NUCLEAR SAFETY DIRECTORATE - BUSINESS MANAGEMENT SYSTEM		
TECHNICAL ASSESSMENT GUIDE **STRUCTURAL INTEGRITY:** **CIVIL ENGINEERING ASPECTS**		**T/AST/017** ISSUE 002
Approved By: *Derek Lacey*	Derek Lacey	Issue Date: 17/03/05
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1. Purpose and scope

1.1 This guide provides guidance on the interpretation of those HSE Safety Assessment Principles for Nuclear Plant 1992 (SAPs) which relate to the integrity of civil engineering works and structures at nuclear licensed sites. The scope includes structures supporting safety related plant and equipment and founding materials supporting those structures. Although this guide specifically addresses the Structural Integrity section of the SAPs, including the Additional civil engineering principles, assessors should recognise the importance of the Key and General Principles at the beginning of the section titled, "Engineering Principles". These are covered in other TAGs. The guidance contained in this document is intended for use in the assessment of new and existing nuclear plant.

1.2 For the purposes of this document the term "civil engineering works and structures" applies to site infrastructure (roads, bridges, drainage, railways etc) and structural steel, concrete and masonry structures:

1) which support safety related plant and equipment, contain nuclear matter, provide shielding, retain liquids or gases (eg ponds and concrete pressure vessels), protect the plant from external hazards; or

2) whose failure threatens safety related structures and plant.

1.3 The term "civil engineering works and structures" also includes the materials such as soil and rock which support these structures.

1.4 This guide does not address steel pressure vessels and their internal structures, pipework and metal tanks. These are covered in T/AST/016. Guidance on the assessment of containments for reactor plant is contained in T/AST/020 and for chemical plant in T/AST/021. This guide:

1) identifies the SAPs which relate to the civil engineering aspects of structural integrity;

2) provides an interpretation of these principles; and,

3) identifies the areas assessors should consider when reviewing a safety case.

1.5 This TAG contains *guidance* to advise and inform NSD inspectors in the exercise of their professional regulatory judgement. Comments on this guide, and suggestions for future revisions, should be recorded on the appropriate registry file.

2. SAPS addressed

2.1 The specific SAPs which should be considered in the assessment of civil engineering works and structures are contained within the Engineering Principles between P145 to P177, and P323. However, not all these principles are applicable since some are only relevant to steel containment type structures and their penetrations and attachments. Those excluded are: P148 to P153, P161 and P168. P143, relating to the use of fire resistant materials, P102, relating to ageing and time dependent effects, and P330 concerning decommissioning, also apply.

2.2 This section provides an outline of the intent of the relevant principles. Since some of the principles link together and others are self explanatory, interpretation is in some cases for groups of principles which cover a similar topic such as analysis or manufacture and construction. In general the interpretation applies to the assessment of both new and existing plant. Where there are exceptions these are identified.

2.3 When interpreting the SAPs it is important for the assessor to recognise that the general lack of adequate reliability data for civil engineering structures has led to their design or assessment being based primarily upon established and proven engineering practice. The assessor should adopt a sceptical attitude towards any case which attempts to substitute probabilistic analysis for a proper deterministic analysis or which attempts to justify questionable engineering on probabilistic grounds. However, the full safety case should include civil engineering aspects within the plant PSA as far as practical.

2.4 For the purposes of interpretation, the SAPs applicable to this guide have been grouped into the following areas:

1) general;

2) stress analysis (structural analysis);

3) design;

4) manufacture and construction;

5) operation;

6) pre and in-service inspection and testing.

2.5 General

1) **P143 -** This principle advises that consideration be given to materials used in the construction and their contribution to the fire loading in the structure.

2) **P145 and P146** - The purpose of these principles is to determine whether safety related structures were designed, and constructed or manufactured to the standards determined from the design and construction specifications. These specifications should be determined from the safety function requirements. In civil engineering it is common practice to use external contracting organisations for the construction of the works. The selection and control of these contractors will be fundamental to the successful completion of the work and to the ultimate standard of construction and hence structural integrity achieved. For civil structures arrangements for inspection should be made by the licensee to confirm continued "fitness for purpose" during the plant lifetime. The methods should be capable of identifying deviations, eg defects, from the design intent.

3) **P169** - The purpose of this principle is to demonstrate stability of the soil and rock which provide support for the foundations and superstructure of a nuclear plant. To determine the suitability of these materials site investigations are normally carried out. These should follow the appropriate codes and standards applicable to the safety function of the structures proposed.

2.6 Stress analysis (structural analysis)

1) **P165** - The applicability of this principle to civil engineering structures warrants special consideration. The analysis of civil structures, typically constructed from structural steel or concrete, uses idealised stress models to determine characteristic "stresses" that can be used to select the size of structural elements and/or the disposition of reinforcement. This process, known as structural analysis, differs from that envisaged by P165. There are certain classes of civil engineering structures that can benefit from a detailed stress analysis, eg concrete vessels and containment. However, reinforced concrete presents particular difficulties for the stress analyst because it does not behave elastically. Similarly complex structural frames may be analysed using structural analysis techniques to determine the response of the structure to complex loading regimes such as thermal, dynamic and impact.

2) **P166** - The purpose of this principle is to advise that in the stress or structural analysis due consideration has been given to uncertainties in material properties and that the methodology and loading data have been verified to ensure that the analysis is demonstrably conservative. This is particularly important when analysing safety critical reinforced or prestressed concrete or steel structures.

3) **P167** – The purpose of this principle is to advise that the uncertainty and variability of input data and methodology do not have a disproportionate effect on the results of an analysis and that the analysis takes account of any such variability or uncertainty.

4) **P175** - The purpose of this principle is to advise that where computer analyses have been carried out to determine structural loadings, the methods have been adequately validated. This should be done using alternative methods where possible or alternative, previously validated, computer codes. In cases where data are sparse and uncertainty exists in the validation process it may be necessary for model tests to be carried out.

2.7 Design

1) General - Design codes are generally applied to new designs. The codes make allowances for uncertainties in knowledge of loading conditions, material properties, degradation and assumptions in analysis. However, in assessment of existing structures, there can be a better understanding of some or all of these issues and it may be considered appropriate to make a corresponding allowance in the application of codes.

2) **P147 and P174** - The purpose of these principles is to establish initially whether the licensee has identified the safety function of structures and their performance requirements. If this procedure has been adopted, then a schedule of all design basis loading conditions for construction, testing, normal and accident conditions should be produced. For more severe loadings, predicted failure modes should be gradual and detectable. This is to ensure that the structure fails in a ductile rather than brittle mode under higher loadings. ‘Failure’ may range from excessive deflection to overall structural collapse. The failure criterion needs to be defined for each structure and loading condition. Levels of unacceptable structural performance should be determined through the risk assessment and risk control measures.

3) **P170** - This principle concerns whether the foundation design has taken into account the results of the site investigation report and incorporated the recommendations for material properties for the soil and rock into the design calculations. Where a structure is required to resist seismic loading the soil and rock properties for use in dynamic analysis should be determined. Consideration should also be given to the possibility of liquefaction of the foundation material under seismic loading. Investigation into ground water levels and flow characteristics should be considered.

4) **P171** – This principle seeks demonstration has been provided which shows that the foundation design has considered the effects of normal operation and fault loading. The integrity of the foundations should be demonstrated using the material properties derived from the site investigations (P170 refers).

5) **P172** - The purpose of this principle is to advise that excavated or embankment slopes of material adjacent to a nuclear installation are shown to be stable under normal and external hazard loadings to ensure plant safety The SAP refers only to excavated slopes, but the stability of man made embankments is also relevant in this context. Consideration should also be given to variations in ground water level resulting from either climatic change or construction activities in order to ensure settlement of structures is within acceptable safety limits.

6) **P173** - The purpose of this principle is to advise that if naturally explosive gases or vapours could occur (see P119) then the design of underground basements, foundations and tunnels should take the possible consequences of the presence of such gases or vapours into account. The design should include measures to prevent the ingress and build up of gases.

7) **P176** - The possible requirement for secondary containment should be considered in the design.

8) **P330 –** The purpose of this SAP is to advise that designs incorporate measures that facilitate decommissioning and dismantling. This may include the use of suitable surface materials for ease of decontamination, and structural materials and details which facilitate dismantling.

2.8 Manufacture and construction

1) **P154** - This principle concerns the selection of materials for manufacture and construction. It is normally impractical to replace civil engineering components, other than glazing, cladding and roofing, and therefore materials should be shown to be suitable in all respects for the purpose of enabling an adequate design to be constructed, operated, inspected and maintained throughout the life of the plant.

2) **P156** – This principle requires inspection during construction of civil engineering works.

3) **P157 –** Any remedial work following identification of construction defects or non-conformities with procedures should be carried out to an approved procedure and subject to the same design requirements as the original work.

4) **P158 –** This principle concerns the detection, location, monitoring and management of leakage. It links with LC34.

5) **P323** - The purpose of this principle is to advise that the safety case should, at all times, reflect the plant as designed and constructed. Procedures should be in place to control design changes throughout the design and construction process and

assess their effects on the safety case. These design changes and modifications should be incorporated into the safety case, and ‘as built’ drawings and a health and safety file should be maintained throughout the life of the plant. Further guidance is available in the Technical Inspection Guide to Licence Condition 22 (T/INS/022).

2.9 Operation

1) **P158 and P160** - The purpose of these principles is to guide the assessor to determine whether the licensee has:

a) arrangements for detecting, locating, monitoring and managing leakage; and,

b) that adequate margins exist on safety related components to ensure the plant remains within its operating envelop throughout its operating life.

2.10 Pre and in-service inspection and testing

1) **P162 to P164** - These principles guide the assessor to determine whether the licensee has:

a) arrangements for in-service inspection to demonstrate "fitness for purpose";

b) considered the need for diversity of inspection and testing techniques; and,

c) carried out proof testing where it is a recommendation of suitable codes or otherwise essential for the safety case.

2) Designs that do not allow key load bearing elements to be inspected and if necessary maintained should be avoided. The design should take account of hinderances to inspection, such as radiation. For prestressed concrete reactor pressure vessels the LC 28 arrangements should include the appointment and responsibilities of an Appointed Examiner and insurance inspections.

3) **P176** - The purpose of this principle is to advise that for liquid or gas retaining structures leak tightness tests should be carried out prior to plant operation. This is to ensure that the design intent has been met. For liquid retaining structures drainage systems would be expected to collect and quantify leakage. For gas retaining structures detection or monitoring systems should be available to monitor leakage.

4) **P177** - The purpose of this principle is to advise that under LC28 arrangements should exist for the inspection and maintenance of any sea and river defences which protect a nuclear licensed site from flooding. The inspections should be carried out to confirm the condition of the materials or structures are still within the design intent. This would involve consideration of erosion protection and material degradation. Local changes which may affect the integrity or function of the defences, such as new development, should be considered. Climate change effects should be considered when defining the design load cases.

3. Relationship to licence and other relevant legislation

3.1 Licence conditions applicable to the SAPs covered in the guide are as follows:

LC 14 Safety documentation

LC 12 Duly authorised and suitably qualified and experienced persons

LC 15 Periodic review

LC 16 Site plans, designs and specifications

LC 19 Construction of new plant

LC 20 Modification to design of plant under construction

LC 22 Modification or experiment on existing plant

LC 23 Operating rules

LC 25 Operational records

LC 28 Examination, inspection, maintenance and testing

LC 29 Duty to carry out tests, inspections and examinations

LC 34 Leakage and escape of radioactive material and radioactive waste

LC 35 Decommissioning

4. Advice to assessors

4.1 This section identifies the key elements which an assessor should consider in a safety case submission from a licensee for each relevant SAP. The topics identified for consideration in the following paragraphs should not be considered as a checklist, but as important areas which may be addressed when assessing a safety case. There may be good reasons for a licensee not meeting a SAP. In these cases the assessor should ascertain the validity of the arguments presented.

4.2 Since the principles are not prescriptive the assessor will need to judge the extent to which the safety submissions presented satisfy the principles. For many areas this will rely on the skill and expertise of the assessor. In the case of existing plant there may well be some areas where the SAPs would not be satisfied. The assessor would be expected to judge the significance of the shortfall against the overall safety case for the plant and ALARP considerations.

4.3 In assessing a licensee’s submission the following points should be considered when interpreting the SAPs.

General

P145 - Design, construction and inspection

Has a design intent been produced and is it consistent with the safety function and performance requirements?

Has a construction specification been produced?

Have the design intent and the construction specification been met?

Are or were the arrangements for inspection during construction sufficient to identify defects?

If several standards have been applied to design or construction of the works, are they compatible with each other?

Are the materials used in manufacture / construction compatible with the design standards? Where optional parts of codes are used, is their use appropriate and has this been justified in the safety documentation? Where foreign codes and standards are used, are they compatible for use with UK materials and UK materials practice? (For example compare the use of ACI 318 with the use of UK specified concrete and bar bending shapes.)

Refer to T/AST/039 for advice on safety management of contractors.

P146 - Identification of defects

Has the structure been inspected for defects or sub-standard workmanship? Are these within the design intent?

Are the inspection arrangements during the structure's operational life sufficient to detect defects of structural significance?

What are the consequences of a defect becoming worse?

Are adequate records of defects maintained?

Design

P147 - Structural design

Have the applied loads been correctly identified?

Has load development and a schedule of load combinations been determined?

Does the schedule include construction, normal, accident and test conditions?

Has the schedule of load combinations been used for design?

Should more severe loadings than the design basis have been considered?

Is the behaviour of the structure beyond the design basis elastic, ductile or brittle?

Have other regulatory requirements applicable to Civil Engineering work been taken into account in the design and construction of the work, eg Construction (Design and Management) Regulations, Control of Substances Hazardous to Health Regulations, Building Regulations?

Manufacture and construction

P154 - Choice of construction materials

Have material tests been carried out? Did the results comply with the requirements of the design?

Has the material been widely used before?

If novel materials or innovative processes are used, have they been adequately justified including testing, installation and durability?

Are the materials suitable for the operating environment and expected structural life?

Are there any limitations on construction, inspection and maintenance for the materials proposed?

P155 - Construction methods

Is the construction technique novel?

Are there limitations on the use of the material in construction?

Have procedures been produced for the material production, construction or fabrication?

Have the requirements of the Construction (Design and Management) Regulations (1994) been taken into account in the construction phase?

P156 - Inspection during manufacture

Have procedures been produced for the manufacture of components?

Are there procedures for in-house testing, verification and quality control and/or the procurement and control of external inspection and testing services?

How have these been monitored to ensure compliance against the specification?

Does the licensee have adequate control of the inspection process?

P157 - Non conformances

Are there procedures for identifying non-conformances?

Are there arrangements for repairing defects?

Do these arrangements ensure the same standards of construction?

Are records of non-conformances kept?

P323 - Design changes

Are procedures in place to ensure that design changes/modifications are/have been assessed as to their safety significance and effect on the safety case, and referred back to the Design Authority?

Is there evidence to show that these procedures have been implemented correctly?

Have the design changes/modifications been incorporated into the safety case?

Does the safety case as presented reflect the as-designed, as-built plant?

Operation

P158 - Leakage during operation

Should there be arrangements in place for detecting, locating, monitoring and managing leakage?

Should there be clearly defined allowable leakage levels?

Should there be clearly defined procedures if action levels are exceeded?

P160 - Safe operating envelope

Are the monitoring arrangements adequate to ensure safety margins are not reduced?

Should the operating envelope allow sufficient margin for the distribution of instrumentation used for monitoring parameters?

Are operating rules or limits clearly defined and controlled?

Pre and in-service inspection and testing

P162 - Pre and in-service inspection

Are adequate inspection arrangements available for demonstrating that the structure meets the design specification?

Are arrangements in place for inspection of the structure during its operational life?

Are these arrangements sufficient to demonstrate compliance with the design intent?

P163 - Inspection techniques

Should there be sufficiently redundant and diverse inspection techniques?

Should the equipment procedures be validated?

Are inspection personnel suitably qualified and experienced?

Is the detail and level of inspection proportionate to the risk associated with the structure?

Is the inspection interval appropriate to the anticipated rate of degradation and the safety categorisation of the structure?

Does the inspection report state features that were not inspected as well as those that were?

Is there appropriate record keeping?

Is follow-up action being taken?

P164 - Testing

Does the design code require component testing before service?

Stress analysis

P165 - Analysis

Is a detailed stress analysis required? This could include Soil-structure Interaction Analysis, 2D or 3D dynamic or static structural analysis.

If novel structure and/or first of type, is model testing deemed necessary?

What alternative methods have been used to validate the analysis? Are they relevant? Are they adequate?

P166 - Use of data

Have the input data represented the structure or part of structure under consideration?

Should possible variations in material properties be considered in the analysis?

Have uncertainties in the input data been adequately addressed in the calculations and have these been acknowledged in design?

Should the potential material degradation throughout the plant life be taken into account in the analyses?

P167 - Sensitivity studies

Have sensitivity studies been carried out which assess the significance of variations of input parameters on results?

Have different methods of analysis been carried out? Are the results compatible?

Which analysis results have been recommended for design?

Additional civil engineering principles

Additional civil engineering principles

P169 - Site investigations

Has a site investigation been carried out?

Has the site investigation report recommended material properties?

Are the materials suitable for the loadings considered?

Have the appropriate codes and standards applicable to nuclear plant been considered?

Has the site investigation included water table levels, hydrogeology, contamination (all hazardous materials as well as radiological)?

P170 - Foundation design

Has foundation stability been considered in design?

Have the material properties been taken from appropriate data sources such as the site investigation report?

Has the guidance of appropriate codes of practice been used?

If dynamic soil properties are required have appropriate methods been used to obtain them, is the extent of uncertainty adequately addressed and has data from literature been used to validate the data?

Should the potential for liquefaction be considered?

Have external influences on the integrity of the foundation been considered?

P171 - Foundation integrity

Has the design considered all the specified normal loading conditions?

Has the design considered all appropriate fault-loading conditions?

Do the founding materials, under normal and fault loadings, provide an appropriate margin against failure?

P172 - Slope stability

Should there be arrangements for monitoring slope stability of embankments and excavated or natural slopes adjacent to nuclear installations?

Should there be monitoring arrangements for the water table and / or the settlement of structures?

Have calculations been carried out to establish tolerable levels of settlement?

P173 - Explosive gasses or vapours

Has the possibility of naturally occurring gasses and vapours been considered?

If they are shown to occur have they been considered in the design of underground structures?

P174 - Safety categorisation

The safety function of civil works and structures should be identified.

The performance requirements to meet the safety function should be identified eg shielding and radiological protection.

The structural classification and categorisation should be identified from the performance for structural types as appropriate.

P175 - Methods of analysis

Has a validation package been produced?

Has the method of analysis been widely used?

If the methodology is novel are model tests proposed?

Is the extent of uncertainty in the methodology clearly defined?

P176 - Structures containing liquids or gases

Is leakage tolerable? If so are the criteria available and do they conform to the safety function requirements?

Are arrangements available for determining leakage?

For ponds, have leakage sampling and collection provisions been made in the design?

For structures containing gases, have arrangements for monitoring leakage been made and tolerable limits defined?

P177 - Flood defences

Are arrangements available for inspection and monitoring the condition of flood defences?

Are these arrangements consistent with the design intent?

Is material degradation and erosion taken into account?

Is the frequency of inspection adequate?

Have the effects of climate change been allowed for?

P102 – Effects of Plant Ageing

The safe working life of structures and systems should be evaluated as part of the design. Particular attention should be paid to those areas which are difficult to replace such as the main structural components. Typically, consideration should be given to issues such as the following:

a) Corrosion of structural steel

b) Corrosion protection of high tensile pre-stressing tendons and ground anchors

c) Carbonation of concrete

d) Effects of corrosion of reinforcement in concrete

e) Cladding fixings degradation

f) Effects of additives to concrete

g) The effects of chemical attack from groundwater or aggressive environments

h) Exposure of masonry to weathering or chemical attack

i) Relaxation of pre-stressing tendons

j) Creep of concrete

k) Effects of settlement

P330 – Decommissioning and dismantling

Have materials been selected which can be dismantled and disposed of in the safest manner?

Has the structure been detailed so that it can be easily decontaminated?

Has the structure been designed and detailed so that it can be safely dismantled?

Have any specific health and safety control measures been identified for the decommissioning and dismantling stages?

5. References and associated guidance

Associated BMS Guidance

5.1 T/AST/013 External Hazards

5.2 T/AST/014 Internal Hazards

5.3 T/AST/016 Structural Integrity

5.4 T/AST/020 Containment for reactor plant

5.5 T/AST/021 Containment: chemical plants

5.6 T/AST/039 Management for safety

5.7 T/INS/022 Modification or experiment on existing plant

Other guidance and references

1. Institution of Structural Engineers: 1991: Guide to Surveys and inspections of buildings and similar structures. ISBN 0 901297 14 3. Amended 1997.

2. Institution of Structural Engineers: 1996: Appraisal of existing structures. ISBN 1 874266 28 x. Second edition.