

1. Scope

The following Rules are valid for plants and systems which are located aboard the support ship for submersibles and which are necessary for the support of the operation according to type and purpose of the mission of the submersible.

2. Definitions

For the definitions see Section 2, C.

3. Rules to be considered

For the Rules to be considered see Section 2, B.

4. Environmental conditions

The environmental conditions according to Section 2, D. are to be applied analogously for the supporting systems on the support ship.

5. Communication systems

As far as several areas not situated nearby are required aboard of the support ship for the safe operation of the submersible, these are to be connected to each other by a suitable communication system.

B. Classification and Certification

1. To guarantee an undisturbed and safe operation of the submersible resp. of a working machine, the supporting systems are to be either classified or certified, see Section 1, Table 1.1.

2. The systems to be classified (especially according to C.2., C.3. and D.4.) are to be treated within the framework of the Classification of the complete submersible with the Class Notation **SUBMERSIBLE**. The procedure to be applied is defined in Section 1, B.

3. The systems according to C.2., C.3. and D.4. may also be treated within the framework of the Submersible Certification of the complete submersible and a Submersible Certificate will be issued.

4. After judgement of the other systems according to D. to G. a Certificate will be issued or a Proof of Suitability will be required. The procedure for this follows in analogous form the process defined in Section 1, G.

C. Systems for Control

1. General

1.1 As systems for control the control station, the communication systems to the submersible and the dynamic positioning system of the support ship are summarized.

1.2 The proof of the suitability of control station and data transfer has to be given by **TL** Classification or a Submersible Certificate (compare Section 1, Table 1.1). In both cases the following requirements are to be considered:

2. Control station

2.1 All systems aboard of the support ship which are serving for the support of the submersible are to be summarized in a control station. Special emphasize is to be given to the control station for non-autonomous submersibles.

2.2 As far as applicable, the requirements defined in Section 12, B.2. for a control stand are valid for a control station aboard of the support ship in analogous and evident way.

2.3 The following requirements are to be considered additionally:

– The energy demand defined by the manufacturer of the submersible has to be made available.

– The power supply of the control station for non-autonomous submersibles shall be established by two power circuits independent from each other which can be switched over. Alternatively a direct feeding from the emergency switchboard of the support ship may be provided.

– The permissible deviations of voltage and frequency according to **TL** Rules Chapter 5 – Electrical Installation, Section 1 shall not be exceeded.

– For the power supply of control, monitoring and safety systems the requirements according to the **TL** Rules Chapter 5 – Electrical Installation, Section 9 are to be met.

– The minimum degrees of protection for the control station are to be provided according to the **TL** Rules Chapter 5 – Electrical Installation, Section 1.

– If the control station with the communication systems is not located directly at the bridge, a communication system and if necessary a data transfer between them is to be provided.

– Between the control station and the control unit for the supply systems according to D. (e.g. control room for ship machinery) a communication system is to be established.

– In the vicinity of the control station no systems or plants are to be installed which impair the function of the control station.

2.4 For the operation of autonomous submersibles a control station is only required in reduced scope for the supply between the missions.

2.5 Plans and descriptions of the control station and its power supply are to be submitted for the relevant areas.

3. Communication systems

3.1 As far as applicable, the requirements defined in Section 12, C. are valid for the communication systems on board of the support ship in analogous way.

3.2 The communication shall be done from the control station according to 2.

3.3 The energy supply for the communication system to the submersible is to be provided in analogous way to 2.3.

3.4 3.3 is only to be applied to the communication system to an autonomous submersible if the communication is required for a save operation.

3.5 Plans and descriptions of the communication systems of the support ship are to be submitted for the relevant areas.

4. Dynamic positioning of the support ship

4.1 A ship with dynamic positioning is a vessel which automatically keeps its position (fixed location or pre-determined track) exclusively with the aid of propeller/jet drives.

Especially for non-autonomous submersibles it may become necessary to provide a dynamic positioning of the support ship as the submersible is connected to the support ship via an umbilical and/or lifting cable.

4.2 As far as applicable, the requirements for positioning systems defined in Section 10, B.3. are valid for the support ship in analogous way.

4.3 Between the helmstand for dynamic positioning of the support ship and the control station according to 2. suitable communication systems are to be established. For the case of failure of the positioning of one of the two vehicles the possibility to trigger an alarm is to be provided.

4.4 All requirements for Classification of a positioning system are defined in the **TL** Rules Chapter 22 – Dynamic Positioning Systems. According to the degree of redundancy **TL** may assign the Class Notations **DK1**, **DK2** and **DK3**.

The support ship has also to meet the regulations of IMO: “Guidelines for Vessels with Dynamic Positioning Systems” (MSC/Circ. 645).

4.5 Documents for approval

The following documents are to be submitted:

– Description of the main characteristics of the system

– Block schematic diagrams of the control system and applied logics

– Information about possibilities for the position balance between the involved units

5. Tests and trials

5.1 A Classification as for the submersible with an acceptance test after completion, an annual survey, an intermediate survey and a class renewal survey after 5 years is to be performed.

5.2 If control station and communication systems are to be surveyed for issuance of a Submersible Certificate, an acceptance test and an annual survey is required.

5.3 Within the acceptance test the compliance of the documentation with the system as well as the safe functioning during normal and emergency operation has to be proven.

5.4 Within the repeated surveys the complete system is to be checked for visual damages, corrosion, etc. Subsequently a complete functional test is to be performed.

D. Supply Systems

1. General

1.1 Systems of the support ship, which provide energy in form of electrical power, hydraulic oil and breathing air to the umbilicals are supply systems. For non-autonomous submersibles the supply is necessary during the preparation of the mission as well as continuously during the mission, for autonomous submersibles between the missions.

1.2 The proof of the suitability of these systems can be provided by a Class Certificate of the supply ship or by the Certificate of a recognized institution (compare Section 1, Table 1.1). If no Certificate is existing and the establishment of such a proof is ordered from **TL** by the manufacturer or operator, the following requirements are to be considered.

The supply with breathing air according to 4. is as a life support system part of the Classification or Submersible Certification of the non-autonomous submersible.

2. Electrical supply

2.1 As far as applicable, the requirements defined in Section 11 are valid for the support ship in analogous form.

2.2 The following requirements are to be considered additionally:

– The energy demand defined by the manufacturer of the submersible has to be made available at any time.

– If a dangerous condition for the consumer may arrive if the main supply fails, special measures are to be provided in accordance with **TL**.

– The emergency supply on the support ship for non-autonomous submersibles shall be able to provide the energy demand until a safe condition of the mission is reached.

– The permissible deviations of voltage and frequency according to **TL** Rules Chapter 5 – Electrical Installation, Section 1 shall not be exceeded.

2.3 Besides the essential consumers listed in the **TL** Rules Chapter 5 – Electrical Installation, Section 1, B. the following items of electrical equipment on the support ship also count as essential consumers:

– Emergency lighting of the areas essential for the operation of the submersible

– Power supply of the control station for non-autonomous submersibles

– Supply systems, e.g. breathing air compressor, power supply of the submersible

– Launch, recovery and mating equipment

2.4 Plans and descriptions of the electrical supply system of the support ship are to be submitted within the **TL** Certification for the areas relevant here.

3. Hydraulic supply

3.1 As far as applicable, the requirements defined in **TL** Rules Chapter 4 - Machinery, Section 10 are valid for the support ship.

3.2 The following requirements are to be considered additionally:

– As far as applicable, the requirements for hydraulic systems defined in Section 9, B.4. are valid for the support ship in analogous way.

– The demand of hydraulic oil (volume, pressure range) defined by the manufacturer of the submersible resp. the working device has to be made available at any time. The additional demand for eventual working devices (compare **TL** Rules, Chapter 54 – Underwater Equipment) is to be considered.

– If necessary, the emergency supply at missions of non-autonomous submersibles/working devices shall be able to provide the defined oil demand until a safe condition of the underwater mission is reached.

– If a dangerous condition for the consumer may arrive if the main supply fails, special measures are to be provided and to be agreed **TL**.

– The permissible deviations of volume and pressure are to be in accordance with the data of the manufacturer of the submersible and shall not be exceeded resp. shall not fall short of.

– The hydraulic fluid is to be suitable for the operational conditions and especially for the environmental conditions above and under water (see Section 2, D.).

3.3 Plans and descriptions of the hydraulic system of the support ship are to be submitted within the **TL** Certification for the areas relevant here.

4. Supply of breathing air

4.1 The requirements for breathing air supply defined in Section 13, C. are valid in analogous way also for breathing air supply systems on the support ship.

4.2 The following requirements are to be considered additionally:

– The supply pressure is to be indicated at the control station.

– If the supply pressure falls short an alarm is to be triggered at the control station.

– An emergency supply is to be established for the time until a safe condition of the mission respectively surfacing is reached.

– Between the supply system for breathing air and the compressed air system for the operation of the support ship a safe separation is to be provided.

– Measures are to be taken to hinder the entrance of seawater in the systems as far as possible.

4.3 Plans and descriptions of the breathing air system of the support ship are to be submitted.

5. Tests and trials

5.1 For the Classification of the breathing air supply according to 4. like for the submersible an acceptance test after completion, an annual survey , an intermediate survey and a class renewal survey after 5 years have to be passed.

If the breathing air supply is to be checked within the Submersible Certificate an acceptance test and an annual survey are required.

5.2 If the other systems are to be checked within Certification an acceptance test and an annual survey are required.

5.3 All systems are to be checked visually for damages, influence of corrosion, etc. Subsequently a complete functional check for normal and emergency operation is to be performed.

E. Launch and Recovery System

1. General

1.1 The following requirements are valid for all systems and plants for launch and recovery as well as for coil-up/coil-off mechanism for umbilicals of submersibles to be certified by **TL**, compare Section 1, Table 1.1.

1.2 If the systems contained in this Section fulfil the defined requirements and are constructed and tested under **TL** surveillance, a Certificate for the system can be issued and a Register of launching appliances can be opened. The latter has the purpose to provide information about the actual situation with regard to general data plus the test, examination and maintenance status.

Details are defined in the **TL** Rules, Chapter 50 – Lifting Appliances.

1.3 Besides of the launch and recovery system an emergency recovery system is to be provided that allows the submersible to be lifted to the surface and towed away in an emergency.

1.4 Between the launch and recovery system and the coil-up/coil-off mechanism for umbilicals, if separately arranged, a communication facility with the control station according to C.2. is to be established.

2. Principles for design

2.1 General principles

2.1.1 The launch and recovery equipment shall be capable of safely launch and recovering the submersible in the seaway conditions stated in Section 2, D.

2.1.2 The launch and recovery equipment should be fitted with devices for reducing the dynamic loads during launch and recovery operations in a seaway.

2.1.3 A coupling system is to be provided to enable the submersible to be safely and efficiently coupled to, and uncoupled from the launch and recovery system.

2.1.4 Devices are to be provided to stabilize the submersible during launch and recovery.

2.1.5 Launch and recovery equipment for submersibles with a diver's lockout shall in addition conform to the requirements set out in Chapter 52 – Diving Systems, Section 2, D.

2.1.6 Unless otherwise specified in the following Sections, the mechanical equipment of launch and recovery systems is to conform to **TL** Rules, Chapter 50 – Lifting Appliances.

2.2 Power supply, mechanical drives

2.2.1 The launch and recovery system is to be provided with at least two mutually independent power sources, each of which shall be capable of supplying all the power needed to launch and recover the submersible. For hydraulic drives two power pumping sets independent from each other are to be provided.

2.2.2 The power sources, together with their feed lines and switchgear, are to be so arranged that a failure or burn-out of one system cannot lead to the failure of the standby system.

2.2.3 The launch and recovery system is to be equipped with auxiliary drives enabling a launch or recovery manoeuvre which has already been started to be safely concluded should the winches or hydraulic pumps fail.

2.2.4 Launch and recovery systems using an "A" frame are to be equipped with two hydraulic cylinders which are to be so designed and arranged that each is fully capable of safely performing the launch and recovery operation under load. In addition, they are to be connected to the hydraulic system in such a way that a single fault in the hydraulic system cannot lead to the failure of both hydraulic cylinders.

2.3 Control equipment

2.3.1 Launch and recovery systems are to be fitted with control equipment enabling the system to be operated intermittently with smooth accelerations. In addition, the controls are to be designed and arranged in such a way that the operator has the submersible in view throughout complete launch and recovery and is fully able to perform all the necessary actions safely.

2.3.2 The controls are to be fitted with blocking devices which ensure that only those commands can be performed simultaneously which do not produce a dangerous or unintended condition.

2.3.3 Control systems are to be provided with EMERGENCY SHUT-OFF buttons.

2.3.4 Wherever possible, control units are to operate on the fail-safe principle.

2.3.5 Control units with remote control are to be additionally equipped with a direct control override. In the event of failure or malfunction of the remote control, all operating sequences which have been initiated shall be automatically STOPPED.

2.3.6 All control units are to be clearly and permanently marked and shall be adequately illuminated.

2.3.7 An operating platform with good view over the complete launch and recovery system is to be provided.

3. Calculation

3.1 Design loads

3.1.1 The "safe working load **SWL**" of the launch and recovery system summarizes as follows:

– Weight of the submersible, including its equipment, ballast weights, etc.

– Weight of the working devices

– Payload **NL** of the submersible

– Total weight of the crew with 75 kg each and fully equipped divers with 150 kg each

– Weight of the load transmitting devices which are not connected in a fixed way with the launch and recovery system

– Resulting loads of the umbilical according to 5.3 if this is existing and it is transferred via the launch and recovery system

3.1.2 Calculations are normally to be based on the assumption that the angle of engagement of the load strength member may be 12° off perpendicular in any direction.

3.1.3 For the Calculation also possible external loads, which may occur during operation (e.g. dynamics, wind loads, ice accretion, etc.) are to be considered.

3.1.4 Finally also the forces from maximum ship motions and green seas, wind, ice, etc. have to be checked for the launching and recovery system in resting position and stowed on the support ship. A proof of strength considering the seaway and wind conditions according to Section 2, D. is to be submitted.

3.1.5 Further on the minimum lifting speed is to be specified by the manufacturer and to be agreed by **TL**.

3.1.6 The driving machine of the winch has to be designed in a way, that a maximum torque according to a maximum pull of 1,5 times the nominal pull of the winch can be developed at reduced speed for at least 5 minutes. In analogy the hydraulic cylinders are to be laid out for 1,5 times the nominal cylinder force. For both a calculational proof is to be provided.

3.2 Materials

3.2.1 For the manufacture, processing and testing of materials the **TL** Rules Chapter 2 - Material are valid.

3.2.2 Other materials as defined in 3.2.1 are to be manufactured and processed according to recognized standards resp. according to specifications of the material manufacturer checked and approved by **TL**.

3.3 Calculation procedure

3.3.1 The calculation of the launch and recovery system as well as of the coil-up/coil-off mechanism for umbilicals is to be performed according to the principles of **TL** Rules, Chapter 50 – Lifting Appliances. For this computation the system is to be considered as offshore lifting gear.

If the system is equipped with shock absorbers or swell compensators approved by **TL**, a reduction of the working load may be dispensed with totally or partially if agreed by **TL**.

3.3.2 Deviating from the design of offshore lifting gears, for the dimensioning of launch and recovery systems a hoist load coefficient of 2,7 and a dead load coefficient of 1,5 are to be considered independently of type and size of their safe working load.

In this regard it is assumed, that the employment in a seaway is restricted to significant wave heights up to 2 m.

Where it is proposed that launch or recovery operations should be performed in even more unfavourable conditions, previous agreement with **TL** is necessary.

4. Equipment

4.1 Where cranes are used for launch and recovery, measures are to be taken to prevent the uncontrolled turning or slewing of the crane in a seaway. The turning or slewing gear has to be capable of holding the crane in any position. The gear is also to be designed to ensure that all movements are initiated and arrested smoothly.

4.2 Launch and recovery systems are to be equipped to prevent excessive turning resp. swinging of the submersible during recovery (e.g. by the use of non-spin ropes and additional pendants).

4.3 Measures are to be provided to prevent the submersible from striking against the ship's hull or against the launch and recovery gear.

4.4 Winches are to be equipped with two independent brakes. One of the brakes is to be energy independent and shall be activated in case of voltage failure.

4.5 The capacity of the brakes has to be sufficient to safely hold the dynamic test load specified in 7.1.

4.6 The final positions of the launch and recovery system, like upper and lower hook and jib position as well as the slewing range, are to be monitored. The starting and breaking velocities are to be controlled.

4.7 In the case the submersible is not hanging on the lifting cable, a coupling system is to be provided to enable the submersible to be safety and efficiently coupled to and uncoupled from the launch and recovery system.

4.8 All interchangeable single components such as blocks, hooks, shackles, etc. are to conform to recognized standards, shall have a safety of 8 against fracture related to the safe working load **SWL** and are to be marked with their safe working load.

4.9 The maximum static tensile stress imposed on steel wire ropes by the safe working load may not exceed 1/8 of the proven rupture strength.

4.10 The use of ropes made of fibres is only permissible in special cases and with consent of **TL**. For the use of natural or synthetic fibres the maximum static tensile stress imposed by the safe working load may not exceed 1/10 of the proven rupture strength.

5. Coil-up/coil-off mechanism for umbilicals

5.1 Coil-up and coil-off mechanism for umbilicals describe the complete equipment for handling of the umbilical on the support ship. They may be of different types, but often an umbilical winch is an integrated part of this system.

5.2 An adequate coil-up and coil-off mechanism is to be provided for the umbilical, which is tracking the umbilical without restriction of the freedom to move and without additional mechanical loads to the element under water.
If a control for following up umbilicals (TMS – Tether Management System) is provided for the mechanism, the requirements of Annex E, B.2.2 are to be considered.

5.3 The following requirements are to be considered for the design of coil-up and coil-off mechanism for umbilicals:

– Specified operating conditions, e.g. wave height and type of support ship

– Safe working load **SWL** of the coil-up and coil-off mechanism for umbilicals considering the weight of the umbilical, its buoyancy in water (filled and empty) as well as the friction in water and dynamic effects, e.g. by the seaway

– The radius of the umbilical in the coil-up and coil-off mechanism is not to be less than the specified bending radius of the umbilical.

– The most unfavourable arrangement of the umbilical in relation to the coil-up and coil-off mechanism (e.g. coil-up angle, position of the winch drum, application of guide pulleys, etc.) is to be considered.

– The material Certificates have to be in accordance to the **TL** Rules, Chapter 50 – Lifting Appliances.

– The coil-up and coil-off mechanism have to have a power source which is in the condition to safely coil-up and coil-off the umbilical under the specified conditions.

– The coil-up and coil-off mechanism is to be equipped with auxiliary drives to be able to finish an already started coil-up and coil-off procedure in a safe way if the main drive respectively the hydraulic pump are failing.

– To avoid overstressing of umbilical and the coil- up and coil-off mechanism measuring of the tension force is to be provided at a suitable position of the system, which triggers an alarm at the control station in case of exceeding the safe working load **SWL**.

6. Documents for approval

The following documents are to be submitted:

6.1 Description of the system with definition of the mission conditions and technical data including recovery and launching speed.

6.2 Data about installation and connection conditions including operating plattform.

6.3 Design drawings of:

– Launch and recovery systems

– Coil-up and coil-off mechanism for umbilicals

– Substructure for gears and winches

6.4 Detailed drawings of exchangeable single parts and fittings or definition of the standards where they are based on.

6.5 Drawings of the machinery equipment like e.g. winches, drives, etc.

6.6 Connection diagram of the hydraulic and pneumatic systems.

6.7 Control scheme and description of the safety systems.

6.8 Information about nominal data and type of protection of the electrical installation

6.9 Data for lifting cables/umbilicals.

7. Tests and trials

7.1 Acceptance test

Before putting into operation of the launch and recovery system as well as the coil-up/coil-off mechanism for umbilicals an acceptance test with the following single tests is to be performed:

– Check that proofs are available for all exchangeable single parts

– The breaking strength of the used ropes is to be proven by a total rupture test and to be certified.

– Static test of the system at the manufacturer with a test load equal to 2,2 times the safe working load **SWL**

– Dynamic test (brake test) aboard with 1,25 times the safe working load **SWL**

– For an A-frame operated by two hydraulic cylinders an additional test with **SWL** and use of only one cylinder is to be performed.

– Check of minimum lifting speed

– Test that the procedure of launch and recovery of the submersible is performed in normal and emergency operation safely and without jerk

– Check of lifting cable coupling system, if applicable

– Test of function including safety and alarm systems

7.2 Repeated tests

For maintaining the Certificate the launching and recovery system is to be subjected to an annual survey.

For this the complete system including all lifting tackles is to be checked for visible damages, cracks, deformations and corrosion and is to be subjected to a functional test including a brake test (power failure).

Every 5 years a dynamic test with 1,25 times **SWL** including a brake test (energy failure) is to be performed.

8. Marking

The launch and recovery systems as well as the coil-up/coil-off mechanism for the umbilicals are to be marked with a fixed type plate at a good visible position which contains at least the following data:

– Manufacturer

– Serial number and year of construction

– Safe working load **SWL** [t]

– Load radius [m]

– Date of test and test stamp, for cranes at the bottom end of the right-hand jib member and next to the point where the member joints to the crane housing

F. Stowage and Deck Transport

1. General

1.1 As stowage and deck transport the transfer of the submersible recovered by the launch and recovery system to a deposit location aboard is to be understood. The deposit location is to be protected normally against environmental influences, especially if maintenance and repair work has to be done. The submersible is to be safely stowed and lashed for all thinkable ship movements.

If requested in addition the transport of a diving chamber to the decompression chamber resp. to its mating equipment is to be enabled.

1.2 If no adequate proof of suitability by e.g. test stamps, test marks, etc. for this equipment is existing (compare Section 1, Table 1.1) and **TL** is appointed to establish such a proof by the manufacturer or operator, the following requirements are to be recognized.

2. Principles for design and equipment

The requirements of the IMO Code A.714(17): "Code of the Safe Practice for Cargo Stowage and Securing" are to be considered.

2.1 Mechanical requirements

Aboard of the support ship and under consideration of maximum ship movements, sufficiently dimensioned measures, like cargo securing elements are to be provided from ship side for:

– Complete transport way

– Storage of the submersible/the diving chamber

– Lashing on deck or within the containers/hatches

– Lashing of containers with equipment

2.2 Electrical requirements

2.2.1 At the superstructures of the support ship a connecting possibility in form of a connecting plate with stay bolt preferably M 12 is to be provided at an easily accessible position, on which the protective conductor of the submersible/the diving chamber can be connected without using tools.

2.2.2 For the stay of the submersible resp. the diving chamber on deck of the support ship the measures defined in 2.2.1 are to be so arranged, that an uninterrupted equalization of the potential is possible.

2.2.3 Areas for transport and stowage are to be sufficiently illuminated.

2.3 Fire and explosion protection

The stowage location for the submersible/ the diving chamber on the support ship is to be equipped with suitable fire extinguishing systems. This system may be a part of the fire extinguishing system of the support ship.

Explosion protection measures for areas with explosion danger, from which the submersible shall undergo missions, are to be provided.

3. Documents for approval

The following documents are to be submitted:

- Plans with description of the transport, the stowage and the lashing measures including piece lists with the lashing material used
- Description with the electrical measures
- Description of the fire protection measures
- Description of the explosion protection measures

4. Tests and trials

4.1 Acceptance test

Before use of the stowage and transport system an acceptance test with the following single test is to be performed:

- Check that proofs are available for all exchangeable single parts
- Check, that proofs are available for the rupture strength of the used ropes
- Check that the transport of the submersible resp. the diving chamber in normal and emergency operation is safe and without jerk
- Functional test including check of the safety devices

4.2 Repeated tests

For maintaining the Certificate the systems are to be subjected to an annual survey.

For this the complete system including all lashing and transport devices is to be checked for cracks, deformations and corrosion and is to be subjected to a functional test.

G. Mating Equipment

1. General

For the transfer of divers under pressure from their working place under water to the support ship by a submersible with diver's lockout/diving chamber a suitable mating equipment at the decompression chamber on board the support ship is to be provided. The same is valid for the pre-compression of divers to their working conditions under water.

2. Between the mating equipment and the control station according to C.2. a communication system is to be established.

3. To proof the suitability of the pressure chamber with mating equipment a Certificate of a recognized institution is required. If the manufacturer or operator gives an order for the issuance of such a Certificate the requirements of the **TL** Rules Chapter 52 – Diving Systems, Section 2, J for the mating equipment and Section 2, K. for the hyperbaric rescue system are to be considered.

4. Documents for approval

The following documents are to be submitted:

– Description of system with data about operating conditions

– Data concerning installation and connecting conditions including control station

– Design drawings of the mating equipment

– Control scheme and description of the safety equipment

ANNEX A

CALCULATION OF THE PRESSURE HULL

A.	**GENERAL**	**A-**2
B.	**FATIGUE STRENGTH**	**A-**3
C.	**STRESSES AT NOMINAL DIVING PRESSURE**	**A-**3
D.	**STRESSES AT TEST DIVING PRESSURE**	**A-**4
E.	**PROOF OF ULTIMATE STRENGTH AT COLLAPSE DIVING PRESSURE**	**A-**4
F.	**CALCULATION**	**A-**4
G.	**LITERATURE**	**A-**32

A. General

1. Introduction

1.1 In the following a calculation method is described which investigates the stress and stability situation in the pressure hull for the load cases I, II and III with the pressures:

– Nominal diving pressure **NDP** (load case I according to **TL** Rules for Section 4, E.)

– Collapse diving pressure **CDP** (load case II)

– Test diving pressure **TDP** (load case III)

In the following the method of calculation for stiffened cylindrical shells is presented. For unstiffened cylindrical shells with dished ends the calculations are analogously performed for the sectional area of the stiffening ring A_{eff} = A_F = 0, whereas the buckling length is limited by the dished ends. If the buckling length is limited by dished ends, 40 % of the curve depth is to be added for each dished end to the cylindrical length.

The method of calculation presented takes account of manufacturing related deviations from the ideal form of the shell (e.g. out-off-roundness). The manufacturing tolerances defined in Annex B have to be applied for the calculation.

1.2 Conical shells are calculated in sections, each of which is treated like cylindrical shells.

1.3 The overall collapse of the construction is regarded as buckling of the pressure hull between bulkheads, web frames and dished ends.

For the states of stability described, proof is required of sufficient safety in respect to the particular form of damage concerned.

1.4 When using the method of calculation it is to observe, that both elastic and elastic-plastic behaviour can occur in the materials of the shell structure and the frames.

It is generally the case that:

– At nominal diving pressure, the stress is within the purely elastic range of the material

– At test diving pressure, the stress may lie at the commencement of the elastic-plastic range of the material

– But for calculation against exceeding of the permissible stress elastic material behaviour of the material can be assumed

– At collapse diving pressure, the stress may lie in the elastic or the elastic-plastic range of the material

1.5 When calculating a pressure hull the calculation data are to be introduced according to the planned operating conditions under consideration of **TL** Rules for Section 5, D.

1.6 Pressure hulls subjected to internal overpressure are to be calculated in addition according to the **TL** Rules for Chapter 4 – Machinery, Section 14.

2. Longitudinal strength

For the longitudinal strength of the pressure hull the longitudinal bending moments and shear forces are to be considered. It is to be checked only on request of **TL**.

3. Vessels similar to the pressure hull

For vessels which are partly or totally arranged like the pressure hull and from which the safety of the submersible depends in the same way, like e.g. entrance trunk, containers for rescue equipment, etc., the same proofs have to be carried out as for the pressure hull.

4. Acrylic windows

The requirements for design and manufacturing of acrylic windows are defined in Annex C.

B. Fatigue Strength

1. Proof of fatigue strength has to be carried out for load case I determined by nominal diving pressure **NDP** according to the **TL** Rules for Section 4, B.2.1. resp. Chapter 54 – Underwater Equipment, Section 3.

2. The proof of stresses is to be based on the nominal geometry.

3. For the calculation of the stresses in the pressure hull, the following influences have to be considered with sufficient accuracy:

– Increase of stress at frames, web frames, bulkheads and tripping/transition rings

– Increase of stress at penetrations

– Disturbances of the state of stress because of connection with pressure-proof extensions

C. Stresses at Nominal Diving Pressure

1. Proof of stress has to be carried out for load case I characterized by nominal diving pressure **NDP** according to the Rules for Section 4, B.2.1 respectively Chapter 54 – Underwater Equipment, Section 3.

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the Rules for Section 5, D.3.

3. The proof of stress has to be performed using the methods in F.1, F.6.2, F.4.4 (formula A59), F.7.2 and F.7.4.

D. Stresses at Test Diving Pressure

1. Proof of stresses has to be carried out for load case III characterized by test diving pressure **TDP** according to **TL** Rules for Section 4, B.2.2 respectively Chapter 54 – Underwater Equipment, Section 3.

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the **TL** Rules for Section 5, D.3.

3. For nominal diving pressures of at least 10 bar proof of strength for load case III can be omitted.

4. The proof of stress has to be performed using the methods in F.1, F.6.2, F.4.4 (formula A59), F.7.2 and F.7.4.

E. Proof of Ultimate Strength at Collapse Diving Pressure

1. The proof of ultimate strength has to be carried out for load case II characterized by the collapse diving pressure **CDP** according to the **TL** Rules for Section 4, B.2.3 respectively Chapter 54 – Underwater Equipment, Section 3 as proof of stability and stress.

For the following types of failure it has to be proven that the pressures for a failure are greater or equal to the collapse diving procedure:

– Symmetric buckling between the frames

– Asymmetric buckling between the frames

– General instability under consideration of the partial effect of the web frames

– Tilting of the frames

– Buckling of the dished ends and spheres

– Local yielding in the area of discontinuities

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the Rules for Section 5, D.3.

3. The proof of stress has to be performed using the methods in F.1, F.6.2, F.4.4, F.5.3, F.7.2 and F.7.4.

F. Calculation

1. Calculation of stresses in a uniformly stiffened cylinder or cone as a basis for the calculation of the collapse pressure

1.1 The geometrical situation is defined in Figure. A.1 and a summary of the stresses is given in Table A.1.

Designations in Fig. A.1:

R_m = Mean radius of the cylindrical shell

R = Internal radius of the cylindrical shell

s = Nominal wall thickness of the cylindrical shell after deduction of corrosion allowance c

h_w = Web height of the frame

s_w = Web thickness of the frame

b_f = Flange width

s_f = Flange thickness

L_F = Frame spacing

A_F = Cross sectional area of the frame

R_C = Radius to the centre of gravity of the frame cross section

R_f = Inner radius to the flange of frame

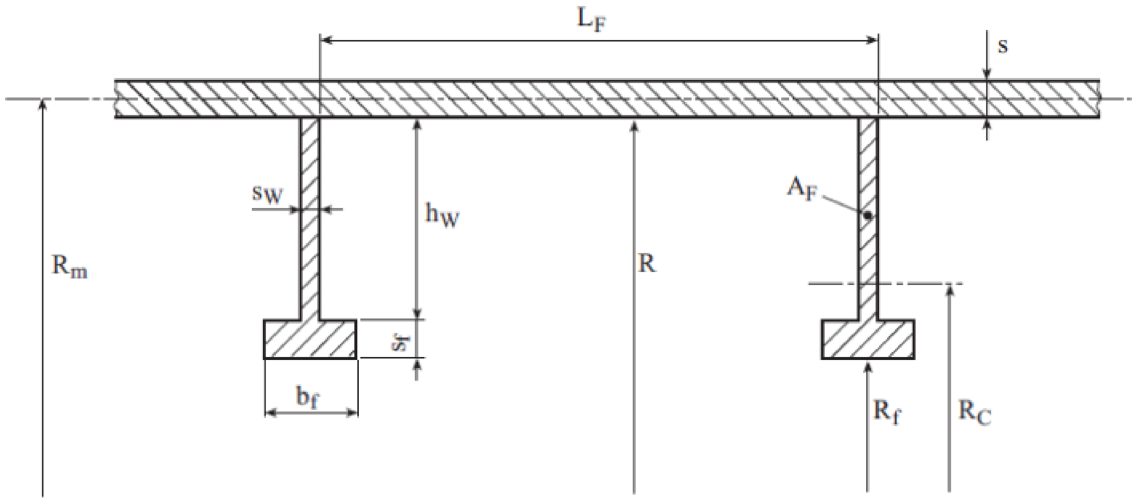

Figure. A.1 Geometrical situation of frames stiffening the pressure hull

Table A.1 Summary of stresses in a stiffened cylindrical shell

Types of stresses	At the frame			In the middle of the field		
	Circumferential	**Equivalent**	**Axial**	**Circumferential**	**Equivalent**	**Axial**
Membrane stress	$\sigma^{m}_{\varphi,F}$ (A19)		$\sigma^{m}_{x,F}$ (A17)	$\sigma^{m}_{\varphi,M}$ (A18)		$\sigma^{m}_{x,M}$ (A17)
Membrane equivalent stress		$\sigma^{m}_{v,F}$ (A14)			$\sigma^{m}_{v,M}$ (A14)	
Bending stresses	$\sigma^{b}_{\varphi,F}$ (A23)		$\sigma^{b}_{x,F}$ (A21)	$\sigma^{b}_{\varphi,M}$ (A22)		$\sigma^{b.}_{x,M}$ (A20)
Normal stress outside	$\sigma^{m}_{\varphi,F} + \sigma^{b}_{\varphi,F}$ (A19) (A23)		$\sigma^{m}_{x,F} + \sigma^{b}_{x,F}$ (A17) (A21)	$\sigma^{m}_{\varphi,M} + \sigma^{b}_{\varphi,M}$ (A18) (A22)		$\sigma^{m}_{x,M} + \sigma^{b}_{x,M}$ (A17) (A20)
Equivalent normal stress outside		$\sigma^{m+b}_{v,F,o}$ (A14)			$\sigma^{m+b}_{v,M,o}$ (A14)	
Normal stress inside	$\sigma^{m}_{\varphi,F} - \sigma^{b}_{\varphi,F}$ (A19) (A23)		$\sigma^{m}_{x,F} - \sigma^{b}_{x,F}$ (A17) (A21)	$\sigma^{m}_{\varphi,M} - \sigma^{b}_{\varphi,M}$ (A18) (A22)		$\sigma^{m}_{x,M} - \sigma^{b}_{x,M}$ (A17) (A20)
Equivalent normal stress inside		$\sigma^{m+b}_{v,F,i}$ (A14)			$\sigma^{m+b}_{v,M,i}$ (A14)	

Remark
The numbers in brackets represent the numbers of the formulas to be applied.

1.2 Calculation of factors and basic formulas

$$F_1 = \frac{4}{\theta}\left\{\frac{\cosh^2\eta_1 - \cos^2\eta_2\theta}{\frac{\cosh\eta_1\theta.\sinh\eta_1\theta}{\eta_1}+\frac{\cos\eta_2\theta.\sin\eta_2\theta}{\eta_2}}\right\} \quad (A1)$$

$$F_3\sqrt{\frac{3}{1-v^2}}\left\{\frac{\frac{\cosh\eta_1\theta.\sinh\eta_1\theta}{\eta_1}+\frac{\cos\eta_2\theta.\sin\eta_2\theta}{\eta_2}}{\frac{\cosh\eta_1\theta.\sinh\eta_1\theta}{\eta_1}+\frac{\cos\eta_2\theta.\sin\eta_2\theta}{\eta_2}}\right\} \quad (A3)$$

$$F_2 = \frac{\frac{\cosh\eta_1\theta.\sin\eta_2\theta}{n_2}+\frac{\sinh\eta_1\theta.\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\sinh\eta_1\theta}{\eta_1}+\frac{\cos\eta_2\theta\sin\eta_2\theta}{\eta_2}} \quad (A2)$$

$$F_4 = \sqrt{\frac{3}{1-v^2}}\left\{\frac{\frac{\cosh\eta_1\theta.\sin\eta_2\theta}{\eta_2}-\frac{\sinh\eta_1\theta.\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta.\sinh\eta_1\theta}{\eta_1}+\frac{\cos\eta_2\theta.\sin\eta_2\theta}{\eta_2}}\right\} \quad (A4)$$

$$p^* = \frac{2\cdot E.s^2}{R_m^2\sqrt{3\left(1-v^2\right)}} \quad (A5)$$

E = Modulus of elasticity

= $2{,}06\cdot10^5$ N/mm² for ferritic steel

= Adequate values for other materials to be agreed

v = Poisson ratio in elastic range

= 0,3 for steel

v_p = Poisson ratio in elastic-plastic range

$$\gamma = \frac{p}{p^{*}} \qquad (A6)$$

P = Calculation pressure

= Alternatively **NDP, TDP** and **CDP**

$$\eta_1 = \frac{1}{2}\sqrt{1-\gamma} \qquad (A7)$$

$$\eta_2 = \frac{1}{2}\sqrt{1-\gamma} \qquad (A8)$$

$$L = L_F - s_w \qquad (A9)$$

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1-v^2\right)}}\sqrt{R_m \cdot s} \qquad (A10)$$

$$A_{eff} = A_F \frac{R_m}{R_C} \qquad (A11)$$

$$\theta = \frac{2 \cdot L}{L_{Eff}} \qquad (A12)$$

For the stress designations the following indices are valid:

0 – Reference value

m – Membrane stres

b – Bending stres

v – Equivalent stres

x – Longitudinal direction

φ – Circumferential direction

r – Radial direction

t – Tangential direction

o – Outer side

i – Inner side

F – At the frame

D – At the web frame

F/D – At the frame/ at the web frame

M – In the middle of the field

f – In the flange of the frame

w – In the web of the frame

C – At the centre of gravity of the frame cross section

c – In the crown of the dished ends

The reference stress is the circumferential stress in the unstiffened cylindrical pressure hull:

$$\sigma_o = -\frac{p \cdot R_m}{s} \qquad (A13)$$

The equivalent stresses are composed of the single stresses in longitudinal and circumferential direction:

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_\varphi^2 - \sigma_x \cdot \sigma_\varphi} \qquad (A14)$$

The radial displacement in the middle between the frames w_M:

$$W_M = -\frac{p \cdot R_m^2}{E \cdot s}\left(1 - \frac{v}{2}\right)\left\{1 - \frac{A_{eff} . F_2}{A_{eff} + s_w \cdot s + L \cdot s \cdot F_1}\right\} \qquad (A15)$$

The radial displacement at the frames w_F:

$$W_F = -\frac{p \cdot R_m^2}{E \cdot s}\left(1 - \frac{v}{2}\right)\left\{1 - \frac{A_{eff} . F_2}{A_{eff} + s_w \cdot s + L \cdot s \cdot F_1}\left[\cosh\eta_1\theta \cos\eta_2\theta + \frac{\sqrt{\frac{1-v^2}{3}}\frac{F_4}{F_2} + \gamma}{4 \cdot \eta_1 \cdot \eta_2}\sinh\eta_1\theta \cdot \sin\eta_2\theta\right]\right\} \qquad (A16)$$

Average membrane stress in longitudinal direction (independent of the longitudinal coordinate x):

$$\sigma_x^m = -\frac{p \cdot R_m}{2 \cdot s} \qquad (A17)$$

Membrane stress in circumferential direction in the middle between the frames:

$$\sigma_{\varphi,M}^m = E\frac{W_M}{R_m} + v \cdot \sigma_x^m \qquad (A18)$$

and at the frames:

$$\sigma_{\varphi,F}^m = E\frac{W_F}{R_m} + v \cdot \sigma_x^m \qquad (A19)$$

Bending stresses in longitudinal direction in the middle between the frames:

$$\sigma^{b}_{x,M} = \pm \sigma_{o}\left(1-\frac{v}{2}\right)F_{4}\frac{A_{eff}}{A_{eff}+s_{w}\cdot s+L\cdot s\cdot F_{1}} \qquad (A20)$$

and at the frames:

$$\sigma^{b}_{x,F} = \pm\left(\sigma_{o}-\sigma^{m}_{\varphi,F}\right)F3 \qquad (A21)$$

The positive sign is valid for the outside of the cylindrical shell, the negative preceding sign for the iner side.

Bending stresses in circumferential direction in the middle between the frames:

$$\sigma^{b}_{\varphi,M} = v\cdot\sigma^{b}_{x,M} \qquad (A22)$$

and at the frames:

$$\sigma^{b}_{\varphi,F} = v\cdot\sigma^{b}_{x,F} \qquad (A23)$$

The circumferential stress follows from the radial displacement to:

$$\sigma^{m}_{\varphi,Fw} = E\frac{W_{F}}{R_{f}} \qquad (A24)$$

in the frame foot,

respectively

$$\sigma^{m}_{\varphi,Ff} = E\frac{W_{F}}{R_{f}} \qquad (A25)$$

in the frame flange.

The equivalent stresses as well as the circumferential stresses in the frame summarized in Table A.1 are to be limited with the value of the permissible stresses $\sigma_{zul,NDP}$, $\sigma_{zul,TDP}$ resp. $\sigma_{zul,CDP}$ belonging to each load case according to **TL** Rules for Section 5, D.3.

1.3 Calculation of the stresses for a conical pressure hull

The formulas given above are also applicable to stiffened conical shells.

The relevant formulas have to be modified using the half apex angle α. For this, the mean radius yields to:

$$R_{m,eqv} = R_{m}/\cos\alpha \qquad (A26)$$

and the equivalent frame spacing turns to:

$$L_{F,eqv} = L_F / \cos\alpha, \text{resp.} \qquad (A27)$$

$$L_{eqv} = L / \cos\alpha$$

R_m = radius midway between the frames of the area under consideration

The calculation has to be carried out for both frames of the bay under evaluation. The dimensions of the frames have to be multiplied by the radius ratio $R_m/R_{m,F}$. For the following calculation of the collapse pressures the (absolutely) greatest value is decisive.

2. Calculation of the collapse pressure for the asymmetric interstiffener buckling of the shell in uniformly stiffened sections of the pressure hull

2.1 For conical pressure hulls the same values as defined for the stress calculation above are to be used.

For calculation of the minimum buckling pressure which depends on the number of circumferential lobes, the following approximation may be used:

2.2 Elastic buckling pressure

$$p_{cr}^{el} = \frac{2 \cdot \pi^2 \cdot E \cdot f}{3 \cdot \Phi \cdot \left(1 - \nu^2\right)} \cdot \left(\frac{s}{R_m}\right)^2 \cdot \frac{\frac{R_m \cdot s}{L^2}}{3 - 2 \cdot \Phi \cdot (1 - f)} \qquad (A28)$$

Theoretical elastic-plastic pressure:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{1 - \nu^2}{1 - \nu_p^2} \cdot \left\{ \frac{E_t}{E} \cdot \left(1 - \frac{3\Phi}{4}\right) + \frac{E_s}{E} \cdot \frac{3\Phi}{4} \right\} \qquad (A29)$$

with:

$$\Phi = 1{,}23 \frac{\sqrt{R_m \cdot s}}{L} \qquad (A30)$$

$$f = \frac{\sigma_x^m}{\sigma_{\varphi,M}^m} \qquad (A31)$$

$$\sigma_v = \sqrt{\left(\sigma_{\varphi,M}^m\right)^2 + \left(\sigma_x^m\right)^2 - \sigma_{\varphi,M}^m \cdot \sigma_x^m} \qquad (A32)$$

For secant module:

$$E_s = \frac{\sigma_v}{\varepsilon_v} \qquad (A33)$$

For tangential module:

$$E_t = \frac{d\sigma_v}{d\varepsilon_v} \qquad (A34)$$

For elastic-plastic Poisson's ratio:

$$\nu_p = 0{,}5 - (0{,}5 - \nu)\frac{E_s}{E} \qquad (A35)$$

f, σ_v, E_s, E_t are functions of the elastic-plastic buckling pressure p_{cr}^{i} to be determined. For the iterative evaluation of the value f can be computed for the calculation pressure **CDP** and be assumed as constant in the following calculation. σ_v can be determined by linear extrapolation starting from the value of the calculation pressure **CDP**.

2.3 Secant module and tangential module of steels

For various types of steel is valid:

$$z = \frac{\sigma_e}{\sigma_{0,2}} \qquad (A36)$$

σ_e = limit of proportional extension

$\sigma_{0,2}$ = 0,2 % yield strength, R_{eH}

z = 0,8 for ferritic steel
= 0,6 for austenitic steel

If $\sigma_v > \sigma_e$ the formulas defined in 2.3.1 and 2.3.2 are valid.

For $\sigma_v \leq \sigma_e$ is valid:

$$E_s = E_t = E \qquad (A37)$$

2.3.1 Modules for z ≥ 0,8

$$E_t = E \cdot \left\{1 - \left(\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z)\cdot \sigma_{0,2}}\right)^2\right\} \qquad (A38)$$

$$E_s = E \cdot \frac{\sigma_v}{\sigma_{0,2}\left(z + (1-z)\,\text{arc tanh}\,\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z)\cdot \sigma_{0,2}}\right)} \qquad (A39)$$

2.3.2 Modules for z < 0,8

$$E_t = E \cdot \left\{1 - k\left(\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z)\cdot \sigma_{0,2}}\right)\right\} \qquad (A40)$$

$$E_s = E \cdot \frac{\sigma_v}{z \cdot \sigma_{0,2} - \frac{1}{k}(1-z)\cdot \sigma_{0,2}\,\text{In}\left(1 - k\,\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z)\cdot \sigma_{0,2}}\right)} \qquad (A41)$$

k has to be calculated from the condition:

$$\sigma_{0,2} + 0{,}002 \cdot E = z \cdot \sigma_{0,2} - \frac{1}{k}(1-z) \cdot \sigma_{0,2} \cdot \ln(1-k) \qquad (A42)$$

at least with the accuracy of two decimals.

2.4 Secant modules and tangent modules for other metallic materials

For other metallic materials z is to be agreed.

2.5 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure p_{cr}^{i} multiplied by the reduction factor r, is at least equal to the calculation pressure **CDP** of the pressure hull.

With the reduction factor:

$$r = 1 - 0{,}25 \cdot e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \qquad (A43)$$

3. Calculation of the collapse pressure for the symmetric interstiffener buckling of the shell in uniformly stiffened sections of the pressure hull

3.1 For conical pressure hulls the equivalent values as defined for the stress calculation above have to be used.

3.2 Elastic buckling pressure:

$$p_{cr}^{el} = \frac{2}{\sqrt{3\left(1-v^2\right)}} \cdot E \cdot \frac{s^2}{R_m^2} \left\{ \left[\frac{2 \cdot L}{\pi \cdot L_{eff}}\right]^2 + \frac{1}{4}\left[\frac{\pi \cdot L_{eff}}{2 \cdot L}\right]^2 \right\} \qquad (A44)$$

Theoretical elastic-plastic buckling pressure:

$$p_{cr}^{i} = \frac{2}{\sqrt{3\left(1-v^2\right)}} \cdot E_s \cdot \frac{s^2}{R_m^2} \cdot C \cdot \left\{ \left[\frac{\alpha \cdot L}{\pi}\right]^2 + \frac{1}{4}\left[\frac{\pi}{\alpha \cdot L}\right]^2 \right\} \qquad (A45)$$

With:

$$\alpha = \sqrt[4]{\frac{3\left(\frac{A_2}{A_1} - v_p^2 \frac{A_{12}^2}{A_1^2}\right)}{R_m^2 \cdot s^2}} \qquad (A46)$$

$$C = \sqrt{\frac{A_1 \cdot A_2 - v_p^2 \cdot A_{12}^2}{1 - v_p^2}} \qquad (A47)$$

$$v_p = \frac{1}{2} - \frac{E_s}{E}\left(\frac{1}{2} - v\right) \qquad (A48)$$

$$A_1 = 1 - \frac{1 - E_t/E_s}{4\left(1 - v_p^2\right)K^2 \cdot H}\left[\left(2 - v_p\right) - \left(1 - 2 \cdot v_p\right)k\right]^2 \qquad (A49)$$

$$A_2 = 1 - \frac{1 - E_t/E_s}{4\left(1 - v_p^2\right)K^2 \cdot H}\left[\left(1 - 2 \cdot v_p\right) - \left(2 - v_p\right)k\right]^2 \qquad (A50)$$

$$A_{12} = 1 + \frac{1 - E_t/E_s}{4v_p\left(1 - v_p^2\right)K^2 \cdot H}\left[\left(2 - v_p\right) - \left(1 - 2 \cdot v_p\right)k\right] \cdot \left[\left(1 - 2 \cdot v_p\right) - \left(2 - v_p\right)k\right] \qquad (A51)$$

$$H = 1 + \frac{1 - E_t/E_s}{4\left(1 - v_p^2\right)K^2}\left\{\left[\left(2 - v_p\right) - \left(1 - 2 \cdot v_p\right)k\right]^2 - 3\left(1 - v_p^2\right)\right\} \qquad (A52)$$

$$k = \frac{\sigma_{\varphi,M}^m}{\sigma_x^m} \qquad (A53)$$

$$K^2 = 1 - k + k^2 \qquad (A54)$$

The procedure for the evaluation of the theoretical elastic-plastic buckling pressure is analogous to that described for asymmetric buckling.

3.3 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure p_{cr}^i multiplied by the reduction factor r, is at least equal to the calculation pressure **CDP** of the pressurehull.

With the reduction factor:

$$r = 1 - 0{,}25\, e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \qquad (A55)$$

4. Proof of the collapse pressure for the general instability under consideration of the web frames

4.1 The proof of the general instability has to be done on the basis of a stress calculation which meets the equilibrium criteria in a deformed state. As pre-deformation, the out-of-roundness of the frames has to be considered. It has to be proven, that the out of roundness permissible according to Annex B can not lead to a global collapse.

4.2 Consideration of the stress-strain behaviour

For austenitic steels and other materials, for which $\sigma_{0,01} < 0{,}8 \cdot \sigma_{0,2}$ is valid, the actual stress-strain behaviour has to be considered by adequate calculation. The pressure hull, pre-deformed to the permissible out-of roundness and inclinations of the frames, has to be incrementally pressure loaded. For the calculation of the increasing elastic displacement and stresses, the deformations in equilibrium condition and the actual, local material behaviour have to be considered.

For materials with $\sigma_{0,01} > 0,8 \cdot \sigma_{0,2}$ a linear elastic behaviour can be assumed for a stress calculation according to a theory of 2nd order. In this case the following stress limits (without consideration of local weaknesses) have to be met:

– The sum of basic stress and stress due to out-of-roundness in the frame flange shall not exceed $\sigma_{0,2}$.

– The sum of basic stress and stress due to out-of-roundness in the web frame flange shall not exceed 80 % of $\sigma_{0,2}$.

4.3 The calculation procedure is described in the following:

Definitions:

p = Collapse diving pressure of the pressure hull **CDP**

$n \geq 2$ = Number of circumferential lobes of out-of- roundness

w_0 = Maximum permissible out-of-roundness of the pressure hull according to Annex B

R_m = Mean radius of the pressure hull in the con- sidered field

$R_{m,F/D}$ = Mean radius of the pressure hull at particular frame or web frame

e = Distance from the centroid of the frame or web frame plus the effective length of shell to the furthest surface of the flange (see Figure. A.2). For conical shells e' =e/cosα is valid.

R_C = Radius to the centroid of the frame or web frame cross section

L_D = Length of the generating shell line at the considered area of the web frame

$L_{D,r}$, $L_{D,1}$ = Length of the generating shell line of the left hand or the right hand adjacent field, depending on the field boundary for which the proof is made (see Figure. A.3)

L_B = Distance between bulkheads

$$\beta_D = \frac{\pi \cdot R_m}{L_D} ; \beta_B = \frac{\pi \cdot R_m}{L_B} \qquad (A56)(A57)$$

α = Half apex angle (see Figure. A.2)

Generally the apex angle is not constant, neither in the actual web frame field nor in the adjacent field. Which angle is decisive will be described in the following for each particular case.

I, I_D = Area moment of inertia of frame respectively web frame including effective length of pressure hull shell, to be assumed always paralel to the axis of the pressure hull

The effective length is:

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1-v^2\right)}} \sqrt{R_{m,F} \cdot s / \cos\alpha} \qquad (A58)$$

but not greater than the average value of both adjacent frame distances.

α_{D1}, α_{Dr} = The local half apex angle at the adjacent web frame, right or left

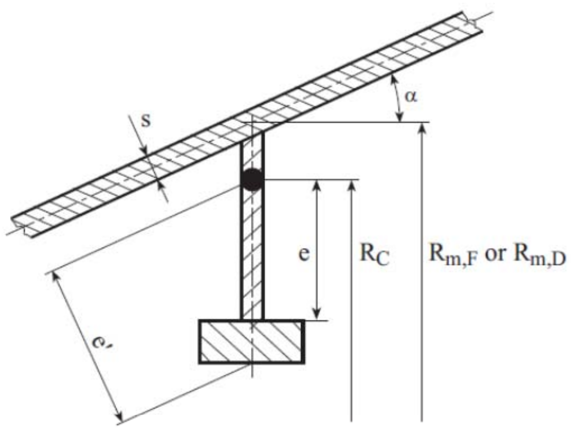

Figure. A.2 Situation at a frame or web frame

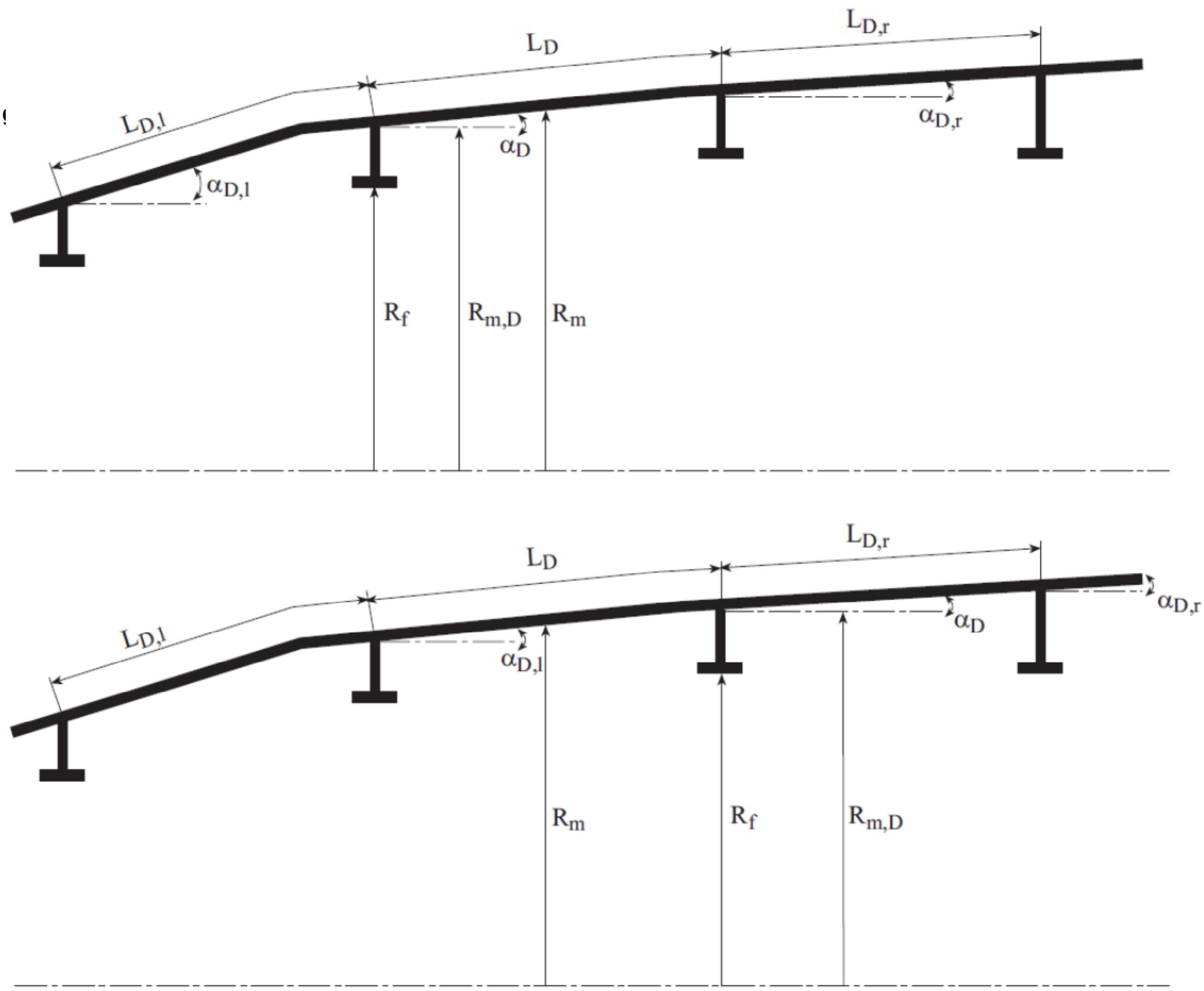

Figure. A.3 General stability - both calculation cases for a conical pressure hull

The area moment of inertia has to be converted to the radius R_m of the actual field by multiplying them by the ratio $(R_m/R_{m,F})^4$.

The proof has to be done for each section of the pressure hull, bounded by web frames, bulkheads or dished ends. Dished ends are to be considered as bulkheads.

A pressure hull section relevant for general instability may be limited by two web frames, followed by two adjacent web frame (or bulkhead) fields at each end, compare Figure. A.3. The calculation has to be performed for both relevant, adjacent fields in question. The most unfavourable case is decisive.

4.4 Basic stress in the frames and in the web frames

The basic stress in a frame flange has to be calculated according to 1.2, equation (A25) for R = R_f.

The effect of the half apex angle α is explicitly considered in the following formulas.

The basic stress in a deep frame can be conservatively evaluated according to the following formulas:

$$\sigma_{\varphi,D} = -\frac{p \cdot R_m \cdot L_{eff}\,(1 - v/2)\dfrac{R_m}{R_f}}{A_D \dfrac{R_m}{R_D} + Leff \cdot s}\,\frac{1}{\cos\alpha} \qquad (A59)$$

R_f = Radius of the flange

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1 - v^2\right)}}\sqrt{R_m \cdot s/\cos\alpha} \qquad (A60)$$

It has to be observed that A_D is the sole section area of the web frame and R_D the corresponding radius. For the thickness of the shell s the locally reinforced shell thickness at the web frame has to be used, if applicable.

The bending stress in the frame respectively web frame is:

$$\sigma_{\varphi,D} = \pm w_{el} \cdot E \cdot e \frac{n^2 - 1}{R_C{}^2} \qquad (A61)$$

R_C = see Figure. A.2

The elastic deflection w_{el} for the frames reads:

$$w_{el} = w_0 \frac{p}{p_g^n - p} \qquad (A62)$$

and for web frames:

$$w_{el} = w_0 \frac{p}{p_g^n - p}\,\frac{p_m}{p_m + p_D} \qquad (A63)$$

With the membrane part:

$$p_m = \frac{E \cdot s}{R_m} \cos^3 \alpha \frac{\beta^4}{\left(n^2 - 1 + \beta^2 / 2\right)\left(n^2 + \beta^2\right)^2} \qquad (A64)$$

α is the average half apex angle and s the average cylinder shell thickness in the considered field.

And with the web frame part p_D:

$$p_D = \frac{2\left(n^2 - 1\right) E \cdot I_D \cdot \cos^3 \alpha}{R_{C,D}^2 \left[R_m - 4\left(R_m - R_{C,D}\right)\right]\left(L_D + L_{D,1/r}\right)} \cdot \frac{n^2 - 1}{n^2 - 1 + \beta_B^2 / 2} \qquad (A65)$$

α is the maximum half apex angle along the pressure hull section starting at the middle of the field under consideration and ending at the middle of the adjacent field:

$$\alpha_{max} = \max\left(\alpha; \alpha_{Dl}\right) \text{resp} \cdot \alpha_{max} = \max\left(\alpha; \alpha_{Dr}\right)$$

see Figure. A.3

$R_{C,D}$ applies to web frames.

The total instability pressure p_g^n has to be evaluated as follows:

$$p_g^n = p_F + \frac{p_m \cdot p_D}{P_m + P_D} + p_B \qquad (A66)$$

Using p_m and p_D described above, and the frame part p_F as well as the bulkhead part p_B as follows:

$$P_F = \frac{\left(n^2 - 1\right) E \cdot I_F}{R_{C,F}^3 \cdot L_F} \cos^4 \alpha \frac{n^2 - 1}{n^2 - 1 + \beta^2 \frac{1}{2} \frac{p_D}{p_D + p_m}} \qquad (A67)$$

$R_{C,F}$ applies to frames.

$$p_B = \frac{E \cdot s}{R_m} \cos^3 \alpha \frac{\beta_B^4}{\left(n^2 - 1 + \beta_B^2 / 2\right)\left(n^2 + \beta_B^2\right)^2} \qquad (A68)$$

α is here to be understood as the average half apex angle in the field considered.

The frame part has to be calculated with the dimensions of an equivalent frame including equivalent frame spacing. Generally these are the dimensions of the frame closest to the midway point of the field under evaluation, which have to be converted to the average field radius in a manner described in 1.3.

The following condition has to be met:

For each frame of the considered field the permissible out-of-roundness has to be calculated for n = 5, assuming for p_g^5

an infinitive field length (β_D = 0). The arithmetic average of the out-of-roundness values evaluated in this way for three adjacent frames divided by the related frame radius shall not be less than the out-of-roundness for the equivalent frame evaluated in analogous way.

5. Proof of the collapse pressure for tripping of frames

5.1 Stability against tripping

The proof of the tripping stability has to be done for frames and web frames on the basis of a stress calculation,which fulfils the status of equilibrium in deformed condition. As pre-deformations the tolerances of the frames as defined in Annex B may be considered

Concerning the consideration of the stress-strain behaviour the rules defined in 4.2 are valid.

For materials with $\sigma_{0,01} \geq 0,8 \,.\, \sigma_{0,2}$ linear elastic behaviour can be assumed for a stress calculation according to 2nd order theory. The following stress limits have to be observed (disregarding local material weakening):

– The equivalent stress in frame web shall not exceed $\sigma_{0,2.}$

– The circumferential stress in frame flange shall not exceed $\sigma_{0,2}$.

The effects to be considered in this procedure are defined further on.

5.2 Additional stresses caused by frame imperfections

The additional stresses caused by imperfections of the frame cross section have to be evaluated for internal frames according to the following formulas. See also Figure A.4.

The imperfections "inclination of web to plane of frame Θ", " eccentricity of flange to web u_{ex}" and "misalignment of frame heel to frame plane d" are defined in Annex B, C.2.5 to C.2.7.

$$h'_w = h_w + \frac{s_f}{2} \qquad (A69)$$

$$\beta = \frac{h'_w}{R} \qquad (A70a)$$

$$R'_f = R_f + \frac{s_f}{2} \qquad (A70b)$$

$$\beta_f = \frac{h'_w}{R'_f} \qquad (A71)$$

$$A'_f = b_f s_f - \frac{s_f \cdot s_w}{2} \qquad (A72)$$

$$I_f = \frac{b_f^3 \cdot s_f}{12} \qquad (A73)$$

$$J_f = \frac{b_f \cdot s_f^3}{6(1+v)} \qquad (A74)$$

$$A'_w = h'_w \cdot s_w \tag{A75}$$

$$D = \frac{E \cdot s_w^3}{12\left(1 - v^2\right)} \tag{A76}$$

$$L_o = \frac{\sigma_0 \cdot A_F}{R} \tag{A77}$$

$$F_f = \sigma_0 \cdot A'_f \tag{A78}$$

σ_0 = Basic stress in flange according to 5.3 / 5.4.

$$\lambda = \frac{A'_w}{A_F} \tag{A79}$$

n = number of circumferential lobes of imperfections; the calculation has to be performed for n = 3.

$$e = \frac{h'^2_w \cdot L_0}{D} - 2 \cdot n^2 \cdot \beta^2 \tag{A80}$$

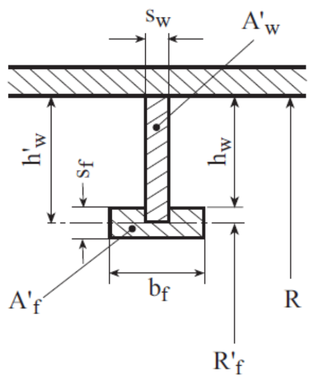

Figure. A.4 Local situation at the frame

$$\varepsilon = \lambda \frac{h'^2_w \cdot L_0}{D} \tag{A81}$$

$$g = n^2 \cdot \beta \left(\lambda \frac{h'^2_w \cdot L_0}{D} - n^2 \cdot \beta^3 \right) \tag{A82}$$

$$k_{11} = 12 - 1{,}2 \cdot e + 0{,}6 \cdot \varepsilon - \frac{13}{35} g \tag{A83}$$

$$k_{12} = 6 - 0{,}1 \cdot e - \frac{11}{210} g + v \cdot n^2 \cdot \beta^2 \tag{A84}$$

$$k_{22} = 4 - \frac{2}{15} e + 0{,}1 \cdot \varepsilon - \frac{g}{105} \tag{A85}$$

$$k_{31} = 6 - 0{,}1 \cdot e + 0{,}1 \cdot \varepsilon + \frac{13}{420} g \tag{A86}$$

$$k_{32} = 2 + \frac{e}{30} - \frac{\varepsilon}{60} + \frac{g}{140} \qquad (A87)$$

$$A_{11} = \frac{n^2 E}{R_f^4}\left(n^2 \cdot I_f + J_f\right) + \frac{D}{h_w'^3} k_{11} - n^2 \frac{F_f}{R_f^2} \qquad (A88)$$

$$A_{12} = \frac{n^2 \cdot E}{R_f^3}\left(I_f + J_f\right) - \frac{D}{h_w'^2} k_{12} \qquad (A89)$$

$$A_{22} = \frac{E}{R_f^2}\left(I_f + n^2 \cdot J_f\right) + \frac{D}{h_w'} k_{22} \qquad (A90)$$

Amplitudes of the elastic displacement u and twist ω of the connection web-flange:

$$u = \frac{1}{Det}\left(B_1 \cdot A_{22} - B_2 \cdot A_{12}\right) \qquad (A91)$$

$$\omega = \frac{1}{Det}\left(B_2 \cdot A_{11} - B_1 \cdot A_{12}\right) \qquad (A92)$$

with

$$Det = A_{11} \cdot A_{22} - A_{12}^2 \qquad (A93)$$

$$B_1 = \theta\left[\frac{F_f}{R_f}\left(1 + n^2 \cdot \beta_f\right) - L_0 \cdot \lambda \cdot k_{1,\theta}\right] + u_{ex}\frac{F_f}{R_f \cdot h_w'} \cdot n^2 \cdot \beta_f + d\,\frac{L_0 \cdot n^2 \cdot \beta_f}{h_w'}\left[(1-\lambda)\frac{R}{R_f} - \lambda \cdot k_{1,d}\right] \qquad (A94)$$

$$B_2 = -\theta \cdot L_0 \cdot \lambda \cdot h_w' \cdot k_{2,\theta} + u_{ex}\frac{F_f}{R_f} - d \cdot L_0 \cdot \lambda \cdot n^2 \cdot \beta_f \cdot k_{2,d} \qquad (A95)$$

where

$$k_{1,\theta} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0{,}013 \cdot g + 0{,}015 \cdot e^2 - 0{,}025 \cdot e \cdot \varepsilon - 0{,}7 \cdot n^2 \cdot \beta\right) \qquad (A96)$$

$$k_{1,d} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0{,}013 \cdot g + 0{,}015 \cdot e^2 - 0{,}025 \cdot e \cdot \varepsilon\right) \qquad (A97)$$

$$k_{2,\theta} = \frac{1}{12}\left[1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0{,}008 \cdot e^2 + 0{,}013 \cdot e \cdot \varepsilon + 0{,}6 \cdot n^2 \cdot \beta\left(1 + \frac{19 \cdot e}{1260} + \frac{25 \cdot \varepsilon}{336}\right)\right] \qquad (A98)$$

$$k_{2,d} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0{,}008 \cdot e^2 + 0{,}013 \cdot e \cdot \varepsilon\right) \qquad (A99)$$

Stresses in the flange are as follows:

$$\sigma_{r,F/Df}^{b} = \pm\frac{E \cdot b_f}{2.R_f^2}\left(n^2 \cdot u + R_f \cdot \omega\right) \qquad (A100)$$

Bending stress around radial axis, and

$$\tau_{t,F/Df} = \frac{n \cdot E \cdot s_f}{2(1+v)R_f^2}\left(u + R_f \cdot \omega\right) \qquad (A101)$$

Torsion around the tangential axis, which is phaseshifted against $\sigma^b_{r,F/Df}$ by a quarter period.

The bending stress at the toe of the web is:

$$\sigma^b_{r,F/Dw} = \pm\frac{6}{s_w^2}\left[\frac{D}{h'^2_w}\left(k_{31} \cdot u - k_{32} \cdot h'_w \cdot \omega\right) + \lambda L_0\left(k_{3,\theta} \cdot h'_w \cdot \theta + k_{3,d} \cdot n^2 \cdot \beta \cdot d\right)\right] \qquad (A102)$$

with

$$k_{3,\theta} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{140} + 0{,}4 \cdot n^2 \cdot \beta \cdot (1 + 0{,}019 \cdot e - 0{,}009 \cdot \varepsilon)\right) \qquad (A103)$$

and

$$k_{3,d} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{140}\right) \qquad (A104)$$

The stresses resulting from imperfections of the frames are to be checked for frames and web frames, using different procedures.

5.3 Frames

For the stress σ_0 always $\sigma_{0,2}$ of the frame material has to be used.

The bending rigidity of the flange has to be neglected, i.e. set to zero ($I_f = 0$).

The equivalent stress at the web toe has to be evaluated with the calculation pressure for both signs of the bending $\sigma^b_{r,Fw}$ stress b according to formula (A102).

Circumferential stress:

$$\sigma^{m+b}_{\varphi,F} = \sigma^m_{\varphi,Fm} + \frac{e_2}{e_1} \cdot \sigma_{O/R} \pm v \cdot \sigma^b_{r,Fw} \qquad (A105)$$

with $\sigma^m_{\varphi,Fw}$ according to 1.2, equation (A24), compare Figure. A.5 and

$$\sigma_{O/R} = \sigma_{0,2} + \sigma^m_{\varphi,Ff} \qquad (A106)$$

with $\sigma^m_{\varphi,Ff}$ according to 1.2, equation (A25)

Radial stress:

$$\sigma_r = -\frac{L_0}{s_w} \pm \sigma_{r,Fw}^{b} \qquad (A107)$$

The equivalent stress:

$$\sigma_v = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi \cdot \sigma_r} \qquad (A108)$$

shall not exceed $\sigma_{0,2}$

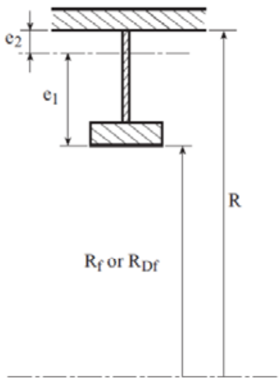

Figure. A.5 Situation of the frame in relation to the axis of the pressure hull

5.4 Web frames

For the basic stress in the flange σ_0 the absolute value of the circumferential stres $\left|\sigma_{\varphi,D}\right|$ according to Formula (A59) has to be taken, as obtained for the half value of the permissible out-of-roundness resulting from the general instability proof performed for n = 2 circumferential lobes according to 4.

It has to be proven that:

a) $$\sigma_0 + \left|\sigma_{r,Df}^{b}\right| \le \sigma_{0,2} \qquad (A109)$$

b) $$\sqrt{\sigma_0^2 + 3 \cdot \tau_{t,Df}^2} \le \sigma_{0,2} \qquad (A110)$$

with $\sigma_{r,Df}^{b}$ according to formula (A100) and $\tau_{t,Df}$ according to formula (A101) considering the relevant dimensions of the web frames and the equivalent stress at the web toe

$$\sigma_V = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi \cdot \sigma_r} \le \sigma_{0,2} \qquad (A111)$$

The circumferential stress σ_φ is the sum of the basic stress $\sigma_{\varphi,D}$ obtained with the formula (A59) in 4.4 and v-times the web bending stress $\sigma_{r,Dw}^{b}$ according to formula (A102):

$$\sigma_\varphi = \sigma_{\varphi,D} + \nu \cdot \sigma_{r,Dw}^{b} \qquad (A112)$$

The radial stress is:

$$\sigma_r = \frac{-A_f \cdot \sigma_0 + A_w \cdot \sigma_D}{R_D \cdot s_w} \pm \sigma^b_{r,Dw} \qquad (A113)$$

For calculation of σ_0 the following simplified Formula can be used:

$$\sigma_0 = \frac{1}{2}\left|\sigma_{\varphi,D}\right| + 0{,}4 \cdot \sigma_{0,2} \qquad (A114)$$

5.5 Modifications for frames arranged outside

For frames arranged outside all radii (R, R_f, R_{Df}) have to be applied as negative values.

6. Spherical shells and dished ends

6.1 General

Spherical shells and dished ends are to be investigated for the load cases defined in **TL** Rules for Section 4, E. respectively Chapter 54 – Underwater Equipment, Section 3. against exceeding stresses and buckling. For dished ends the stresses in the crown and the knuckle are to be investigated. Spheres are to be treated like the crown area of dished ends.

6.2 Stresses

For the crown area the stress results from Formula (A118). For the knuckle area the stress can be evaluated by formula (A119). The coefficients β are to be determined according to the **TL** Rules for Chapter 4 – Machinery, Section 12, D.4.3.2. They can also be evaluated directly with assistance of the following formulas:

For torispherical ends:

$$\beta = 0{,}6148 - 1{,}6589 \cdot x - 0{,}5206 \cdot x^2 - 0{,}0571 \cdot x^3 \qquad (A115)$$

And for semi-ellipsoidal ends:

$$\beta = 1{,}3282 - 0{,}3637 \cdot x - 0{,}1293 \cdot x^2 - 0{,}0171 \cdot x^3 \qquad (A116)$$

with $x = \ln\left(\frac{s}{Da}\right)$

for range of validity $0{,}001 \le \frac{s}{Da} \le 0{,}1$ (A117)

D_a = Outside diameter of the dished end

In the range $0{,}5 \cdot \sqrt{s \cdot R}$ besides the transition to the cylinder the coefficient β = 1,1 for hemispherical ends.

Under the assumption that deviations in the form of dished ends stay within the permissible tolerances, the stresses can be calculated with the following formulas. If the tolerances are exceeded, a separate proof of stress is to be performed.

$$\sigma = -\frac{R_{c,o,l}^{\ 2} \cdot p}{2 \cdot R_{c,m,l} \cdot s} \qquad (A118)$$

$R_{c,o,l}$ = Local outside radius of sphere crown of the dished end

$R_{c,m,l}$ = Local radius of the sphere crown of the dished end at half thickness of the shell

$$\sigma = -\frac{p \cdot D_a \cdot 1{,}2 \cdot \beta}{4 \cdot s} \qquad (A119)$$

For p **NDP**, **TDP** and **CDP** are to be introduced respectively.

The proof has been made if the permissible stresses according to the Rules for Section 5, D.3. are not exceeded.

6.3 Calculation of the collapse pressure

The calculations are based on the local thickness and curvature of the shell and they are considering an out-of-roundness of the shell in the sense of a local flattening up to maximum u = 0,218 · s_l / R_o. This is valid for pressed spherical shells and is adequate to a local outside curvature radius of $R_{o,l}$ = 1,3 · R_o of the outer nominal radius.

The out-of-roundness and herewith the local radius is to be evaluated with a bridge gauge as described in Annex B, E. There a measuring length $L_{cr,l}$ according to formula (A120) has to be used. The out-of-roundness defined in this way is to be understood as local flattening from the theoretical form of the sphere within the diameter $L_{cr,l}$. For the lay out a local radius of 1,3 times the nominal radius and a nominal thickness of the shell (eventually reduced by the corrosion addition) is to be assumed. The corrosion addition shall be considered by keeping the outside radius.

If other tolerances are provided or another out-of-roundness is resulting from the measurement checks according to Annex B, E.3. or E.4., then a recalculation of the permissible pressure according Annex B, E.5. is required.

For mechanically machined spherical shells local radii less than 1,05· R_o are reachable from point of manufacturing. The more favourable geometrical condition of the shell can be introduced in the calculation with at minimum $R_{o,l}$ = 1,05 · R_o under the assumption that the measurement procedure, as described in Annex B, has proven a maximum permissible local flattening of u = 0,035 · s_1 / R_o with an accuracy of at least 0,001.s.

6.4 Definitions

The following definitions are valid:

$R_{m,1}$ = Maximum local mean radius of curvature of the sphere at shell half thickness

$R_{0,1}$ = Maximum local outside radius of curvature of the sphere

s = Nominal thickness of the shell

s_1 = Local average shell thickness

Critical arc length or diameter of the measuring circle to be used for measuring the deviations from the perfect form of the sphere according to Annex B, E.3. and E.4.:

$$L_{cr,1} = \frac{2{,}2}{\sqrt[4]{\frac{3}{4} \cdot \left(1 - \nu^2\right)}} \cdot \sqrt{R_{0,1} \cdot s_1} \qquad (A120)$$

Elastic buckling pressure of the sphere:

$$p_{cr}^{el} = \frac{1,4}{\sqrt{3 \cdot (1-\nu^2)}} \cdot E \cdot \left(\frac{s_1}{R_{0,1}}\right)^2 \qquad (A121)$$

Theoretical elastic-plastic buckling pressure of the sphere:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{\sqrt{E_t \cdot E_s}}{E} \qquad (A122)$$

$$p_{0,2} = \frac{2 \cdot \sigma_{0,2} \cdot s_1 \cdot R_{m,1}}{R_{0,1}^2} \qquad (A123)$$

6.5 Spherical ends made of ferritic steel

For spherical ends made of ferritic steel grade **TL**-M550 or similar material p_{cr} can be calculated as fol lows:

6.5.1 For spherical ends which are not stress re lieved the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,47 \qquad (A124)$$

$$p_{cr} = p_{0,2}\left(0,38 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \text{if} \quad 0,47 < \frac{p_{cr}^{el}}{p_{0,2}} \le 3,18 \qquad (A125)$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 3,18 \qquad (A126)$$

6.5.2 For stress relieved spherical ends (tempered and stress relieved) the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,595 \qquad (A127)$$

$$P_{cr} = p_{0,2}\left(0,475 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \textit{if} \quad 0,595 < \frac{p_{cr}^{el}}{p_{0,2}} \le 2,7 \qquad (A128)$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 2,7 \qquad (A129)$$

The fabrication of ends by welding of stress relieved segments and the welding of the penetrations into the shell after stress relieving is permitted.

The calculated collapse pressure pcr shall be at least equal to the collapse diving pressure **CDP** of the pressure hull.

6.6 Spherical shells of other materials

For spherical ends made of other steel materials the elastic-plastic buckling pressure p_{cr}^{i} which has been evaluated according to the formulas described above has to be multiplied by the reduction factor k defined in Figure. A.6. The reduction factor k is also summarized in tabular form in Table A.2. Intermediate values can be defined by linear interpolation.

For the application of non-iron metal materials the reduction factors are to be evaluated in accordance with **TL** by model tests.

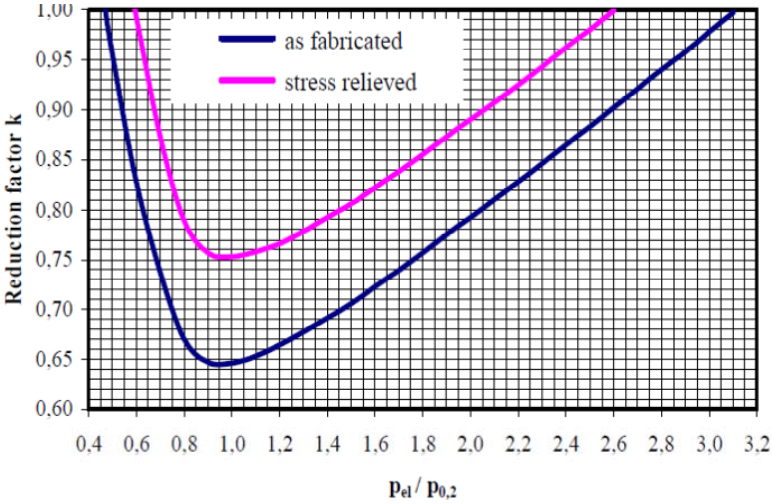

Figure. A.6 Reduction factor "k" for different kinds of steel treatment

Table A.2 Reduction factor "k" for different kinds of steel treatment

Pressure relation	Reduction factor	
$p_{el} / p_{0,2}$	As fabricated	Stress relieved
0,470	1,000	1,000
0,495	0,963	1,000
0,595	0,834	1,000
0,700	0,738	0,874
0,800	0,670	0,789
0,900	0,647	0,757
1,000	0,646	0,753
1,100	0,653	0,758
1,200	0,664	0,766
1,300	0,677	0,778
1,400	0,691	0,792
1,500	0,706	0,806
1,600	0,723	0,822
1,700	0,739	0,838
1,800	0,757	0,855
1,900	0,775	0,873
2,000	0,792	0,890
2,100	0,810	0,907
2,200	0,828	0,925
2,300	0,846	0,943
2,400	0,865	0,962
2,500	0,883	0,980
2,600	0,902	0,999
2,700	0,921	1,000
2,800	0,940	1,000
2,900	0,958	1,000
3,000	0,978	1,000
3,100	0,997	1,000
3,200	1,000	1,000

7. Penetrations of the pressure hull and dis- continuities

7.1 Discontinuities

Discontinuities like

– Connections of cylinders and conical segments

– Transition rings (tripping rings)

– Flanges for the attachment of dome shaped windows

are to be subjected for the load cases nominal diving pressure and test diving pressure to an analysis of the stress and elongation behaviour similar to [10] **(1)** and [11] **(1)**. The equivalent stress follows from formula (A14). Sufficient safety is given, if the permissible stresses according to **TL** Rules for Section 5, D.3. are not exceeded. If stiffeners are interrupted by penetrations, suitable reinforcements are to be provided.

7.2 Penetrations in the cylindrical or conical part of the pressure hull - area comparison principle

Penetrations in cylinders are to be preferably evaluated according to the **TL** Rules for Chapter 4 - Machinery, Section 12, D.2.3.4 with a design pressure pc for which **NDP**, **TDP** resp. **CDP** are to be inserted alternatively.

There is:

$D_i \quad = 2 \cdot R$

and

s_A = Necessary wall thickness at the penetration boundary according to **TL** Rules for Chapter 4 - Machinery, Section 12, D.2.2 which is to be evaluated by iteration.

The following rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material characteristics the rules have to be modified in an analogous way.

7.3 Penetrations in the cylindrical or conical part of the pressure hull – cross sectional

After approval by **TL** the required reinforcement of the penetration boundary can be evaluated also with the cross sectional area substitution principle.

These rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material strength the rules have to be modified in an analogous way.

---

1) *See data about literature in G.*

7.3.1 Small penetrations which do not interrupt frames

7.3.1.1 Circular penetrations in radial direction

The situation is characterised by Figure. A.7 where for the calculation one half of the nozzle is considered. Designations in Figure. A.7:

s = Thickness of the shell of the pressure hull after deduction of corrosion allowance

s_v = Thickness of the shell of the pressure hull in the reinforcement vicinity

R = Internal radius of the pressure hull

d_a = External diameter of the nozzle

ℓ_s, ℓ_s' = Excess lengths of the nozzle

ℓ_{min} = $\min\left(\ell_s, \ell_s'\right)$

= Smaller excess length of the nozzle

ℓ_{max} = $\max\left(\ell_s, \ell_s'\right)$

= Bigger excess length of the nozzle

S_s = Wall thickness of nozzle

A = Cross sectional area to be substituted

A_{eff} = Effective substitutive cross sectional area

l_{eff} = Effective length of the nozzle

$$\ell^* = \frac{\sqrt{0{,}5\left(d_a - s_s\right)\cdot s_s}}{\sqrt[4]{3\left(1-v^2\right)}} \qquad (A130)$$

$$r_m = 0{,}5\cdot\left(d_a - s_s\right) \qquad (A131)$$

It has to be proven that the effective substitutive cross sectional area of the boundary reinforcement A_{eff} of the penetration is at least equal to the cross sectional area A cut out of the shell which is to be substituted.

The area to be substituted is

$$A = 0{,}5\cdot d_a \cdot s \qquad (A132)$$

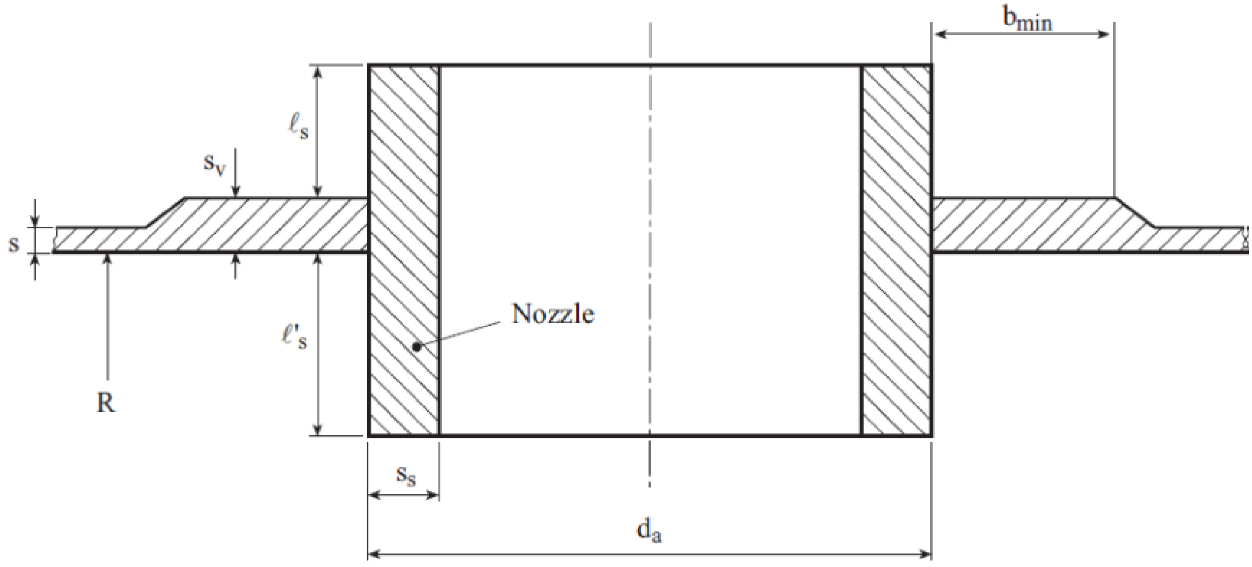

Figure. A.7 Penetration through the enforced shell

For penetrations, which are designed in the form shown in Figure. A.7 the effective substituted cross sectional area can be calculated according to the following formula:

$$A_{eff} = b_{min} \cdot (s_V - s) + s_S \cdot \ell_{eff} \qquad (A133)$$

$$b_{min} = 0{,}78 \cdot \sqrt{R \cdot s_V}$$

Effective length of nozzle:

Case 1:

$$\ell_{eff} = 2 \cdot \ell^* + s_V \quad \text{for} \qquad (A134)$$

$$\ell_s \geq \ell^*; \ell'_s \geq \ell^* \qquad (A135)$$

Case 2:

$$\ell_{eff} = 2 \cdot \ell_{min} + s_V \qquad (A136)$$

$$\frac{\ell^*}{2} \leq \ell_{min} \leq \ell^* \qquad (A137)$$

Case 3:

$$\ell_{eff} = \ell_{min} + \min\left(a, \frac{\ell^*}{2}\right) + s_V \qquad (A138)$$

$$\ell_{min} < \frac{\ell^*}{2}; \quad \ell_{max} > \frac{\ell^*}{2} \qquad (A139)$$

$$a = \ell_{max}\left(0{,}4 + 0{,}6\frac{\ell_{min}^2}{\ell_{max}^2}\right) \qquad (A140)$$

7.3.1.2 Flush form of circular penetrations in radial direction

Penetrations in flush form of the pressure hull $(\ell_s' = 0)$ may have in the penetration area a cut out to include a zinc ring, see Figure. A.8.

In this case ℓ_{eff} can be evaluated with the formulas given above. In addition the strength of the cross section A-A has to be proven.

In the case that the wall of the pressure hull is not reinforced, the following condition has to be met:

$$c > \sqrt{4 \cdot \frac{s \cdot d_a\left(g - \frac{s}{2}\right) - c \cdot g^2}{d_a - c} + c_\tau^2} \qquad (A141)$$

$$c_\tau = \sqrt{3} \cdot \frac{s \cdot d_a - 2 \cdot c \cdot g}{d_a - c} \qquad (A142)$$

7.3.1.3 Non-circular penetrations or penetrations not in radial direction to the shell

If the penetration is not circular or does not cut the shell of the pressure hull in radial direction the diameter da has to be replaced by:

$$d_a = \max\left(L_x, L_\varphi \cdot \frac{\sigma_x^m}{\sigma_\varphi^m}\right) \qquad (A143)$$

L_x = Width of the penetration line in longitudinal direction

L_φ = Width of the penetration line in circumferential direction

σ_x^m = Membrane stress in the pressure hull in longitudinal direction

σ_φ^m = Membrane stress in the pressure hull in circumferential direction

In special cases, if the Rules can only be utilized in limited way, the strength has to be proven by numerical computation.

7.3.2 Big penetrations interrupting frames

For preliminary dimensioning the following procedure is can be used:

The effective border reinforcement for the penetration has, in a similar way as for the small penetrations, to substitute the area cut out. The cross sections of the interrupted frame webs are to be considered additionally. The effective substitutive cross sectional area has to be evaluated in analogous way as for small penetrations. Compact reinforcement rings are fully load carrying if they are located directly in the penetration line.

The construction in the flange plane of the frame has to be designed in such a way that the maximal permissible forces in the flange ($A_f \cdot \sigma_{zul}$) can be transmitted further. For σ_{zul} the value of the permissible stress belonging to the individual load case acc. to **TL** Rules for Section 5, D.3 is to be inserted.

Big penetrations have to be proven by numerical computation.

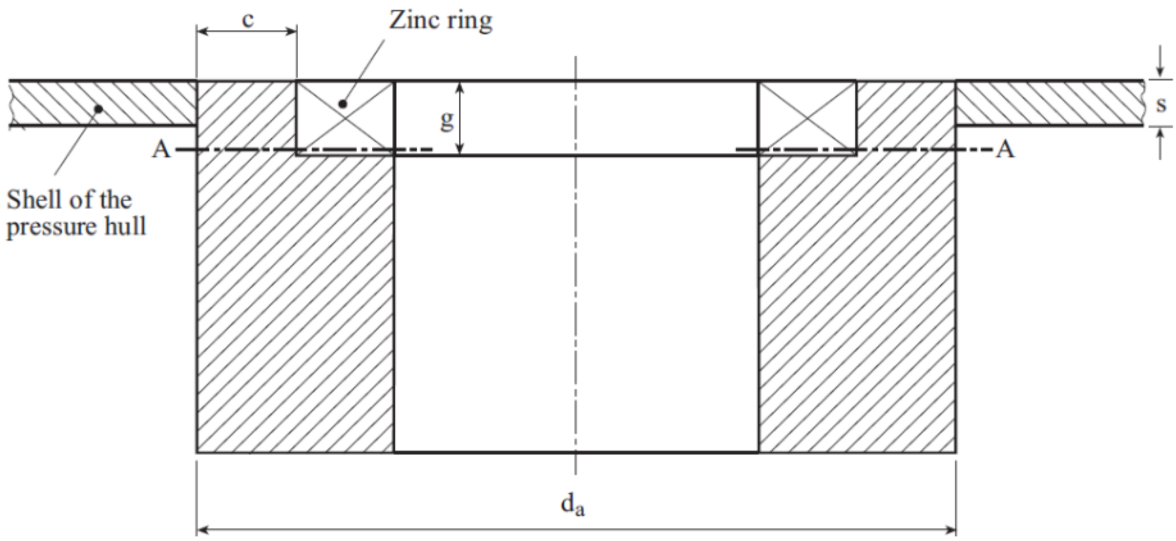

Figure. A.8 Penetration of flush form

7.4 Penetrations of spherical shells

Penetrations in spherical shells are to be evaluated according to the **TL** Rules for Chapter 4 - Machinery, Section 12, D.4.3.3 with a design pressure pc for which 1,2 **NDP**, 1,2 **TDP** resp. 1,2 **CDP** are to be inserted alternatively. There is:

D_i = $2 \cdot R$

and

s_A = Necessary wall thickness at the penetration boundary according to **TL** Rules for Chapter 4 - Machinery, Section 12, D.2.2 which is to be evaluated by iteration.

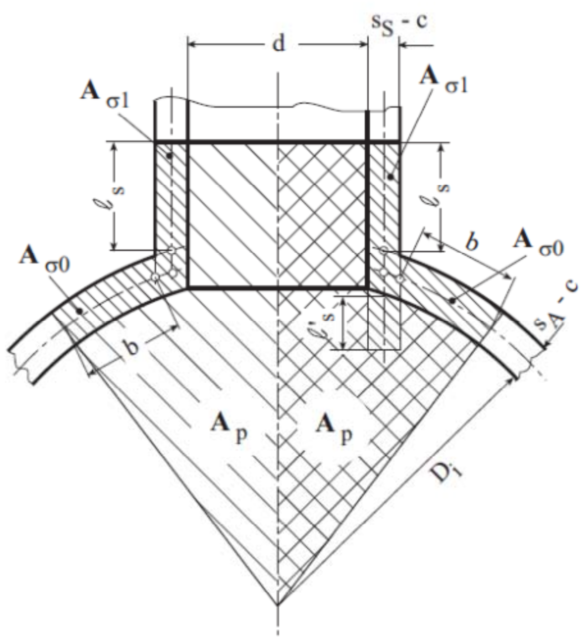

Figure. A.9 Penetrations of spherical shells

After approval by **TL** the cross sectional area substitution principle as described in 7.3 may be applied analogously. For this R is the internal radius of the sphere.

In cases, where area comparison respectively cross sectional area substitution principle are not fulfilled, a numerical proof has to be done. For this the local radius of the spherical shell according to 6.3 is to be chosen adequately in the vicinity of the penetration. The achieved failure pressure is then to be reduced like the elastic-plastic buckling pressure, which has been evaluated for undisturbed dished ends, see Figure A.6.

G. Literature

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[7] DIN 4114, Blatt 2: Stabilitätsfälle (Knickung, Kippung, Beulung), Ausgabe 2.53

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[9] Krenske, Martin A. und Kierman, Thomas J.: The Effect of Initial Imperfections on the Collapse Strength of Sherical Shells, DTMB- Report No. 1757

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[11] Raymond J. Roark and Warren C. Young: Formulars for Stress and Strain, Mc Graw - Hill Book Company

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ANNEX B

MANUFACTURING TOLERANCES FOR THE PRESSURE HULL

A.	**GENERAL**	**B-**2
B.	**DIMENSIONS OF THE PRESSURE HULL**	**B-**3
C.	**PRESSURE HULL FRAMES**	**B-**5
D.	**OUT-OF ROUNDNESS OF THE CYLINDRICAL RESP. CONICAL PRESSURE HULL**	**B-**7
E.	**SPHERICAL SHELLS AND DISHED ENDS**	**B-**11
F.	**LITERATURE**	**B-**15

A. General

1. This Annex describes the permissible manufacturing tolerances for the pressure hull as prerequisite for the application of the strength calculations defined in Annex A.

2. All tests are to be performed by the manufacturer in presence of a **TL** Surveyor and a measurement report has to be sent by the manufacturer to **TL**.

3. The required checks defined in the following are only to be performed, if no following changes of the measurement values are to be expected. Areas with welding seams which have been worked over in the mean time because of impermissible defects have to be measured again.

The component to be investigated shall be cooled down to ambient temperature and is so to be relieved from any tensions by means of installation aids in order to prevent falsification of the measurement results.

B. Dimensions of the Pressure Hull

1. General

1.1 As far as not defined otherwise in these Rules the following tolerances are valid.

1.2 All longitudinal and circumferential seams in the pressure hull plating shall be inspected for edge off-set, weld sinkage, undercuts and hollow grinding. This shall also be valid for the welding connection of the plating with the tripping/transition ring. The inner and outer surface of the plates is to be inspected for damage.

2. Dimensions of the cylindrical and conical parts

2.1 Diameter

The actual mean outside diameter of cylindrical respectively conical pressure hulls shall, calculated from the circumference, deviate not more than ± 0,5 % from the outside diameter on which the calculation is based. The measurements are to be performed in distances of $\sqrt{3 \cdot R \cdot s}$ over the complete lebgth of the component.

s = nominal shell thickness [mm]

R = internal radius of the shell [mm]

2.2 Generating line

The deviation of the theoretical generating line from the straight line shall not exceed ± 0,2 % of the length of the straight forward part of a cylinder resp. cone over three adjacent measuring points, which are given by web frames, bulkheads and connections of cones and dished ends. If web frames, cones and bulkheads are not provided, only between dished ends is to be measured. The deviation is to be measured at minimum 8 positions equally distributed over the circumference.

2.3 Length

The length of the pressure hull rings in manufacturing is to be measured at minimum 4 positions equally distributed over the circumference and to be averaged.

The allowable tolerance of the length of the pressure hull ring shall not be bigger than the sum of the existing deviations of the frame distances within this ring. If no frames are provided, the tolerance is ± 1 % of the nominal length, but not more than 15 mm.

3. Dimensions of spherical shells and dished ends

3.1 Radius of spherical shells and crown of dished ends

For determination of the spherical form of the spherical shell the outside radius is to be evaluated according to E.3.

The spherical form of the spherical shell has to remain within a tolerance of ± 1 % of the nominal outside radius.

3.2 Course of theoretical geometry lines of dished ends (knuckle/crown radius)

The tolerances are to be defined by the manufacturer according to recognized regulations and deviations from it are to be approved by **TL**, compare E.2.

4. Component thickness

Tolerances for components of the pressure hull: –0/+t

Tolerance value t according to material delivery specifications (if the material delivery standard allows minus tolerances, these are to be considered for the calculations)

5. Edge offset and weld sinkage

5.1 The radial deviations x_1 and x_2 are the basis for the determination of weld sinkage and edge offset of sheet metal surfaces with regard to their nominal positions next to a welding seam, compare Fig. B.1. They are measured at a distance $v = s_{max} + 20$ mm on both sides centred over the welding seam.

5.2 The tolerances for the gradient of the theoretical line of the middle plane at the tripping/transition ring are to be documented in the manufacturing protocols and to be checked.

5.3 Edge offset for cylindrical and conical parts

The edge offset of both plates which is determined by the difference of the measuring values $|x_2 - x_1|$, compare Fig. B.1.

For circumferential seams the edge offset shall not exceed 15 % of the nominal thickness of the thinner plate, but maximum 4 mm.

For longitudinal seams the edge offset shall not exceed 10 % of the nominal thickness of the thinner plate, but maximum 3 mm.

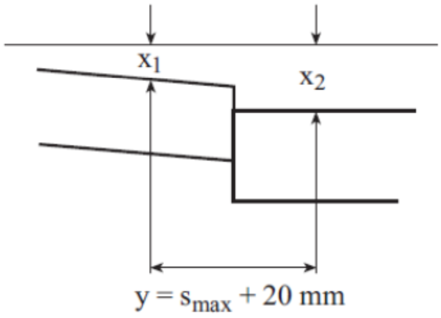


Fig. B.1 Radial deviation of the sheet metal surface of the pressure hull

5.4 Edge offset for spherical shells and dished ends

For butt joints within these shells and dished ends the edge offset shall not exceed 10 % of the nominal thickness of the thinner plate, but maximum 3 mm.

5.5 Weld sinkage for cylindrical and conical parts

The mean value of the deviations

$h = (x_1 + x_2) / 2$

is defined as weld sinkage. If not otherwise agreed with **TL**, the following tolerances are valid:

For circumferential seams the weld sinkage shall not exceed h = ¼ · s, but maximum 5 mm.

For longitudinal seams the weld sinkage shall not exceed h ≤ 1/6 · s, but not more than 3 mm.

5.6 Weld sinkage for spherical shells and dished ends

For butt joints within these shells and dished ends the weld sinkage shall not exceed h = 1/6 · s, but maximum 3 mm.

6. Damages to the component surface

Damage to the surface, such as scores, scratches, arc strikes, indentation pits, etc. shall be thoroughly smoothed and inspected for surface cracks. The flaws treated in this way are permissible without proof of strength, if the following requirements are met:

- The depth shall at maximum 0,05 · s or 3 mm, the smaller value is decisive.
- The area of the undercut of the thickness shall be within a circular area with 2 · s as diameter or 60 mm, the smaller value is decisive.
- The distance between two areas of thickness undercut and the distance from points of disturbance, like e.g. penetrations, shall be at least $\sqrt{2 \cdot R \cdot s}$

Deeper flaws are to be treated specially in agreement with **TL**.

7. Evaluation of the welding seams

The evaluation of other imperfections on welding seams as defined under 5. shall be performed according to the **TL**

Rules for Chapter 3 - Welding, Annex A, quality level B.

C. Pressure Hull Frames

1. Measurements

The following measurements shall be carried out on every frame of the pressure hull at eight measuring points uniformly distributed around the circumference:

– Flange width

– Flange thickness

– Web thickness

– Frame spacing (measured at frame heel)

– Frame height at frame moulding edge

– Eccentricity flange to web

– Web tilt to plane of frame

The spacing k of the frame heel from a reference plane shall be determined by direct measurement, see Fig. B.2. The location of the frame heel is shown as detail "A" in this Figure. For cylindrical pressure hull parts this measurement shall be carried out on a minimum of one frame per ring (with a ring length of up to a maximum of 8 pressure hull frames) and for conical pressure hull parts on every frame at 16 points uniformly distributed around the circumference.

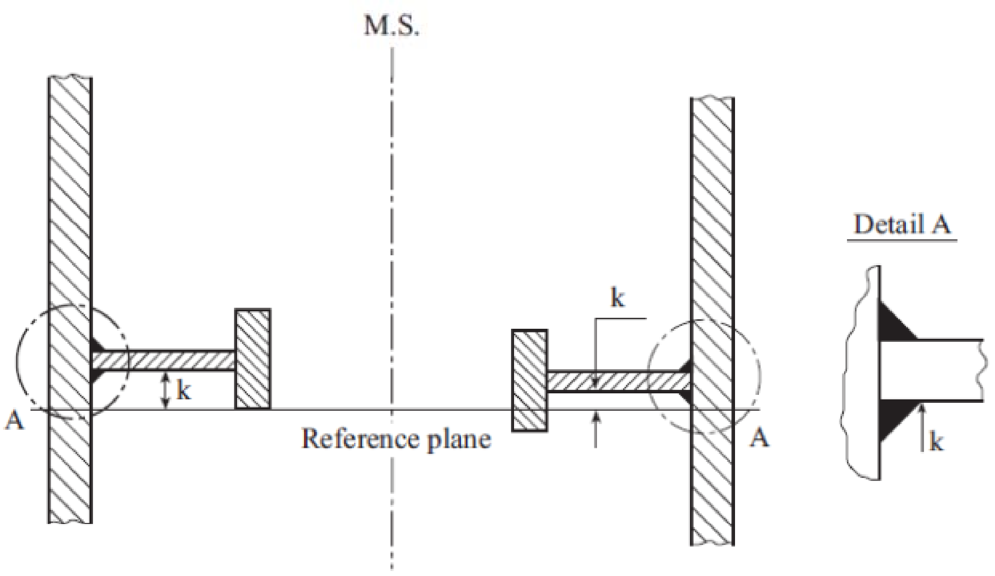


Fig. B.2 Definition of the reference plane of a frame

2. Tolerances

2.1 The following tolerances are maximum values and shall not be exceeded. The tolerances calculated from percentages may be rounded up to half of a millimetre.

2.2 Flange width: 0 % to + 4,5 %
Flange thickness: 0 mm to + 3 mm
Web thickness: 0 mm to + 3 mm

With regard to the flange width resp. flange thickness the nominal cross sectional area of the flange is considered to be a permissible acceptance criteria. Height tolerances of $0{,}2 + 0{,}04 \cdot s \leq 1$ mm (s = material thickness in mm) due to flat grinding of nicks may be exceeded locally, however, the nominal cross section of the flange or web shall not be reduced to more than 90 %.

2.3 Frame spacing: generally ± 1 %
At circumferential seams
+1 % to –3 %

2.4 Frame height at frame moulding edge:
0 % to + 5 %

Tolerances up to –2 % are allowed locally if the mean value of the 8 measuring points reaches nominal value.

2.5 Eccentricity of flange to web:
2 % of frame height

2.6 Inclination of web to reference plane of frame:
± 2 °

2.7 Misalignment of frame heel to reference plane:
+ 4 mm for frames
± 6 mm for web frames

If the maximum difference of determined spacings ($k_{max} - k_{min}$) is larger than 8 mm for frames and 12 mm for web frames, the real deviations of h shall be determined by evaluation according to the following formula:

$$h_i = k_i - k_0 - \Delta k_x \cdot \sin \varphi_i - \Delta k_y \cdot \cos \varphi_i \quad \text{(B1)}$$

$$k_0 = 1/J\,(k_1 + k_2 + k_3 + \ldots\ldots k_J) \quad \text{(B2)}$$

$$\Delta k_x = 2/J\,(k_1 \cdot \sin \varphi_1 + k_2 \cdot \sin \varphi_2 + k_3 \cdot \sin \varphi_3 + \ldots\ldots + k_J \cdot \sin \varphi_J) \quad \text{(B3)}$$

$$\Delta k_y = 2/J\,(k_1 \cdot \cos \varphi_1 + k_2 \cdot \cos \varphi_2 + k_3 \cdot \cos \varphi_3 + \ldots\ldots + k_J \cdot \cos \varphi_J) \quad \text{(B4)}$$

$$\varphi i = 360° \cdot i / J$$

h_i = deviation of the frame heel from the actual plane of frame at measuring point i

k_i = measured distance of frame heel from the reference plane of measuring point i

J = number of measuring points

3. Transition rings and strengthening of pressure hull

Transition rings, strengthenings of cut-outs and other strengthenings of the pressure hull are not to be applied with tolerances which weaken the components.

D. Out-of Roundness of the Cylindrical resp. Conical Pressure Hull

1. The out-of-roundness shall be measured at each frame and also at each transition ring. The measurements are to be conducted with a maximum disdistance according to $\sqrt{3 \cdot R \cdot s}$ over the complete length of the component. For frame spacings above $\sqrt{3 \cdot R \cdot s}$ the out-of-roundness is to be determined also at the shell between the frames considering this measuring distance.

Moreover the course of the theoretical geometry lines at the transition ring is to be determined.

2. The following requirements shall be met prior to conducting out-of-roundness measurements:

– The required tests shall only be carried out when no subsequent changes of measured values are to be expected.

– The section is to be cooled down to ambient temperature and relieved from any tension by means of appropriate aids in order to prevent falsification of measurement results.

3. The measurement of the pressure hull can be carried out from outside or from inside. In principle the measurement of out-of-roundness shall be carried out at 24 points distributed as uniformly as possible around the circumference. It can be conducted with the help of a circular template, callipers, a two point bridge gage (see Fig. B.4), photogrammetry or theodolite methods, in which case access has to be provided by appropriate means. If the measuring of individual values is not possible due to constructional reasons (e.g. in the area of larger openings), it shall be supplemented as far as practically possible (in general by linear interpolation). The measurement shall not be impaired by welding seams (e.g. weld reinforcement) or local imperfections on the surface.

4. The results of the evaluation shall be presented to **TL** as tables and graphs.

5. The maximum permissible out-of-roundness is ± 0,5 % of the nominal pressure hull diameter unless otherwise agreed by **TL**.

6. Measuring method 1: direct measurement of the radii and their deviation from constant radius; from inside or from outside

The measurement can be performed from inside - measurement of the radii, and from outside - measurement of the deviations from the constant, mean radius by rotating the pressure hull around an assumed axis (centre). The assumed centre shall be as near to the true centre as possible, compare Fig. B.3.

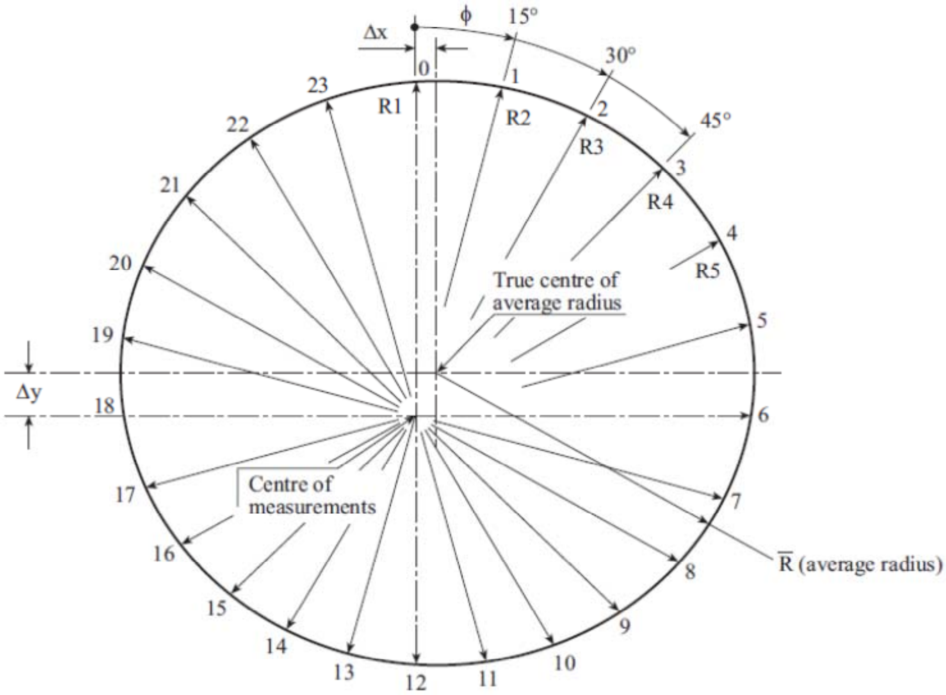


Fig. B.3 Measurement of the out-of-roundness at the cylinder; measuring method 1, explanation of symbols

The following formulas apply to J = 24 measuring points distributed uniformly around the circumference:

$u_i = R_i - \overline{R} - \Delta x \cdot \sin \varphi i - \Delta_y \cdot \cos \varphi i$ (B5)

$\overline{R} = 1/J\,(R_1 + R_2 + R_3 + \ldots + R_J)$ (B6)

$\Delta x = 2/J\,(R_1 \cdot \sin \varphi_1 + R_2 \cdot \sin \varphi 2 + R_3 \cdot \sin \varphi 3 + \ldots + R_J \cdot \sin \varphi_J)$ (B7)

$\Delta_y = 2/J\,(R_1 \cdot \cos \varphi_1 + R_2 \cdot \cos \varphi 2 + R_3 \cdot \cos \varphi 3 + \ldots + R_J \cdot \cos \varphi_J)$ (B8)

i = measuring points 1 to J (for above formula J = 24)

R_i = radial measuring value at the curve shape at measuring point i; measured from assumed centre

$\overline{R}$ = average calculated radius

Δx = deviation of measurement, horizontal

Δy = deviation of measurement, vertical

u_i = calculated out-of-roundness of the pressure hull at the measuring point i

φ_i = angle of the measuring point, see C.2.7

The calculation procedure shall be documented according to Table B.1.

Table B.1 Protocol and calculation table for evaluation of the out-of-roundness according to method 1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i	R_i [mm]	φ_i [°]	$\sin\varphi_i$	$\cos\varphi_i$	$R_i \cdot \sin\varphi_i$	$R_i \cdot \cos\varphi_i$	$\Delta_x \cdot \sin\varphi_i$	$\Delta_y \cdot \cos\varphi_i$	(7)+(8)	(9)+ $\overline{R}$	u_i=(1) – (10)
1		15	0,2588	0,9659							
2		30	0,5000	0,8660							
3		45	0,7071	0,7071							
4		60	0,8660	0,5000							
5		75	0,9659	0,2588							
6		90	1,0000	0,0000							
7		105	0,9659	–0,2588							
8		120	0,8660	–0,5000							
9		135	0,7071	–0,7071							
10		150	0,5000	–0,8660							
11		165	0,2588	–0,9659							
12		180	0,0000	–1,0000							
13		195	–0,2588	–0,9659							
14		210	–0,5000	–0,8660							
15		225	–0,7071	–0,7071							
16		240	–0,8660	–0,5000							
17		255	–0,9659	–0,2588							
18		270	–1,0000	0,0000							
19		285	–0,9659	0,2588							
20		300	–0,8660	0,5000							
21		315	–0,7071	0,7071							
22		330	–0,5000	0,8660							
23		345	–0,2588	0,9659							
24		360	0,0000	1,0000							

7. Measuring method 1: non-uniformly distributed measuring points

In case of non-uniformly distributed measuring points and angular separation of measuring points ≤ 18° the following formulas apply:

$$u_i = R_i - \overline{R}' - \Delta x' \cdot \sin\varphi_i - \Delta y' \cdot \cos\varphi_i \quad \text{(B9)}$$

$$\overline{R}' = [1/(2 \cdot \pi \cdot D)]\,[R_1 \cdot x_2 + R_2 (x_3 - x_1) + R_3 (x_4 - x_2) + \ldots + R_J (x_1 - x_{J-1} + \pi \cdot D)] \quad \text{(B10)}$$

$$\Delta x' = [1/(\pi \cdot D)]\,[R_1 \cdot \sin\varphi_1 \cdot x_2 + R_2 \cdot \sin\varphi_2 (x_3 - x_1) + R_3 \cdot \sin\varphi_3 (x_4 - x_2) + \ldots + R_J \cdot \sin\varphi_J (x_1 - x_{J-1} + \pi \cdot D)] \quad \text{(B11)}$$

$$\Delta y' = [1/(\pi \cdot D)]\,[R_1 \cdot \cos\varphi_1 \cdot x_2 + R_2 \cdot \cos\varphi_2 (x_3 - x_1) + R_3 \cdot \cos\varphi_3 (x_4 - x_2) + \ldots + R_J \cdot \cos\varphi_J (x_1 - x_{J-1} + \pi \cdot D)] \quad \text{(B12)}$$

i = measuring points 1 to J (for above formula J = 24)

J = actual number of measuring points

R_i = see definition in 6.

$\bar{R}'$ = average calculated radius

Δx' = deviation of measurement, horizontal

Δy' = deviation of measurement, vertical

u_i = see definition in 6.

D = diameter of the measuring circuit

x_i = circumferential coordinate at measuring point i (measuring distance from starting point $x_J = x_0 = 0$)

φ_i = angle at measuring point
= $360 \cdot x_i / (\pi \cdot D)$

8. Measuring method 2: indirect measurement of the deviation from the average arc height of the measuring bridge; from outside

The number of planes used for measuring the out-of-roundness of cylindrical pressure vessels is to be agreed with **TL**. For each measuring plane, at least J = 24 measuring points shall be provided and evenly distributed round the circumference. The height of arc x (j) is measured with a bridge extending over a string length $L_s = 4 \cdot \pi \cdot R_0/J$ (see Fig. B.4). From the values x (j) and the influence coefficients C, the out-of-roundness values can be calculated by applying formula (B13). Table B.2 gives the influence coefficients C where J = 24. The values of the out-of-roundness U (j) measured in this way shall not exceed the maximum permissible values defined in 5.

R_0 means here the outer radius of the cylindrical shell.

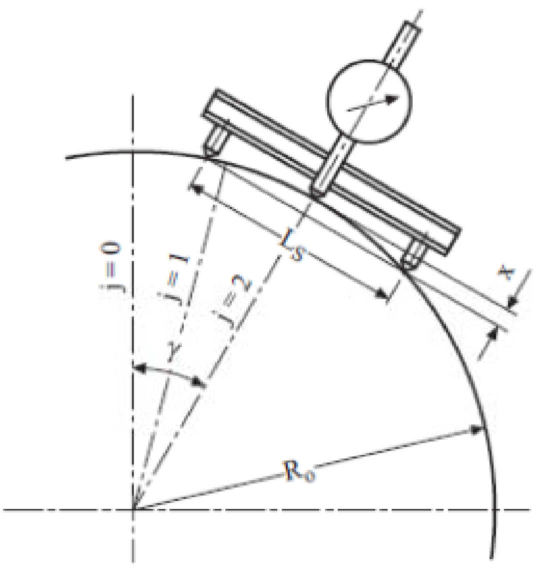


Fig. B.4 Measuring the out-of-roundness of a cylindrical shell, measuring method 2

$$U_j = \sum_{i=0}^{J-1} x_i \cdot C_{|i-j|} \qquad \text{(B13)}$$

Example for out-of roundness U at the point j = 2 for J = 24:

$$U_2 = x_0 \cdot C_2 + x_1 \cdot C_1 + x_2 \cdot C_0 + x_3 \cdot C_1 + ...$$

$$+ x_{21} \cdot C_{19} + x_{22} \cdot C_{20} + x_{23} \cdot C_{21} \qquad \text{(B14)}$$

Table B.2 Influence factors C_i for j = 24

i = j	$C_{\|i-j\|}$	i = j	$C_{\|i-j\|}$
0	1,76100	12	0,60124
1	0,85587	13	0,54051
2	0,12834	14	0,36793
3	–0,38800	15	0,11136
4	–0,68359	16	–0,18614
5	–0,77160	17	–0,47097
6	–0,68487	18	–0,68487
7	–0,47097	19	–0,77160
8	–0,18614	20	–0,68359
9	0,11136	21	–0,38800
10	0,36793	22	0,12834
11	0,54051	23	0,85587

E. Spherical Shells and Dished Ends

1. The following measurements are to be performed for spherical shells and dished ends:

– Course of the theoretical geometry lines at the transition ring (tripping ring)

– Out of roundness, circumference and inclined position of the cylindrical attachment of dished ends

– Out of roundness of the spherical shell (local flattening)

– Spherical form of the shell

2. For dished ends with torispherical resp. semi-elliptical shape the tolerances according to recognized standards, e.g. DIN 28011 resp. DIN 28013 are to be kept. But for the deviations in shape:

– Local flattening

– Out of roundness of the cylindrical attachment the tolerances defined in this Annex are valid, compare 4. bzw. D.5.

3. A permissible spherical form is a shell which keeps a defined radius with a defined tolerance. For evaluation of the spherical form of the shell the outside radii are to be measured in 6 equally distributed (i.e. displaced by 30°) planes cutting a joint axis (Fig. B.5). For spherical segments an analogous procedure

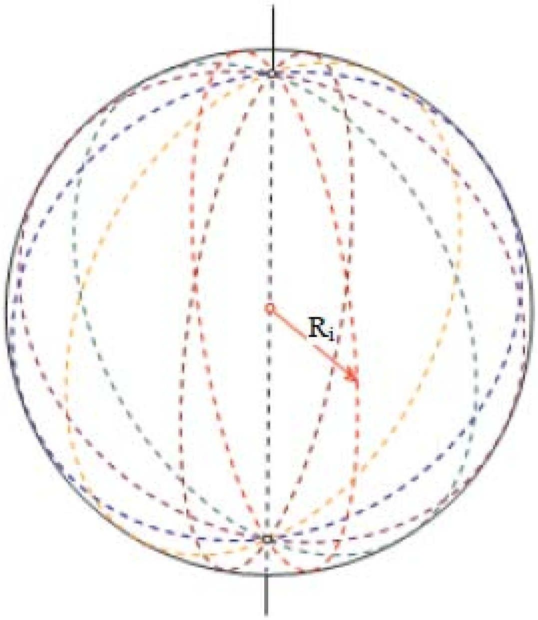


Fig. B.5 Measurement planes of a spherical shell - measuring method 1

The values for the out-of-roundness measured in this way shall not exceed 1 % of the nominal outer radius. If smaller local radii as 1,3 times the nominal outer radius are agreed for local flattenings, a less permissible out-of-roundness of the spherical shell is of advantage. The permissible value of the out-of-roundness is to be agreed with **TL**.

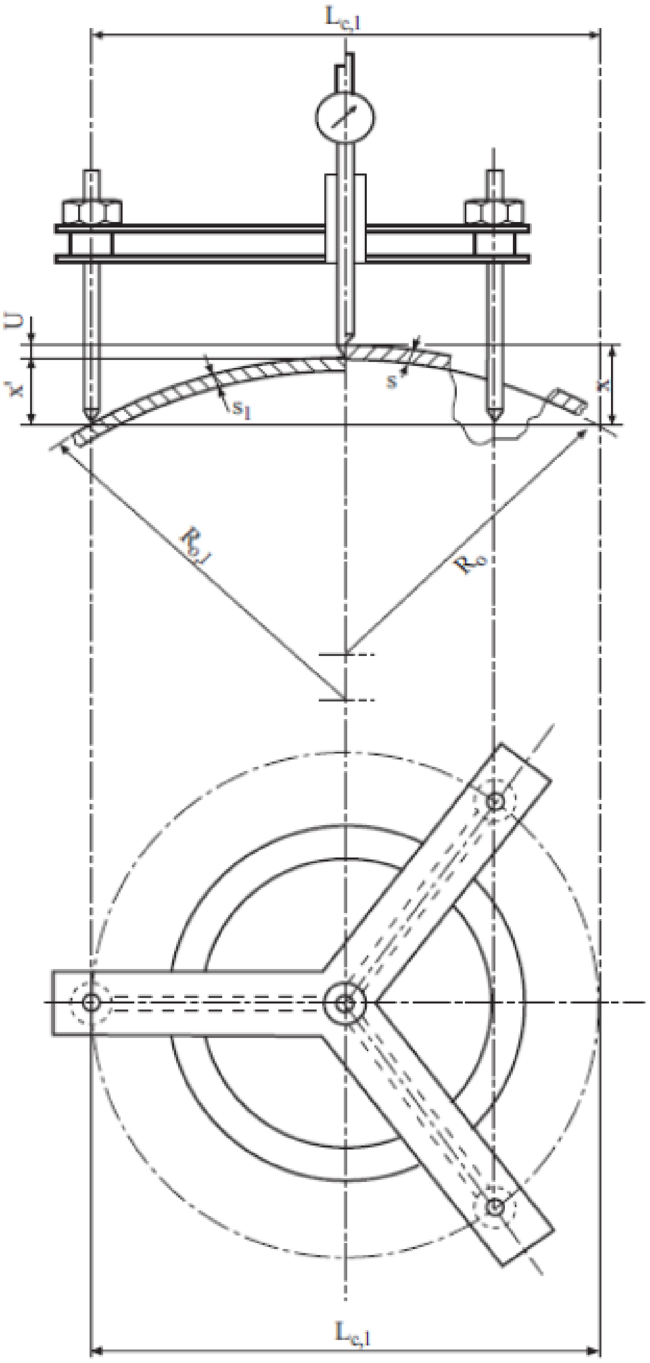


Fig. B.6 Measuring the out-of-roundness of a sphere

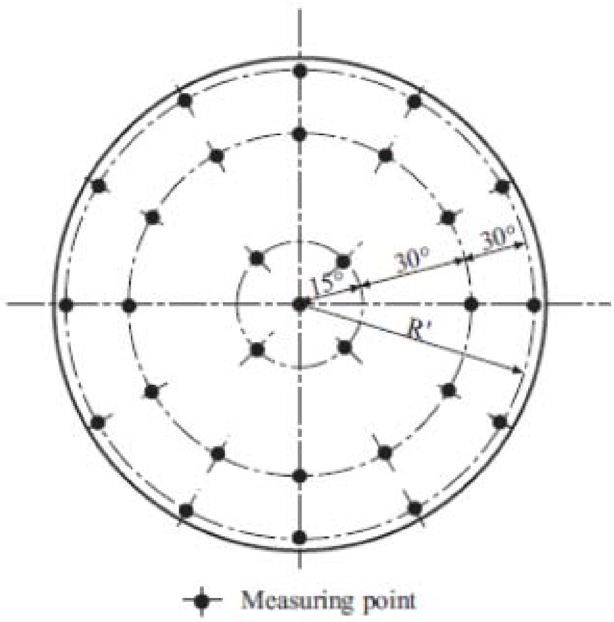


Fig. B.7 Distribution of the measuring points over a hemisphere

4. Measurement of the local flattening at spherical shells

The measurement shall not be impaired by welding seams (e.g. seam reinforcement) or local imperfections of the surface.

The height of arch x' is measured with a 3 point bridge gauge (see Fig. B.6), where the measuring diameter $L_{c,1}$ is to be calculated with formula (B15). The out-of-roundness of the spherical shell follows from the local flattening U according to formula (B17). The maximum permissible value of the local flattening, on the basis of a local radius $R_{o,1}$ = 1,3 · R_o is u = 0,218 · s_l/R_o. Consequently the maximum permissible local flattening U of the spherical shell from the theoretical spherical form is 21,8 % of the plate thickness s_1 (average value of the measured thickness in the measuring area). If a deviating local radius for the layout of the pressure hull is agreed, a corrected collapsing pressure p_{cr}' and a corrected permissible local flattening is to be evaluated according to 5.

$$L_{c,1} = \frac{2,2}{\sqrt[4]{\frac{3}{4} \cdot \left(1-\nu^2\right)}} \cdot \sqrt{R_{o,1} \cdot s_1} \qquad \text{(B15)}$$

$$x = R_o - \sqrt{R_o^2 - \frac{L_{c,1}^2}{4}} \qquad \text{(B16)}$$

$$U = x - x' = u \cdot R_o \qquad \text{(B17)}$$

$L_{c,1}$ = critical arch length (diameter of measuring circle)

s_1 = local average shell thickness

x = arch height at nominal shell radius R_o

x' = measured arch height

v = Poisson's ratio in elastic range
= 0,3 for steel

U = local flattening of the spherical shell within diameter $L_{c,1}$

u = local flattening, related to the nominal radius R_o

The distribution of the measuring points is defined in Fig. B.7. In each measuring point two measurements are to be made: once in a plane through the middle axis and once vertical to it.

5. Calculation of the failure pressure for spherical shells with a deviating out-of-roundness ($u \neq 0{,}218 \cdot s/R_o$)

The corrected maximum permissible out-of roundness can be evaluated with the aid of Table B.3.

The corrected elastic-plastic buckling pressure p^i_{cr} is to be evaluated with formula (B18) using the correction factor c_p under consideration of the actually existing local curvature radius $R_{o,1}$ (relation $\frac{R_{o,1}}{R_o}$). The local curvature radius is to be calculated with formula (B19). The thus evaluated elastic-plastic buckling pressure p^i_{cr}' is to be multiplied with the reduction factor k according to Annex A, F.6.6. Local radii larger than two times the nominal radius are to be avoided. For radii less than 1,3 times the nominal radius the definitions in Annex A, F.6.3 are to be observed.

$$p^i_{cr}{}' = \frac{p^i_{cr}}{c_p} \qquad \text{(B18)}$$

$$R_{o,1} = \frac{x'}{2} + \frac{L^2_{c,1}}{8 \cdot x'} \qquad \text{(B19)}$$

The corrected failure pressure p_{cr}' which is evaluated in this way shall at least be equal to the collapse diving pressure **CDP** of the pressure hull:

$$p_{cr}{}' = \frac{p^i_{cr}{}'}{c_p} \cdot k \geq \textbf{CDP} \qquad \text{(B20)}$$

F. Literature

Concerning literature reference is made to Annex A, G.

Table B.3 Maximum permissible local flattening for deviating local radius

Relation $\frac{R_{o,1}}{R_o}$	**Maximum local flattening** $U = \frac{L_{c,1}^2}{8} \cdot \left(\frac{1}{R_o} - \frac{1}{R_{o,1}} \right)$	**Corrected diameter of the measuring circle *** $L_{c,1} = \frac{2{,}2}{\sqrt[4]{\frac{3}{4} \cdot \left(1 - v^2\right)}} \cdot \sqrt{R_{o,1} \cdot S_1}$	**Correction factor for the elastic-plastic buckling pressure** p_{cr}^{i}, $c_p = \left(\frac{R_{o,1}}{1{,}3 \cdot R_o} \right)^{1{,}07}$
1,3	0,218 · s_1	$2{,}759 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,000
1,4	0,290 · s_1	$2{,}863 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,083
1,5	0,363 · s_1	$2{,}964 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,165
1,6	0,435 · s_1	$3{,}061 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,249
1,7	0,508 · s_1	$3{,}155 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,332
1,8	0,580 · s_1	$3{,}247 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,417
1,9	0,653 · s_1	$3{,}336 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,501
2,0	0,725 · s_1	$3{,}422 \cdot \sqrt{R_{o,1} \cdot S_1}$	1,586

* $L_{c,1} = \frac{2{,}2}{\sqrt[4]{\frac{3}{4} \cdot \left(1 - v^2\right)}} \cdot \sqrt{\frac{R_{o,1}}{R_o} \cdot \sqrt{R_o \cdot S_1}}$

Table B.3 is valid for a wall thickness ratio $\frac{s}{R_0} \geq 0{,}02$ *and for materials with yield strength* $\sigma_{0,2} \leq 550$ *MPa.*

ANNEX C

ACRYLIC WINDOWS

A. **GENERAL** **C-**2
B. **MATERIALS** **C-**3
C. **MANUFACTURE OF WINDOWS** **C-**3
D. **WINDOW SHAPES AND SIZES** **C-**4
E. **INSTALLATION OF WINDOWS** **C-**5

A. General

1. Scope

In the sense of these Rules, acrylic windows are flat or curved windows for the view ports of pressure hulls which are made of cast, unlaminated polymethyl methacrylate plastic.

2. Limits of application

For acrylic windows following limits for application apply:

–	Designed service life (see explanatory notes below)	10 resp. 20 years
–	Temperature range	–18 °C to +66 °C
–	Rate of pressurization	max. 10 bar/s
–	Pressure cycles at design pressure	max. 10.000
–	Period under pressure at design pressure	max. 40.000 h
–	Maximum allowable working pressure	max. 1380 bar

The design service life for acrylic windows depends on numerous factors, in particular on the kind of loading. The maximum design service life to be assumed for spherical or cylindrical windows subjected to external overpressure, which are exclusively exposed to compressive stresses or minor bending stresses only, is generally 20 years, while for flat windows with flat seat it is 10 years. The design service life starts with the date of manufacturing regardless of the use in the submersible.

Depending on the previous actual loads acting on the windows and testing to be agreed with **TL** in detail, extension of the service life of acrylic windows may be approved.

3. Permissions/Approvals

For the design and manufacturing of acrylic windows the following permissions/approvals are required:

– Approval of drawings and of the design for each type of window and each form of application by **TL**

– Approval as material manufacturer by **TL**

– Manufacturer Inspection Certificate for the material, compare B.3.

– Approval by **TL** as manufacturer of acrylic windows

– **TL** Certificate which certifies the manufacturing inspections and the pressure tests according to C.6.

B. Materials

1. Acrylic viewports are to be designed, fabricated and maintained in accordance with the requirements of the latest edition of the American Society of Mechanical Engineers Safety Standard for Pressure Vessels for Human Occupancy (ASME PVHO) Section 2 Viewports and Section 3 Window Fabricators. Other standards and materials may be accepted by **TL** provided they achieve an equivalent level of safety with respect to design, fabrication and maintenance. The producer is required to certify this before manufacture commences.

2. Acrylic windows have to meet the minimum physical requirements stated in Table C.1.

3. For each batch of acrylic plastic processed to windows the manufacturer has to issue a Manufacturer Inspection Certificate containing at least the following details:

– Number and date of Certificate

– Manufacturer's name and address

– Designation and application of casting type

– Batch number, quantity, shape and size of castings

– Marking of castings

– Results of tests applied in accordance with Table C.1

– Stamp and signature

4. Where a Manufacturer Inspection Certificate of the kind required is not available for the acrylic plastic or where the conditions for recognition of the Inspection Certificate are not satisfied, the tests are to be extended in a manner to be agreed with **TL** in each individual case.

5. Each casting is to be provided at one point at least with a marking which identifies the type of casting, the batch number, the date of manufacture and the name of the manufacturer.

C. Manufacture of Windows

1. The manufacture of acrylic windows covered by these Rules may only take place in specialized workshops which have been approved by **TL** for that purpose. Such approval can be granted only to those companies which employ properly trained specialists and which have available the necessary technical facilities enabling them to undertake the expert forming, machining, heat treatment and quality control of acrylic windows.

Application for approval is to be made to **TL** before the manufacture of windows commences.

2. The acrylic plastic to be used has to meet the requirements stated in B. After machining and any necessary forming operations, each window is to be subjected to heat treatment (tempering) in accordance with the acrylic plastic manufacturer's specification. After tempering no further mechanical polishing may be carried out on the window.

Flat disk windows for diving chambers where only the surrounding area is professionally machined need not to undergo a heat treatment after manufacturing.

3. Window surfaces are to be polished in such a way as to meet the optical clarity requirement stated in Table C.1.

4. For each window or series of windows the window manufacturer has to issue a component Certificate specifying all the stages of manufacture such as cutting, sticking, polishing, forming and tempering. In addition the tests carried out, the test results, the marking of the windows and the date of manufacture are to be indicated.

5. Each window is to be permanently marked with at least the following details:

– Design pressure PR = **NDP** [bar]

– Design temperature [°C]

– **TL** approval stamp

– Manufacturer's name or identifying mark

– Serial number and year of manufacture.

– Direction of pressure, if it is not clear

Wherever possible, the marking is to be engraved in the non-load-bearing portion of the window edge. The use of punches is not allowed.

6. Acrylic windows are to be presented to **TL** for an inspection of manufacture. In addition, each window is to be subjected, in the presence of a **TL** Surveyor, to a pressure test in accordance with **TL** Rules for Section 2, F.3.3. At the pressure test the direction of pressure has to be observed. If the windows are subjected to pressure from both sides, this is to be considered for the testing.

D. Window Shapes and Sizes

1. The standard shapes and sizes shown in Table C.2, C.3 and C.4 are to be selected for the acrylic windows. For design pressure PR in general the nominal diving pressure **NDP** is to be used, see also the Rules for Section 4,Table 4.2 resp. Chapter 54 – Underwater Equipment.

2. Acrylic windows of other shapes and sizes or for other ranges of pressure may be used on application if approved by **TL** or if they are designed and manufactured to a standard recognized by **TL**.

Acrylic windows may be performed e.g. according to ASME PVHO-1, Section 2.

3. The design temperature to be assumed for acrylic windows shall be the mean value of the maximum external and internal temperatures to be expected under design pressure conditions.

4. Windows subjected to pressure from both sides are to be designed for the maximum pressure applied, regardless of whether this pressure is external or internal.

5. Pressure may only be applied to the convex side of spherical shell windows.

6. The thickness of the window has to be everywhere equal to, or greater than, the minimum value determined by reference to Tables C.2, C.3 and C.4. For intermediate temperatures linear interpolation may be applied.

7. With flat windows having right-angled edge and an O-ring seal, the outside diameter of the disk shall be within + 0,00/–0,25 mm of the nominal value, or within + 0,00/–0,75 mm where flat gasket seals are used.

8. Because of stress increasing effects grooves for seals shall not be located in the acrylic window bearing surface and also not in the window itself.

9. The greater diameter of the conical bearing surface of an acrylic window shall be within +0,000/–0,002 D_o of the nominal value.

The included conical angle of the window shall be within + 0,25/–0,00 degrees of the nominal value.

10. The concave or convex surface of the window shall not differ from an ideal spherical sector by more than ± 0,5 % of the nominal external spherical radius.

11. The surface roughness R_a of the window bearing surface shall be 0,75 μm or better.

E. Installation of Windows

1. If the window seat is not made of corrosion resistant material, it is to be sufficiently preserved with a suitable agent. In addition window and window seat are to be carefully cleaned using only cleaning material which is compatible with acrylic glass.

2. Conical window seats are to be treated with silicone or a suitable grease before the installation.

3. During installation of the window care is to be taken that the bolts of the fastening ring are to be tightened with the prescribed and all the same torque.

Table C.1 Mechanical and optical properties of acrylic plastics

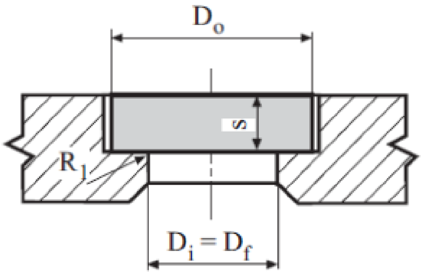
Properties	Specified values	Test method	ASTM
Ultimate tensile strength Elongation at break (in relation to necking zone) Modulus of elasticity measured by tensile test	≥ 62 N/mm^2 ≥ 2 % ≥ 2760 N/mm^2	DIN 53455 **(1)** specimen type 3 test velocity II standard climate 23/50 DIN 53457	D 638 **(1)**
Compressive yield strength Modulus of elasticity measured by compression test	≥ 103 N/mm^2 ≥ 2760 N/mm^2	DIN 53454 **(1)** standard climate 23/50 size of test specimen: 25 × 12,5 × 12,5 mm DIN 53457 **(1)**	D 695 **(1)**
Compressive deformation	≤ 1 %	Constant compressive stress **(1)** of 27,5 N/mm^2 for 24 h at 50 °C test cube: 12,5 mm edge length	D 621 **(1)**
Ulltraviolet transmittance	≤ 5 %	UV-spectrophotometer wave length range: 290 - 370 nm thickness of specimen: 12,5 mm	E 308
Visual clarity	Legibility	A 25 x 25 mm standard type set comprising 7 lines of 16 letters each is to be clearly legible through the acrylic plastic pane at a distance of 500 mm.	D 702
Residual monomers methyl methacrylate aethyl acrylate	≤ 1,6 %	Gas chromatograph	

1) *The mechanical properties are to be verified on at least 2 specimens.*

Table C.2 Standard dimensions for flat disk windows

Range of application:

Minimum wall thickness	:	$s \geq 12{,}5$ mm
Slenderness ratio	:	$s/D_o \geq 0{,}125$
Edge radius	:	$1 \text{ mm} \leq R_1 \leq 2$ mm
Window seating	:	$1{,}25 \leq D_o/D_f \leq 1{,}5$ mm
Max. allowable working pressure	:	$p \leq 170$ bar



Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i at				
	10 °C	**24 °C**	**38 °C**	**52 °C**	**66 °C**
5	0,134	0,146	0,154	0,164	0,188
10	0,154	0,173	0,188	0,201	0,226
15	0,173	0,195	0,210	0,223	0,253
20	0,188	0,210	0,226	0,240	0,281
25	0,201	0,223	0,240	0,257	0,305
30	0,210	0,233	0,253	0,274	0,324
35	0,219	0,243	0,267	0,292	0,344
40	0,226	0,253	0,281	0,305	0,363
45	0,233	0,264	0,295	0,317	0,383
50	0,240	0,274	0,305	0,329	0,402
60	0,253	0,295	0,324	0,354	0,441
70	0,267	0,310	0,344	0,378	0,480
80	0,281	0,324	0,363	0,402	0,520
90	0,295	0,339	0,383	0,427	0,559
100	0,305	0,354	0,402	0,451	0,598
110	0,315	0,368	0,422	0,476	0,637
120	0,324	0,383	0,441	0,500	0,676
130	0,334	0,398	0,461	0,524	0,715
140	0,344	0,412	0,480	0,549	0,754
150	0,354	0,427	0,500	0,573	0,793
160	0,363	0,441	0,520	0,598	0,832
170	0,373	0,456	0,539	0,622	0,871

Table C.3 Standard dimensions for spherical shell windows with conical seat (opening angle 60° / 90°):

Range of application

Opening angle : $\alpha \geq 60°$

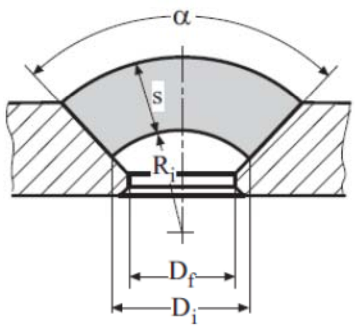
Minimum wall thickness : s ≥ 12,5 mm

Minimum values for s/Ri :

α	$60° \leq \alpha < 90°$	$90° \leq \alpha < 120°$
s/R_i	0,09	0,06

Window seating : $D_i/D_f \geq 1,02$

Max. allowable working pressure : p ≤ 170 bar



Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i for $60° \leq \alpha < 90°$ at					Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i for $90° \leq \alpha < 120°$ at				
	10 °C	**24 °C**	**38 °C**	**52 °C**	**66 °C**		**10 °C**	**24 °C**	**38 °C**	**52 °C**	**66 °C**
5	0,090	0,090	0,090	0,090	0,090	5	0,042	0,042	0,042	0,042	0,049
10	0,090	0,090	0090	0,090	0,112	10	0,042	0,043	0,049	0,054	0,070
15	0,090	0,090	0,097	0,108	0,140	15	0,043	0,052	0,060	0,067	0,089
20	0,090	0,097	0,112	0,126	0,166	20	0,049	0,060	0,070	0,080	0,107
25	0,090	0,108	0,126	0,143	0,191	25	0,054	0,067	0,080	0,091	0,124
30	0,097	0,119	0,140	0,160	0,215	30	0,060	0,075	0,089	0,102	0,142
35	0,104	0,129	0,153	0,176	0,238	35	0,065	0,082	0,098	0,113	0,160
40	0,112	0,140	0,166	0,191	0,259	40	0,070	0,089	0,107	0,124	0,177
45	0,119	0,150	0,179	0,206	0,279	45	0,075	0,095	0,116	0,135	0,194
50	0,126	0,160	0,191	0,221	0,298	50	0,080	0,102	0,124	0,146	0,210
60	0,140	0,179	0,215	0,248	0,332	60	0,089	0,116	0,142	0,168	0,242
70	0,153	0,197	0,238	0,274	0,363	70	0,098	0,128	0,160	0,190	0,272
80	0,166	0,215	0,259	0,298	0,391	80	0,107	0,142	0,177	0,210	0,300
90	0,179	0,232	0,279	0,320	0,416	90	0,116	0,155	0,194	0,230	0,327
100	0,191	0,248	0,298	0,340	0,439	100	0,124	0,168	0,210	0,250	0,351
110	0,203	0,264	0,315	0,359	0,460	110	0,133	0,181	0,226	0,269	0,373
120	0,215	0,279	0,332	0,377	0,480	120	0,142	0,194	0,242	0,287	0,393
130	0,227	0,293	0,348	0,394		130	0,151	0,206	0,257	0,304	0,411
140	0,238	0,307	0,363	0,410		140	0,160	0,218	0,272	0,320	
150	0,248	0,320	0,377	0,425		150	0,168	0,230	0,287	0,336	
160	0,259	0,332	0,391	0,439		160	0,177	0,242	0,300	0,351	
170	0,269	0,344	0,404	0,452		170	0,185	0,254	0,314	0,365	

Table C.4 Standard dimensions for spherical shell windows with conical seat (opening angle 120°/180°)

Range of application:

Opening angle : 180 ≥ α ≥ 120°

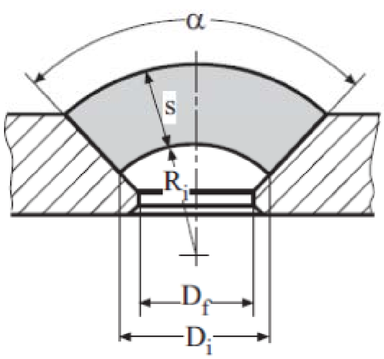
Minimum wall thickness : s ≥ 12,5 mm

Minimum values for s/Ri :

α	60° ≤ α < 90°	90° ≤ α < 120°
s/R_i	0,09	0,06

Window seating : $D_i/D_f \geq 1{,}02$

Max. allowable working pressure : p ≤ 170 bar



Design pressure PR [bar]	Minimum wall thickness / Inside diameter of seat s/D_i for 120° ≤ α < 180° at					Design pressure PR [bar]	Minimum wall thickness / Inside diameter of seat s/D_i for α = 180° at				
	10 °C	24 °C	38 °C	52 °C	66 °C		10 °C	24 °C	38 °C	52 °C	66 °C
5	0,021	0,023	0,025	0,028	0,034	5	0,018	0,018	0,019	0,021	0,026
10	0,025	0,030	0,034	0,038	0,050	10	0,019	0,023	0,026	0,030	0,041
15	0,030	0,036	0,042	0,048	0,067	15	0,023	0,028	0,034	0,039	0,056
20	0,034	0,042	0,050	0,059	0,083	20	0,026	0,034	0,041	0,049	0,071
25	0,038	0,048	0,059	0,069	0,100	25	0,030	0,039	0,049	0,058	0,086
30	0,042	0,054	0,067	0,079	0,117	30	0,034	0,045	0,056	0,068	0,101
35	0,046	0,061	0,075	0,090	0,131	35	0,038	0,051	0,064	0,077	0,115
40	0,050	0,067	0,083	0,100	0,146	40	0,041	0,056	0,071	0,086	0,129
45	0,054	0,073	0,092	0,110	0,161	45	0,045	0,062	0,079	0,096	0,142
50	0,059	0,079	0,100	0,119	0,175	50	0,049	0,068	0,086	0,105	0,155
60	0,067	0,092	0,117	0,138	0,204	60	0,056	0,079	0,101	0,122	0,182
70	0,075	0,104	0,131	0,157	0,232	70	0,064	0,090	0,115	0,139	0,207
80	0,083	0,117	0,146	0,175	0,259	80	0,071	0,101	0,129	0,155	0,232
90	0,092	0,127	0,161	0,193	0,285	90	0,079	0,112	0,142	0,172	0,256
100	0,100	0,138	0,175	0,211	0,310	100	0,086	0,122	0,155	0,188	0,278
110	0,108	0,149	0,190	0,228	0,334	110	0,094	0,132	0,168	0,204	0,299
120	0,117	0,161	0,204	0,245	0,357	120	0,101	0,142	0,182	0,220	0,319
130	0,123	0,171	0,218	0,262	0,379	130	0,108	0,152	0,194	0,235	0,337
140	0,131	0,182	0,232	0,278	0,400	140	0,115	0,162	0,207	0,250	0,352
150	0,138	0,193	0,245	0,294		150	0,122	0,172	0,220	0,264	0,366
160	0,146	0,204	0,259	0,310		160	0,129	0,182	0,232	0,278	
170	0,153	0,214	0,272	0,325		170	0,135	0,191	0,244	0,292	

ANNEX D

MANUFACTURE AND TREATMENT OF FIBRE REINFORCED PLASTICS (FRP)

A. **GENERAL** **D-**2
B. **REQUIREMENTS FOR THE MATERIALS AND THEIR PROCESSING** **D-**2
C. **REQUIREMENTS FOR THE DESIGN** **D-**4

A. General

1. Definition

Fibre reinforced plastics are heterogeneous materials, consisting of a thermosetting resin as the matrix and an embedded fibrous reinforcing material.

2. Scope of application

For submersibles plastics are mainly used for the following components:

- Exostructure
- Rudder and propeller
- Pressure vessels

B. Requirements for the Materials and their Processing

1. Materials

1.1 Approval

1.1.1 The materials used for the manufacturing of components from FRP shall be assessed and approved by **TL**.

1.1.2 The approval refers only to the approved material. The applicability of this material in connection with other materials shall be demonstrated independently by the manufacturer or the user in a suitable manner.

1.2 Quality assurance

1.2.1 A constant material quality shall be secured by the manufacturer through constant quality assurance measures.

1.2. **TL** reserve the right to demand resp. carry out spot tests of the material properties during the duration of the material approval.

1.3 Types of materials

For the construction of submersibles in general the following materials are to be considered:

- Laminated resins, e.g. cold-setting or hot-setting unsaturated polyester (UP) resins and cold setting epoxy (EP) resins
- Reinforcing materials, e.g. fibre reinforcements made of glass and carbon

– Prepregs as reinforcing materials, which are pre-impregnated with a thermosetting resin and which can be processed without any further addition of resin or hardener

– Core materials, e.g. rigid foams with adequate compressive strength

– Adhesives, e.g. cold- and hot-setting thermosetting adhesives and hot-melt adhesives

– Flame retardant laminates produced by additives to the resin system, whereby the viscosity of the resin or the mechanical properties of the manufactured laminates not be changed essentially

Other materials may be approved in agreement with **TL** Head Office.

2. Manufacturing

2.1 Approval

2.1.1 Manufacture of FRP-components shall only be performed by workshops which are approved by **TL** for the manufacture of components made from fibre-reinforced thermosetting resins.

2.1.2 The manufacture of FRP-components shall only be carried out by persons with professional knowledge. This professional knowledge shall in general be verified by certificates of the corresponding training courses.

2.1.3 All manufacturing facilities, store-rooms and their operational equipment shall fulfil the requirements of the responsible authorities. The manufacturer is alone responsible for compliance with these requirements.

2.2 Store rooms and laminating workshops

The danger of contamination of laminating materials is to be minimized through separation of production facilities from store rooms.

2.3 Guidelines for processing

2.3.1 As a matter of principle, only materials approved by **TL** shall be used. In addition to the choice of suitable and approved materials, special care shall be taken when working with them because of the great influence on the properties of the product.

2.3.2 For the preparation and processing of the resin compounds and reinforcing material, beside the **TL** Rules, the instructions issued by the material manufacturers and the regulations of the competent authorities are to be observed.

2.4 Manufacturing surveillance

For components made of FRP, manufacturing surveillance has to consist of the quality control of the basic materials, production surveillance and the quality inspection of the finished components.

2.5 Repair of components

2.5.1 Repairs of structural FRP-components shall only be performed by workshops which are approved by **TL**.

2.5.2 For the approval of a repair, all design and repair drawings needed to assess the repair of the relevant components are to be submitted to **TL**. The repair plan is to be examined by **TL** Head Office and approved.

2.5.3 A report is to be established for each repair which has to be signed by the head of the repair team.

2.5.4 If the materials and laminates used for the repair are not identical to those employed when the component was manufactured, equivalence of the combination of materials shall be verified with respect to their properties.

3. Detailed requirements

The detailed requirements for the areas pointed out are defined in the **TL** Rules for Chapter 2 - Material, Section 13.

C. Requirements for the Design

1. Design data

The mechanical properties and the nominal thickness of the laminate as well as weight, type and portion of the reinforcement layers, which can be individually used, are to be defined on the design drawings.

2. Design measures

For the design of components the following measures are to be considered:

2.1 Changes in the laminate thickness are to be established with a smooth transition of 25 mm per 600 g/m². In the transition area from a sandwich design to massive laminate the core material is to be gradually tapered (at least 3 : 1).

2.2 In general frame and stiffening sections are to be built up by layer and layer on the laminate, as far as the last layer is not yet cured. Where internal structural members are crossing each other, special care is to be taken that the load-bearing capacity remains unchanged.

2.3 Closed hollow spaces in the structure which may be subjected to external pressure are to be avoided.

2.4 If core materials are used in areas which may be subjected to external pressure, pressure-proof materials like e.g. rigid foams are to be used.

2.5 Stress concentrations, peaks in stiffness and discontinuities are to be avoided. It has to be ensured, that because of cut-outs, openings in load carrying elements and the connection of fittings the strength of the component is not impaired.

2.6 If various components which have been produced in different moulds are to be connected with each other, then the connecting laminates have to be finished before curing of the components.

If components of FRP are bolted which each other or with components of other materials, the connecting elements (bolts, nuts, washers) are to be of seawater resistant material. Bolted connections are to be dimensioned according to the occurring forces.

2.7 In areas with local force introduction (e.g. connecting elements of the exostructure, bitts, cleats) sole pieces and/or shims of adequate strength are to be situated. The strength, e.g. bearing strength is to be proven in a suitable way. The connecting area of these sole pieces is to be prepared in a suitable way and shall be free of contamination.

2.8 Metallic materials used in the design, like e.g. steel or aluminium alloys have to be suitable for the intended purpose and shall not impair the curing of the laminating resins.

Local reinforcements of metallic materials are to be cleaned and degreased carefully and, if possible, are to be shot blasted or roughened up to achieve a toothing effect.

2.9 For sandwich laminates in way of bolted connections and fittings, inserts of a material, which can withstand the compression and the design loads, are to be provided. The inserts are to be connected with the core material and the laminate layers in the best way.

2.10 Laminate edges and holes are to be sealed.

2.11 Further design measures which are recommendable for different shipbuilding components made of plastics are contained in the **TL** Rules for Chapter 9 - Construction and Classification of Yachts, Section 4.

ANNEX E

BASIC REQUIREMENTS FOR UMBILICALS

A. **General** **E-**2
B. **Principles for Layout and Design** **E-**3
C. **Documents for Approval** **E-**8
D. **Tests and Trials** **E-**9
E. **Marking** **E-**12

A. General

1. Definition

The umbilical is regarded as the connecting link between support ship and an element under water, which may include hose assemblies for liquid and gas transport and monitoring, communication, data transfer and energy supply cables as well eventually a lifting cable.

This bundled or integrated supply line may also be used between elements under water.

As elements under water in the sense of this Annex are to be regarded e.g.:

– Diving chambers

– Non-autonomous (manned) and remotely controlled (unmanned) submersibles

– Launchers

– Underwater working machines

– Diving equipment

The integrated or also independent lifting cable serves for launching and recovery, as well as for lifting and lowering of an element under water as well as for absorption of tension loads during operation. The lifting cable may also be designed as bearing element, e.g. as netting within the sheathing of the umbilical.

2. Scope

This Annex is valid for the technical requirements and the testing of umbilicals including connecting pieces as well as shut-off devices at the ends and the load transfer points. The load transfer points of the support ship/element are not subject of this Annex.

Furtheron this Annex is valid for cables and hose assemblies which may be subjected to external overpressure and integrated lifting cables.

The penetration into the pressure hull or a vessel under pressure is part of the element.

Some basic requirements for the coil-up/coil-off mechanism are defined.

The supply systems for the materials, data and energies transferred by the umbilical form part of the support ship or element and are not treated in this Annex.

Umbilical systems for production duties, as e.g. used in the oil and gas industry, are primarily not subject of this Annex.

3. Quality Management System

The manufacturer of umbilicals has to apply a recognized quality management system, like e.g. ISO 9001 or equivalent. This system has to cover design, manufacture and testing.

4. Equivalence

Umbilicals deviating from this Annex in their type, structure and the compliance with some detailed requirements may be accepted by **TL**, provided that they are found to be equivalent to the principle requirements defined in this Annex.

B. Principles for Layout and Design

1. General

1.1 The requirements defined in the following are minimum requirements for the majority of the prospective applications. For special use the selection of the requirements is to be agreed with **TL**.

1.2 Generally the following requirements are to be considered for the design:

– Environmental influences, see the **TL** Rules for Section 2, D.

– Influence of weight (deadweight, empty, full)

– Buoyancy behaviour (positive and negative buoyancy, neutral buoyancy)

– Dynamic influences because of ship movements and increasing and lowering the pressure inside

– Thermal influences on expansion and shrinking because of possible temperature changes inside and outside

– Thermal influences because of power cables partly on drum

– Pressure differences in hoses between upper and lower end of umbilical

– Chemical and electrochemical influences

1.3 The control of the coil-up/coil-off mechanism for the umbilical and the monitoring of the supply flow through the umbilical including the production of materials to be supplied are to be concentrated at a central position.

For manned, non-autonomous submersibles the control and monitoring is to be integrated into the control stand which maintains the connection with the submersible. For unmanned, remotely controlled submersibles and other elements these are to be integrated into the control station.

1.4 Umbilicals shall be produced in one piece for the complete required length and shall not be divided into different parts.

1.5 Requirements and tests of umbilicals for hose supplied diving equipment are to be taken from standard EN 15333-1.

2. Mechanical requirements

2.1 Materials

Only materials according to generally recognized standards are to be used and their application has to be clearly recorded and traced.

The materials are to be suitable for the use in salt water. If a mission in other media than water is planned, these are to be adequately considered.

The material of hose assemblies is to be suitable for the media to be transported.

The materials are to be suitable for permanent and varying bending stress.

If hoses are used for breathing gases their suitability is to be proven (e.g. off-gassing test).

Umbilicals, hose assemblies and cables are to be protected against abrasion and damages.

For the protection cover of umbilicals attention is to be given that no internal pressure can be built up if little leakages occur in the hose. Metal inserts in the protection cover are to be avoided.

2.2 Tensile load

2.2.1 For umbilicals with integrated lifting cable the mechanical characteristics are to be judged according to the submitted documentation. Hereby the maximum permissible tension load and the minimum breaking load of the umbilical are to be defined by the manufacturer. For the use of lifting cables made of steel the maximum static tension load created by the safe working load shall not exceed 1/8 of the proven breaking load of the cable. For the use of lifting cables made of chemical fibre the maximum static tension load created by the safe working load shall not exceed 1/10 of the proven breaking load of the cable.

For the use of lifting cables for simple scientific devices a reduced breaking load of the cable may be approved in agreement with **TL** under consideration of risk potential and intended use.

Further on the functionality of the elements contained in the umbilical at maximum possible longitudinal extension of the umbilical is to be considered. The umbilical is to be constructed to reach neutrality to tension for the whole range of tensional stresses.

2.2.2 If there is no lifting cable included, the integrated cables and hose lines are to be protected from longitudinal stress by a strain relief. The minimum tension load is to be defined considering the duty of the mission, is to be agreed with **TL** and to be proven.

2.2.3 If buoyancy elements or weights are used to change the buoyancy behaviour, these are to be securely fastened without damaging the umbilical.

Over the complete appearing tension range no additional torsional effects shall be created.

For hoses with non corrosion-resistant wire mesh inlets the mesh is to be protected against the surrounding media.

2.3 Bending and buckling

Umbilicals shall be buckling safe and bending resistant respectively being adequately arranged to avoid buckling safely. According to the structure of the umbilical the minimum bending radius is to be agreed with **TL**.

The minimum bending radius of a single component (e.g. lifting cable, cable, hose assembly, etc.) shall not be bigger than the minimum bending radius of the complete umbilical. **(1)**

If special elements are used for avoidance of bending and buckling, these have to be securely fastened without damaging the umbilical.

2.4 Hose lines

2.4.1 Lay out

For the layout is to be considered:

– Each hose line is to be designed for an internal burst pressure, which shall at least be for liquids 4 times, for gases 5 times of the maximum allowable working pressure.

– Hose assemblies to be subjected to external pressure, are to be designed for at least 1,1 times (manned submersibles) and 1,0 times (unmanned submersibles and other elements) the collapse diving pressure **CDP**.

– Moreover the maximum possible pressure difference Δp between inside and outside pressure has to be considered.

2.4.2 Type test

– Burst pressure test:

Each hose is to be subjected to internal pressure until bursting. The minimum burst pressure is to be for liquids 4 times, for gases 5 times the allowable maximum working pressure.

– External pressure test:

Hose assemblies which are additionally subjected to external overpressure have to undergo a hydraulic pressure test with 1,5 times the maximum possible pressure difference between inside and outside (but at least 10 bar).

2.4.3 Routine test

Within the series production the routine test contains the following test steps:

– Pressure test:

Before integration into an umbilical, each hose is to be tested with an internal pressure according to 1,5 times (metallic hose assemblies) respectively 2 times (non-metallic hose lines) maximum allowable working pressure.

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(1) *For bending radius and bending number compare also CIGRE Recommendation 68 under consideration of the mechanical requirements according to 2.1 and additional influences of temperature, load, salt water, if necessary diesel fuel.*

– External pressure test:

Hoses which are additionally subjected to external overpressure have to undergo a hydraulic pressure test with 1,5 times the maximum possible pressure difference between inside and outside.

2.5 Fittings

Connecting elements and fittings have to meet the same inside and outside design pressures as the umbilical, shall not unintentionally disconnect, shall be corrosion resistant and suitable for the planned media.

3. Electrical requirements

3.1 Umbilicals may contain monitoring and communication/data transfer cables and also energy supply lines.

3.2 Lay out

For the lay out has to be considered:

- Flexible cables resp. highly flexible cables e.g. of class 5 acc. to IEC have to be used, whereby for energy supply cables a minimum sectional area of the single copper conductor of 2,5 mm^2 is to be provided. Empty spaces are to be filled with suitable filler material like petroleum jelly, to maintain form stability.

- Electrical cables and optical conductors are to be designed according to their specification. The maximum length is to be considered hereby.

- For special duties it may be necessary to construct cables with longitudinal water tightness.

- For different cables with several levels of voltage negative influences between them have to be avoided.

- For cables mechanical forces shall not be transferred by the conductors or their insulation.

- Cables have to provided at least cross water tight.

- Each cable is to be designed for an external pressure which is at least for manned submersibles 1,1 times and for unmanned submersibles and other elements 1,0 times the collapse diving pressure **CDP**.

- Extended stowage of cables in water shall not lead to a remarkable reduction of the insulation resistance.

3.3 Type test

Fundamentally the electric and electronic characteristics specified for the project have to be proven, e.g. by a type test according to IEC 60092-350/351.

The type test contains the following test steps:

- Visual check

- Check of dimensions, structure and marking

– The cross - watertightness of electrical cables / single conductors is in general to be tested with 2 × PN (cyclic). If the cables are integrated in a cross-watertight umbilical, the test may be cancelled in agreement with **TL**.

– Evaluation of voltage insulation strength according to Table E.1

Measurement of the insulation of energy supply lines with at least 500 V (guiding value: > 500 MΩ × km)

For cables with a nominal voltage up to 1 kV a check of the insulation values is to be performed with a test voltage equal to 2 times the nominal voltage, but at least 500 V.

For energy supply lines with a nominal voltage above 1 kV a check of the insulation values is to be performed with a test voltage of at least the nominal voltage.

The test comprises the evaluation of the insulation value of all conductors against each other as well as of each single conductor against the external insulation layer.

The measurement of the insulation is to be performed before and after the test of cross water tightness and after the test for voltage insulation strength.

– Resistance measurement of all single conductors

– Measurement of partial discharging according to IEC 60885-2 at voltages above 3,6/6 kV (U0/U) for all single conductors of the cable

– Impedance and capacity test depending on voltage and duty of mission in agreement with **TL**

– Check of compliance with the specifications for insulation, capacity and eventually impedance

Table E.1 Test voltages for cables

U_m	**kV**	1,2	3,6	7,2	12
U_0/U	**kV / kV**	0,6 / 1,0	1,8 / 3,0	3,6 / 6,0	6,0 / 10
AC test voltage	**kV**	3,5	6,5	11	15
DC test voltage	**kV**	2 × U	1,5 × U	1,3 × U **(1)**	1,25 × U **(1)**

Remarks:
U_0 : nominal main voltage between conductor and earth or metallic screen
U : nominal main voltage between the conductors for which the cable is designed
U_m : maximum permissible voltage for equipment

(1) *test voltage case by case according to agreement with **TL***
The test period is in case of using AC as test voltage 15 minutes.
The test period is in case of using DC as test voltage 1 minute.

3.4 Routine test

Within the series production the routine test contains the following test steps:

- Visual check
- Check of dimensions, structure and marking
- Covering failure test, if applicable
- Evaluation of voltage insulation strength according to Table E.1
- The cross - watertightness of electrical cables / single conductor is in general to be tested with 1,5 × PN (cyclic) according to **TL** Rules for Section 11, Fig. 11.2 If the cable is integrated in an umbilical which is cross - watertight, this test may be avoided in agreement with **TL**.
- The insulation measurement according to 3.3 is to be performed before and after the test of cross water tightness and after the test for voltage insulation strength.

3.5 Electrical connecting elements

Connecting elements are to be designed for the same external pressure as the cables, shall not unintentionally disconnect and shall be corrosion-resistant. Electrically they shall follow the layout of the adjacent cables and are to be watertight in longitudinal direction in addition. The electrical and mechanical characteristics are not to be influenced in a negative way by the connecting elements.

4. Coil-up/coil-off mechanism for umbilicals

Concerning technical requirements for coil-up/coil-off mechanism for umbilicals on the support ship see the **TL** Rules for Chapter 54 – Underwater Equipment resp. Section 17, E.5.

5. Jettisoning of the umbilical

5.1 In case the umbilical is caught at an underwater obstacle and this hindrance cannot be removed by relevant manoeuvring, it may be necessary to separate the umbilical from the element under water and to initiate an independent surfacing procedure.

5.2 For manned submersibles it has to be possible to drop respectively to cut-off the umbilical by the crew from inside the submersible. The jettisoning system is to be so designed that two operational actions which are independent from each other and which need no electric energy are required to activate the separation.

5.3 For unmanned elements, for which jettisoning is required, the umbilical has to be dropped respectively cut-off at the connecting point with the submersible from the control station. The jettisoning system is to be designed that an unintentional jettisoning is avoided.

5.4 For other elements under water the possibility for jettisoning is to be agreed with **TL** according to type and mission duty.

C. Documents for Approval

It is to be submitted:

- General description of the mission duty

– Description of the structure and the applied materials of the single components

– Definition of main parameter, compare E.

– Drawing of the cross section

– Data concerning connecting elements and fittings, eventually drawings, if existing

– Data concerning pressure and flow conditions and capacity for gas and liquid transport

– Data concerning the energy, communication and data transfer, e.g. voltage, amperage, transfer rates

– Specification of impedance, capacity and resistance values

– Data concerning tests with Certificates already performed

– Data concerning installation, maintenance, operation and repair

– Description of marking

D. Tests and Trials

1. General

1.1 The required tests are to be divided into a type test for the prototype and a routine test within the manufacturing for the effective use.

1.2 A trial and test program is to be established by the manufacturer of the umbilical according to the specification of the requirements profile defined by the end client (element producer or operator) and to be submitted to **TL** for approval. Generally this program shall contain at least the test steps defined in the following.

1.3 About the scope of the presence of **TL** Surveyors at these tests and trials **TL** will decide in each individual case.

2. Type test

2.1 Mechanical requirements

The type test contains the following test steps:

– Visual check

– Check of dimensions, structure and markings

– Weight evaluation:

The effective weight for missions of the umbilical [t/1000 m] is to be determined in air, water (if not specified otherwise: seawater with 1028 kg/m^3) empty and filled and under defined dynamic load (with friction in water) with the aim to determine the safe working load **SWL** at the upper end of the umbilical.

– Test of tensile strength:

The minimum tensile strength of the elements provided for the tension load of the umbilical is to be determined.

– Buckling test:

The umbilical is to buckle 5000 times with the defined bending radius at one location and in one direction. Subsequently insulation and resistance measurement of the single conductors are to be performed.

– Torsion test:

A part of at least 1 m length is to be loaded vertically with 0,3 **SWL** and to be twisted by 90° for 5 minutes. After the test no remarkable lengthening or twist shall be noticeable. Subsequently electrical lines are subjected to a resistance measurement, hose lines to a tightness test under working pressure.

– Stretch loading test:

A part of at least 1,5 m length is to be fixed at the ends and a pretension in longitudinal direction will be brought up. The size of the pretension is to be agreed with **TL**. For 5 cycles the size of the pretension will be increased by 5 times and lowered again. Subsequently electrical lines are subjected to a resistance measurement, hose lines to a tightness test under working pressure.

– External pressure test:

In general the umbilical is to be subjected to a cyclic hydraulic pressure test with 2 times the nominal pressure of the umbilical PN. For big water depths the test pressure is to be agreed with **TL**.

Attention is to be paid to the fact, that for the use of hose lines the internal pressure is not below the diving pressure, as far as possible.

– Tightness test of the complete umbilical type:

All hose assemblies are to be subjected at the same time to the maximum allowable working pressure and an eventual loss of pressure because of leakage is to be checked. A maximum allowable leakage rate of 1 % pressure loss within 24 hours is acceptable for the different hose lines.

- If gases with a content by volume greater 25 % oxygen shall be transported, all materials coming into contact with oxygen are to be checked for their oxygen suitability (e.g. according to EN 559). For allowable working pressures of more than 25 bar an oxygen pressure surge test is to be performed (e.g. according to EN 15333-1).

- In an actual case of application, depending on mission duty and operational conditions it will be decided by **TL** if all defined tests are to be performed.

- If required, the specified liquid and gas volume which can be put through is to be checked (if need be with projection to the effective length of the umbilical).

2.2 Electrical/electronic requirements

Principally the electric and electronic characteristics specified for the project are to be proven e.g. by a type test according to IEC 60092-350.

The type test contains the following steps:

– Each single cable has to meet the requirements according to B.3.3.

– The cross - watertightness of the umbilical is to be proven within the external pressure test according to 2.1.

– The measurements of the insulation according to B.3.3 are to be performed before or after the test of cross - watertightness.

– Impedance and/or capacity tests are to be performed depending on voltage and duty of mission in agreement with **TL**.

– Evaluation of voltage insulation strength according to Table E.1

– Check of compliance with the specifications for insulation, capacity and eventually impedance

– Check of transfer of the specified data volume/time unit (If data cables are tracked together with cables for voltage supply within the umbilical, the check of data transfer is to be done with active nominal voltage. Voltage peaks by e.g. switching actions are to be considered.)

3. Routine test

3.1 Mechanical requirements

Within the series production the routine test contains the following test steps:

– Visual check

– Check of dimensions

– External pressure test:

In general the umbilical is to be subjected to a hydraulic pressure test with 1,5 times the nominal pressure of the umbilical PN (cyclic according to the **TL** Rules for Section 11, Fig. 11.2).

Attention is to be paid to the fact, that for the use of hose assemblies the internal pressure is not below the diving pressure.

– Pressure and tightness test of the complete finally assembled umbilical including end fittings:

All hose lines are to be subjected to 1,5 times (metallic hose lines) resp. 2 times (non-metallic hose lines) the maximum allowable working pressure at the same time using the original media (as far as possible) and an eventual pressure decrease because of leakage is to be checked.

– The cleanliness of the hose lines is to be checked.

3.2 Electric/electronic requirements

Within the series production the routine test contains the following test steps:

– Each single cable has to meet the requirements according to B.3.4.

– covering failure test, if applicable

– Measurements of the insulation according to B.3.4 are to be performed before and after the test of cross water tightness within the external pressure test according to 3.1.

– Evaluation of voltage insulation strength according to Table E.1 in agreement with **TL**

– Check of faultless transfer of the specified data volume/time unit by the data cables

E. Marking

1. Marking of umbilicals

A durable marking fixed at the upper end of the umbilical shall contain the following data:

– Name of manufacturer

– Year of construction and serial number

– Safe working load of the umbilical **SWL** [t]

– Total length [m]

– Overall diameter [mm]

– Minimum bending radius [m]

– Maximum allowable internal working pressure of hose lines [bar]

– Allowable external pressure of the umbilical PN [bar]

– Data about cables for transmission of electric power (maximum voltage and amperage)

– Data concerning communication/data transfer

Further on the umbilical is to be marked with a longitudinal marking for torsion control as well as with longitudinal markings every 100 m and at the first and last 100 m every 10 m.

Placed markings shall not contain elements which may create corrosion damages.

2. Marking of hose assemblies

The marking on hose assemblies shall contain the following data:

– Name of manufacturer

– Year of construction and serial number

– Outside and internal diameter [mm]

– Maximum allowable working pressure of the hose line [bar]

– Media of the different hose lines

The different hose assemblies of the umbilical are to be repeatedly marked at suitable distance to easily recognize duty and medium.

3. Marking of cables

– Name of manufacturer

– Year of construction and serial number

– Maximum voltage [V]

– Maximum amperage [A]

– Cross section of the single conductors [mm^2]

It is recommended to mark the different electrical wires with different colours.

The cables are to be repeatedly marked at suitable distance.