Office for Nuclear Regulation

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CIVIL ENGINEERING – AGEING MANAGEMENT AND DAMAGED STRUCTURES			
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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AGR	Advanced Graphite (moderated) Reactor
BRE	Building Research Establishment
BS	British Standards
CDM	Construction (Design and Management) Regulations
DTA	Damage Tolerance Assessment
EIMT	Examination, Inspection, Maintenance and Testing
ENSREG	European Nuclear Safety Regulators Group
FEMA	Federal Emergency Management Agency
HSE	Health & Safety Executive
IAEA	International Atomic Energy Agency
IGALL	International Generic Ageing Lessons Learned
ISO	International Standards Organisation
JRC	Joint Research Centre
LC	Licence Condition
NDT	Non-destructive testing
ONR	Office for Nuclear Regulation
PAS	Publicly Accessible Standard
PSR	Periodic Safety Review
RGP	Relevant Good Practice
SAP	Safety Assessment Principle(s)
SHM	Structural Health Monitoring
SQEP	Suitably qualified and experienced person
SSC	Structure, System and Component
TAG	Technical Assessment Guide(s) (ONR)
TIG	Technical Inspection Guide(s) (ONR)
TLAA	Time Limited Ageing Analysis
WENRA	Western European Nuclear Regulators' Association

GLOSSARY

Term	Description	Source
Ageing degradation	Ageing effects that could impair the ability of a structure, system or component to function within its acceptance criteria. • Examples include reduction in diameter due to wear of a rotating shaft, loss in material toughness due to radiation embrittlement or thermal ageing, and cracking of a material due to fatigue or stress corrosion cracking.	IAEA Safety Glossary
Ageing management	Engineering, operations and maintenance actions to control within acceptable limits the ageing degradation of structures, systems and components. • Examples of engineering actions include design, qualification and failure analysis. Examples of operations actions include surveillance, carrying out operating procedures within specified limits and performing environmental measurements.	IAEA Safety Glossary
Catastrophic failure	A failure with major consequences from which recovery is impossible.	derived
'Civil works and structures'	See Appendix A of TAG 17 head document	derived
Construction	"construction work" means the carrying out of any building, civil engineering or engineering construction work and includes— (a) the construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance (including cleaning which involves the use of water or an abrasive at high pressure, or the use of corrosive or toxic substances), de-commissioning, demolition or dismantling of a structure; (b) the preparation for an intended structure, including site clearance, exploration, investigation (but not site survey) and excavation (but not pre-construction archaeological investigations), and the clearance or preparation of the site or structure for use or occupation at its conclusion; (c) the assembly on site of prefabricated elements to form a structure or the disassembly on site of the prefabricated elements which, immediately before such disassembly, formed a structure; (d) the removal of a structure, or of any product or waste resulting from demolition or dismantling of a structure, or from disassembly of prefabricated elements which immediately before such disassembly formed such a structure; (e) the installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunications, computer or similar services which are normally fixed within or to a structure, but does not include the exploration for, or extraction of, mineral resources, or preparatory activities carried out at a place where such exploration or extraction is carried out	CDM2015
	The activities related to installation or building, modifying, testing, remediating, repairing, renovating, repurposing, alteration, refurbishment, replacement, maintaining, decommissioning, decontamination, dismantling or demolishing a civil engineering structure, system or component. 'Construction' can happen at any stage in the lifecycle of the site, including earthworks, site preparation, enabling works, ground investigations, geotechnical or ground engineering, foundations and superstructure construction works, mock-ups and trials, and temporary works to support the same. Construction may also include civil engineering works associated with examination, inspection, testing and maintenance.	For the purposes of this TAG and the associated annexes
Damage	An unfavourable change in the condition of a structure that can adversely affect current or future structural performance	Reference [6]
Design	The definition of design for this civil engineering annex applies equally across all stages of a nuclear facility's lifecycle, including generic and/or concept design, licensing, site identification, site specific design,	For the purposes of this document

	construction and installation, operation, modifications, post-operation, decommissioning and demolition, 'care and maintenance' phase etc. 'Design' can also include, the safety case documentation, supporting references, justification and substantiation of claims, modelling or other analysis tools, the process(es) and records of design decision making, and independent reviews of the above. It should be recognised, within the life cycle of 'civil engineering works', that the assumptions made by the designer and incorporated within the justification of the design within a safety case, must be properly carried through the construction stage and through to modifications, demolition and site clearance. All associated construction activities throughout the life cycle are much a part of the safety case as the design.	
	"design" includes drawings, design details, specifications and bills of quantities (including specification of articles or substances) relating to a structure, and calculations prepared for the purpose of a design;	CDM2015
Design Life	The period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.	IAEA Safety Glossary
Dutyholder	For the purpose of this annex, the dutyholder is any organisation or person that holds duties under legislation that ONR regulates. 'Dutyholder' includes Licensees, Requesting Parties, Potential Future Licensees, Operational Licence Dutyholders, Decommissioning Site Licensees, New Build Site Licensees, budget holders, vendors and supply chain members.	For the purposes of this document
Life management	The integration of ageing management with economic planning: (1) to optimize the operation, maintenance and service life of structures, systems and components; (2) to maintain an acceptable level of safety and performance; and (3) to improve economic performance over the service life of the facility.	IAEA Safety Glossary
Localised failure	A failure with minor or localised consequences which does not result in failure to adjacent or co-dependant SSC.	derived
Serviceability failure	A single or group of related SSC fail to perform some of their non-safety functions or fail to meet some of their specified parameters, but do not collapse.	derived
Structural robustness	Robustness is the ability of a structure to withstand events like fire, explosions, impact or the consequences of human error, (e.g. design basis events) without being damaged to an extent disproportionate to the original cause	BS EN 1991-1-7 'Actions on structures'
Structure	"structure" means— (a) any building, timber, masonry, metal or reinforced concrete structure, railway line or siding, tramway line, dock, harbour, inland navigation, tunnel, shaft, bridge, viaduct, waterworks, reservoir, pipe or pipeline, cable, aqueduct, sewer, sewage works, gasholder, road, airfield, sea defence works, river works, drainage works, earthworks, lagoon, dam, wall, caisson, mast, tower, pylon, underground tank, earth retaining structure or structure designed to preserve or alter any natural feature and fixed plant; (b) any structure similar to anything specified in paragraph (a); (c) any formwork, falsework, scaffold or other structure designed or used to provide support or means of access during construction work, and any reference to a structure includes part of a structure;	CDM2015
Structures Systems and Components (SSCs)	A general term encompassing all of the elements (items) of a facility or activity which contribute to protection and safety, except human factors. - Structures are the passive elements: buildings, vessels, shielding, etc. - A system comprises several components, assembled in such a way as to perform a specific (active) function. - A component is a discrete element of a system.	WENRA DSRL

1 INTRODUCTION

1. This annex to Technical Assessment Guide 17 (TAG 17) provides guidance on the main aspects of ONR's approach to the assessment of ageing management and structural damage. It includes general guidance and advice to ONR inspectors on aspects of post operational management and related assurance. This TAG is not intended to provide detailed guidance on any ageing mechanisms or processes: its main purpose is to highlight certain salient areas for inspectors to consider as part of their regulatory assessment. It aims to highlight the application of the Safety Assessment Principles (SAPs) [1] to aid the assessment of civil engineering works and structures (see Appendix 1 of TAG 17), for activities that can happen post civil engineering SSC construction.

2. This annex focusses on nuclear safety functions provided by civil engineering structures, systems and components (SSCs), but the guidance herein is equally applicable to any security, safeguarding or environmental protection functions provided by civil engineering SSCs.

1.1 Structure of this annex

3. This annex identifies the ageing and damage effects and associated assessment considerations:

- Section 2 of this annex describes the common ageing effects and associated failure modes,
- Section 3 of this annex provides guidance on the mitigation activities (repair) and ongoing ageing management,
- Section 4 this annex provides guidance on the situation where damage to a structure cannot be readily or reasonably practicably repaired and the ongoing demonstration of safety,
- Section 5 presents relevant civil engineering guidance and good practice,
- Section 6 presents the references made in this annex.

1.2 Applicable SAPs to this annex

4. The assessment of civil engineering SSC operation and examination, inspection, maintenance and testing (EIMT) is informed by and meets the expectations of the SAPs. The following SAPs are particularly relevant for this annex:

- EAD.2, EMC.25, EMC.31, EMC.32, ECE.3, ECE.20 are related to lifetime margins, periodic measurements, in-service repairs, detecting and monitoring leakage, stress analysis for design life and degradation, and defect management,
- SC.8 states the expectation that those who have direct responsibility for safety own the safety case,
- EMC.11 establishes the expectations that failure models should be gradual and predictable.
- ECS.3, ECS.4 and ECS.5 when applying codes and modern standards (or lack of them) to existing structure analysis
- EAD.3 and EAD.4 establishes the expectations for periodic measurement of material properties and parameters
- ECE.2 ECE.3, ECE.4 ECE.8, ECE.16, ECE.17, ECE.18, ECE.19, ECE.25 and ECE.26 apply at varying stages of a lifetime of a structure, but especially so when considering the impact ageing can have on lifetime safety functional requirements
- SC.6 establishes the expectation that the Safety Case should identify areas of maintenance to ensure continued safe operation and how these will be implemented
- SC.7 states the expectation that safety cases will be actively maintained and reviewed regularly.

- EHA.12 refers to the prevention of flooding and an appropriate level of EIMT,
- EHA.15 establishes the expectation that design should prevent water from adversely affecting SSCs
- EMT.2, EMT.6 and EMT.8 6 establishes the expectation that provision should be made for EIMT throughout the life, including after events that may compromise the structure
- ERL.1 establishes the expectation that safety claims on reliability will be supported by case by case analysis
- EDR.1 establishes the expectation that SSCs will 'fail safe', identifying potential failure modes using a formal analysis where appropriate

5. Inspectors should also be cognisant of the broad intent of the SAPs; namely that it is not the level of conservatism assigned to one element of the civil engineering analysis and maintenance process, but the (overall) level of conservatism, applied to the substantiation and justification process and the structure as a whole.

1.3 Exclusions

6. The following are considered out of scope for this annex:

- detailed review of damage mechanisms,
- detailed review of monitoring systems or repair methods,

7. There is an expectation that during the design and construction of a facility, due consideration of potential ageing effects is undertaken. These aspects are not described in detail in this annex. For guidance, see:

- TAG 17 Annex 1, 'Civil Engineering - Design',
- TAG 17 Annex 4, 'Civil Engineering – Construction Assurance'.

8. Whilst this annex refers to As Low as Reasonably Practicable (ALARP) principles, including the concept of 'time at risk', this annex does not elaborate on the background of the principles. When assessing 'time at risk', the Inspector needs to have confidence in the way that the dutyholder has demonstrated holistically that the risks associated with the civil engineering works have been assessed in line with the ALARP principles.

1. For guidance on ALARP principles, see:

- ONR-NS-TAST-GD-005 'Demonstration of ALARP (As Low as Reasonably Practicable)'.

9. This annex includes limited information for considering adjacent operational structures to repair or other works, or for consideration of facilities that are beyond operation, but which still provide a safety function. For more guidance regarding activities that occur once a civil engineering structure is no longer operational, see:

- TAG 17 Annex 6, 'Civil Engineering - Post-Operations'.

10. This annex includes limited information for considering the potential impact on operational structures that are adjacent to works for repairs, or for repairs undertaken during construction activities. For more guidance regarding repair work being undertaken on operational sites or during a construction phase, see:

- TAG 17 Annex 1, 'Civil Engineering – Design',
- TAG 17 Annex 4, 'Civil Engineering - Construction Assurance'.

2 AGEING EFFECTS

11. Whilst this annex applies to all phases of civil engineering (design and construction through to delicencing), many of the considerations and principles in this annex are of particular applicability and consideration when assessing sites after cessation of operations. After operation, some safety functional requirements may still be required to be met even though the site is no longer operational. In this case, the Inspector may expect ageing of civil engineering SSCs to be considered after operation has ceased. For SSCs that are no longer operational, the way the SSC responds to an event may have considerably less consequence regarding off site release but may still have safety functions to be met. When assessing ageing on post-operational sites, the Inspector may sample the changes in operation identified in the decommissioning safety case, decommissioning strategy and decommissioning plan. The Inspector is specifically reminded of SAPs DC.3, DC.4, and DC.5 when considering civil engineering SSCs in the decommissioning phases. For guidance on decommissioning and condition of civil engineering SSCs, see:

- TAG 17 Annex 6, ‘Civil Engineering – Post Operation’,
- ONR-NS-TAST-GD-026 ‘Decommissioning on Nuclear Licenced Sites’.

12. The plans and review arrangements considered herein are often referred to as ‘asset management’. Asset management considers the condition of civil engineering SSCs, and how the current (and likely foreseeable) condition may influence the way in which SSCs will likely respond to the anticipated design loading conditions (including design basis, beyond design basis and cliff edge effects). It also considers any associated EIMT actions required to ensure that SSCs remain capable of fulfilling their safety functions throughout the periods of construction, operation and decommissioning, including any period of deferred decommissioning. For guidance on asset management, see:

- ONR-NS-TAST-GD-098 ‘Asset Management’.

2.1 Timing of ageing

13. A key point for the Inspector to consider is that the ageing process can occur as soon as the structure is built. Civil engineering SSCs can experience accelerated ageing because of construction workmanship, the environment in which the structure is placed, or physical damage / demands. The Inspector may consider the potential for ageing and degradation as soon as the SSC is constructed, because the asset may be subject to an unusually aggressive environment until the weatherproof envelope is completed and the ventilation system becomes operational. For some projects, construction may be halted before completion or operations may be delayed due to changes in plans. Hence, ageing before operation starts can become a significant factor, and one which may take many years to materialise.

14. Ageing effects considered herein include changes to SSC which develop over time and / or with continued use, including those resulting from construction defects.

15. The identification and subsequent management of ageing effects are based on the examination, inspection, maintenance and testing (EIMT) undertaken as part of Licence Condition 28 management arrangements. The function and operation of a structure for the full design life is reliant on the expectations established in SAPs ECE.3, ECE.8, ECE.16, ECE.17, ECE.18, ECE.19, ECE.25 and ECE.26 having been met.

16. There are existing structures providing safety functions on GB nuclear sites that are now of considerable age, sometimes in excess of their original design life. Even for facilities where a substantive proportion of the hazard is reduced, once operations cease, the civil engineering SSCs may be required to provide important safety functions long beyond the originally envisaged design life. For example, containment and shielding safety functions may be required for an extended period after end of operations. Even when

nuclear safety functions are no longer required as the original (operational) design intended, the civil engineering SSCs may need to continue to meet safety functions such as maintaining the weatherproof envelope, providing structural support, maintaining access and egress or non-radiological material storage.

17. While obsolescence of components is unlikely to affect nuclear civil engineering SSC, records relating to the design, construction and maintenance of civil SSC need to be kept and stored appropriately. Loss of knowledge may lead to increased risks during inspection, assessment, maintenance, change of use, modification and deconstruction of civil engineering SSCs providing a nuclear or conventional safety function.

18. A key consideration for the Inspector regarding ageing management is, whether ageing effects have degraded the ability of civil engineering SSCs to provide their safety function to a point where the safe operation of a facility can no longer be assured. This could include consideration of margins against failure to resist loads resulting from design basis events and accidents, with due account taken of uncertainty of both the loading and of the rate of future degradation as well as the required lifetime of the structure. The Inspector may wish to assess Periodic Review submissions in order to gain confidence that adequate consideration has been given to the remaining required life, as stated in the decommissioning strategy.

19. For more information on Periodic Safety Reviews, see:

- ONR-NS-TAST-GD-050 ‘Periodic Safety Review (PSR)’.

20. As replacement of defective civil SSC is frequently not practical for nuclear facilities, a greater reliance may be placed on the ageing management of civil engineering SSCs when compared with other engineered items. Operational experience within the nuclear industry suggests that a significant number of civil engineering ageing effects are identified when non civil engineering related inspection or maintenance works are being undertaken. The Inspector may seek assurance that dutyholders do not assume that a concrete structure is ‘massive and passive’, if this assumption results in claims not being explicitly made and EIMT not adequately implemented, as it is ‘assumed’ the structure will respond to loading demands as it is designed to do so. The expectation is that claims on civil engineering SSC are made explicitly, with each claim appropriately substantiated, and the safety functional requirements (SFRs) placed on the structures stated in the arrangements when implementing an effective EIMT regime as part of the golden thread. The Inspector may wish to consider the adequacy of EIMT regimes to ensure that the passive safety measure(s) (e.g. shielding from a civil engineering structure) will continue to be met by demonstrating the civil engineering SSC is still within the original design intent and meets the safety case claims placed upon it.

21. Ageing effects result in a change to the physical or chemical properties of civil engineering materials, the majority of which have the potential to negatively affect the ability of the SSC to perform its safety functions. These changes may result in a:

- reduction in load resisting properties,
- reduction in durability (which often results in a consequential reduction in load resisting properties),
- loss of serviceability.

22. The SAPs SC.5, EKP.3, ERL.4, EAD.2, EHA.7 and ECE.1, ECE.2 and ECE.6 set the expectation that civil engineering SSCs providing a nuclear safety function have a margin against failure, which means the onset of ageing effects would not necessarily result in an immediate loss of the safety function. With a few exceptions, such as post hardening strength gain of cementitious materials, ageing effects erode margins against failure. On the condition that nothing unforeseen has occurred and subject to the assumptions made by the designer, the expectations of SAP EAD.1 are that ageing effects should not be sufficient to undermine the ability of a civil engineering SSC to

perform its safety function(s) within the originally specified design life. The expectation is that adequate margins should exist throughout the lifetime of the facility to allow for the effects of materials ageing and degradation processes, as well as changes to the hazards through the lifetime, e.g. climate change. This includes the expectation of consideration of ageing at the design stage and during periodic reviews to ensure that sufficient margin is maintained throughout the required life.

23. Ageing effects largely fall into six groups, listed below. The first group are generally taken into account when specifying the design life of the civil engineering SSCs. During operation, the Inspector may consider that any single or related group of civil engineering SSCs could be subject to simultaneous ageing effects from several of these groups at one time:

- Anticipated ageing due to time and use effects (e.g. thermal or moisture movement creep, relaxation, fatigue, identified chemical processes).
- Unanticipated ageing due to inadequate in-service maintenance of the SSC (e.g. vegetation damage, ponding or standing water due to blocked gutters etc.).
- Unanticipated ageing due to changes to the functionality of the building, the operational state, or changes to the environment or process inside (e.g. failure of another SSC placing additional demands upon the element being considered, or changes of internal environment).
- Design basis or accidental loading or misuse (e.g. excursion beyond normal operating parameters, impact damage, fire damage). While these might have been considered within the original design parameters, they are unlikely to have been factored in when considering the design life and are likely to result in accelerated ageing effects.
- Defects incorporated into SSC (e.g. design errors, construction errors, unanticipated chemical processes and inclusion of deleterious materials, settlement or other anticipated movements)
- Defects or changes of loading associated with modification of the structure throughout its lifetime, or change of use.

2.2 Examination, Inspection, Maintenance and Testing (EIMT)

24. EIMT is key to ensuring the design life of civil engineering SSCs are achieved. For example, whilst the SAP EHA.15 states the expectation that design should prevent water from adversely affecting SSCs and SAP EHA.12 refers to the prevention of flooding, without the appropriate level of EIMT, the operation of the engineered measures in place to prevent flooding may fail and cause degradation to the civil engineering SSC.

25. For further information on EIMT, see:

- TAG 17 Annex 1, ‘Civil Engineering – Design’,
- ONR-NS-TAST-GD-009 ‘Examination Inspection Maintenance and Testing of Items Important to Safety’.

26. A selection of the ageing effects and potential consequences are provided in Table 1.

2.3 Hazards arising from ageing effects

27. Ageing effects may result in the creation of hazards to nuclear and conventional safety. In assessing operational sites, the Inspector should be aware that primary hazards have the potential to develop into a number of secondary (or consequential) hazards to SSCs which may not fall within the scope of Civil Engineering assessment. A number of related or unrelated ageing effects (coincidental hazards) may occur to the same or adjacent SSC, increasing the potential consequences of the hazard created.

28. The following nomenclature can be adopted when considering hazards arising from ageing effects:

- *Direct effect*: A hazard caused directly to an SSC by the ageing mechanism.
- *Consequential effect*: A hazard that is caused by and dependent on the occurrence of a primary hazard.
- *Potential coincidental ageing*: Realistic combinations of independent ageing mechanisms occurring simultaneously.

2.4 Revealed and unrevealed ageing mechanisms

29. The Inspector should consider the potential for unrevealed ageing mechanisms and encourage dutyholders to develop safety cases which are tolerant of the effects of possible unrevealed ageing mechanisms. The Inspector is reminded of the following definitions:

- *Revealed ageing mechanism:* A process which results in some measurable effect, which can be detected via non-destructive or non-invasive means. (E.g. visible steel corrosion staining, concrete cracking, spalling, excessive defection, etc.).
- *Unrevealed ageing mechanism:* A process which results in effects which will only become apparent via intrusive or destructive testing, or when the structure is subject to design basis event or accident loading conditions.

30. Note that for buried SSC or areas where the radiological hazard precludes visual inspection, what might normally be considered a revealed ageing mechanism may be, in effect, an unrevealed ageing mechanism for the SSC being considered.

31. SAP EAD.4 establishes the expectation that parameters that could change with time and affect safety should be periodically measured. When undertaking assessment of inspections, the Inspector may expect a description of the intent of the inspections, e.g. condition is as per design intent, degradation mechanism is gradual and will not undermine design intent, margin is sufficient for remaining life etc., in line with the expectations of EAD.2. EMT.6 establishes the expectation that provision should be made for EIMT throughout the life, commensurate with the reliability required of each SSC.

2.5 Common failure modes

32. It is often useful to classify the significance of the potential failure mechanism of the civil SSC which may result due to the ageing effect. Regulatory interest should be directed to those areas with the greatest potential consequence, or where the risks are least well controlled.

- *Serviceability failures*: While some operational functionality may have been lost, the claimed safety functions are still satisfied (e.g. excessive deflection of a roof deck). These types of failure can have a negative effect upon the resilience of facilities to design basis or accident situations. These may also lead to an increase in ageing effects to the SSC.
- *Localised failures*: A non-critical or secondary safety function has been lost, or the effect of the failure is localised and has limited consequences (e.g. cracking through a wall leading to seepage of uncontaminated water, failure of a lintel leaving a masonry wall unsupported). These are likely to lead to an increase in ageing effects to the failed SSC and potentially adjacent SSC. These also might reduce the number of available lines of defence or redundancy within facilities.
- *Progressive failures*: A failure of a safety function which rapidly propagates to adjacent SSC (e.g. failure of a cladding panel which leads to ‘unzipping’ of the cladding, where the remainder of the cladding on that elevation fails). These may continue to propagate and ultimately result in a catastrophic failure.

- *Catastrophic failures*: A complete failure of a load bearing structure leading to collapse of a major element or an entire facility (e.g. topple of a concrete stack). Once initiated, it is not possible to prevent a catastrophic failure.

33. SAP EMC.11 establishes the expectation that failure modes are gradual and predictable, and as such, the Inspector may seek confirmation that there has been correct use of modern design standards and codes which preclude progressive or catastrophic failures. If a dutyholder or contractor is using an approach that is not considered relevant good practice, the Inspector may seek assurance that the use of such an approach meets the expectations of the SAPs. In this instance, the Inspector is reminded of the expectations in SAPs ECS.3, ECS.4 and ECS.5.

34. The Inspector should note when considering structures where the primary load-path is via components in tension: ageing effects to tension structures are more likely to be unrevealed, the progression from evident distress to failure is more likely to be extremely rapid (possibly instantaneous), and the results of failure are more likely to be progressive (unzipping) or catastrophic. While most design codes do not recommend increased margins for tension structures, it may be appropriate when considering ageing effects, for the Inspector to seek evidence that, in light of the limited potential for load redistribution or secondary load paths, tension structures providing nuclear safety functions have higher margins against failure than comparative compression structures. The Inspector should also expect that arrangements and regimes for EIMT provide adequate evidence through inspection records for validation of continued operation. For more information on designing out such risks, see:

    - TAG 017 Annex 1, ‘Civil Engineering – Design’.

35. The Inspector should be aware of situations that could reduce the capability to withstand design basis and beyond design basis events (including cliff edge effects), or reduce the margins claimed in the safety case. SAPs EHA.7, EHA.18 and ECE.6 establish the expectations of consideration for cliff edge effects for civil engineering structures. The Inspector should consider how the Safety Case identifies what design basis events the civil engineering SSCs are required to withstand and to what level of confidence. The Inspector may wish to seek assurance that the claimed safety functional requirements will continue to be met post-event. SAP EMT.8 establishes the expectation that SSCs will be inspected and / or re-validated after any event that might have challenged their design basis. The Inspector may wish to gain confidence that such an inspection or re-validation exercise takes into consideration any ageing or degradation of the structure, alongside any consequences of the event, to maintain adequate margin for the remaining life of the SSC.

36. When undertaking an assessment of the current condition, the Inspector may wish to seek assurance that, for beyond design basis or severe accident events (including cliff edge effects), the safety functional requirements placed on the SSC (e.g. collapse in a particular way, escape routes remain safe) is not undermined by the existing condition of the structure. Depending on the severity of the event, the SSCs may or may not be returned to operational status. Where the plant can be returned to service post-event, the re-validation considerations regarding condition of structures apply. This is in line with SAP ECE.2, establishing the expectation that the required resilience of the structures when subject to beyond design basis loadings during severe accidents is understood and deemed achievable, considering the current condition of the structure.

37. A selection of the most important ageing effects provided in Table 1 are summarised below. The most significant potential consequential and coincidental hazards are briefly discussed.

2.6 Corrosion of embedded reinforcement due to chlorides in concrete

38. *Direct effect*: As the corrosion products of chloride induced reinforcement corrosion do not immediately lead to cracking or spalling of the concrete, vulnerable structures could suffer significant loss of embedded reinforcement cross-section without any visible evidence of ageing or distress, i.e. the ageing effect could be unrevealed. Once even a small area of cracking and spalling is visible to the surface, there may already be considerable loss of reinforcement cross-section at depth. This could leave structures which are designed to resist loads resulting from design basis events or accidents unable to perform their safety function when the demand is placed upon them.

39. There is evidence that some nuclear structures built prior to the late 1970s may have incorporated significant quantities of chlorides into the concrete, either added as an accelerant or due to the use of partly saline water in the concrete mix. Unprotected concrete structures in aggressive coastal environments can also absorb significant chlorides into their surfaces during their life.

40. *Coincidental effects*: Chloride corrosion can occur coincidently with anaerobic corrosion, especially in saturated or below ground concrete. Some forms of anaerobic corrosion do not create expansive corrosion products, and hence the combined ageing effect may remain unrevealed.

41. *Potential consequential effects*: Large or tall structures have the potential to collapse onto adjacent facilities or disrupt site services upon which non civil engineering SSC depend. Hence unpredicted failure of such a structure could result in consequences greater than loss of that structure alone.

42. *Regulatory expectation*: The Inspector may expect the dutyholder to demonstrate that all structures considered potentially at risk of chloride induced corrosion are not vulnerable to failure as a result of unrevealed corrosion. This might be satisfied by testing the concrete for chloride content, testing for electro potential at the depth of the reinforcement or exposure of a sample of the embedded reinforcement to allow visual inspection.

43. There are similar regulatory expectations for the consideration of concrete carbonation, particularly in structures with extensions to the design life. Concrete cover to reinforcement is typically 50mm minimum to modern standards, and condition of cover depends on the workmanship and other ageing or degradation factors over the lifetime of a structure. For older structures, the cover achieved was often considerably less than 50mm. Over a period of several decades, carbonation can permeate the concrete to a level where it reaches the reinforcement. Further, other chemical attack is possible where there is an aggressive chemical environment for concrete, e.g. reinforcement or embedment corrosion induced by chlorides where the concrete is exposed to sea water (or airborne salt from sea water). The Inspector should expect the dutyholder to have adequate maintenance and monitoring regimes in place, including undertaking prevention and remediation measures where inspections and testing indicate that damage to the reinforcement can be prevented. The Inspector should expect the dutyholder to be able to demonstrate adequate margins are maintained for the remainder of the required lifetime of the structure.

2.7 Damage to weatherproof envelope (multiple potential ageing effects)

44. *Direct effects*: The direct effects of weather penetration into facilities could include:

- loss of secondary containment safety function,
- challenges to internal air pressure gradients (often used to mitigate against migration of contaminants,
- creation of slip hazards (rainwater penetration),
- increase in the weight of absorbent materials such as insulation.

45. As highlighted in Table 1, there are a number of ageing effects which have a primary hazard of damage to weatherproof envelopes, including below ground waterproofing. Two or more ageing effects may act at the same time, one cause potentially contributing to or accelerating another. These might include:

- thermal movement of roof fabric leading to fatigue of weatherproof envelope,
- damage to roof fabric or supporting members leading to ponding of rainwater,
- damage to any part of the weatherproof envelope leading to dominant openings that could undermine the ability of the structure to withstand wind loads,
- exposure to foot traffic leading to mechanical damage to weatherproof envelope,
- ultraviolet radiation embrittlement of weatherproof envelope,
- legacy defect(s) revealed from substandard construction workmanship,
- lack of maintenance leading to blockage of gutters and rainwater outlets, etc.

46. *Coincidental effects*: Saturation of insulation materials often results in loss of its ability to perform its function. This could result in condensation of internal moisture upon cold surfaces, adding to the hazard caused by water penetrating from outside the structure, or which could impact on controlled internal environments. Damage to weather envelopes and dominant openings could impact internal air pressure gradients.

47. *Potential consequential effects*: Rainwater penetration within facilities which were designed to be weatherproof could lead to:

- spread of soluble contamination,
- localised flooding
- electrical systems arcing and fire,
- reduced capability to withstand design basis external hazard loading
- corrosion of support structure or items inside the building e.g. cranes or waste packages,
- corrosion to metallic components (structural and building services),
- any loss or damage to the roof fabric could create dominant openings, which may cause further damage even in moderate wind speeds,
- condensation on internal surfaces,
- failure of activity-in-air monitoring equipment,
- unexpected waste e.g. contaminated water,
- accelerated ageing effects to internal SSC or items stored within the facility.

48. *Regulatory expectation*: The Inspector may seek confirmation that the dutyholder has arrangements in place to undertake regular planned inspections and preventative maintenance to vulnerable elements of the weatherproof envelopes. The Inspector should expect all debris, vegetation growth and other material that could lead to failure of rainwater disposal systems should be removed as soon as reasonably practicable once identified. The Inspector should expect that fixings to cladding panels are inspected for evidence of deterioration or impending failure. The Inspector should expect localised failures of the weatherproof envelope to be addressed in a timely way to prevent consequential effects that may undermine the safety function of other SSC. The Inspector should expect the dutyholder to notify ONR (e.g. using the ‘INF1’ reporting system) where there is a threat to nuclear safety significant SSCs as a result of a breach to weatherproofing of civil engineering SSCs.

2.8 Through thickness cracking to concrete water retaining/excluding structures

49. *Direct effects*: Initial through thickness cracks to concrete structures resulting from early age drying shrinkage or the heat of hydration can be exacerbated by ageing effects. Where existing cracks that have previously healed, the ageing effects may re-activate through thermal or physical movement, leaving the crack unable to re-heal due to the absence of any free lime (used in the first healing process). If the structure is water retaining, this can result in long term water egress through the crack, (or ingress for water excluding structures). Due to the considerable section thickness required to

provide shielding and cooling, water retaining structures, e.g. fuel storage ponds, can be vulnerable to early age cracking.

50. *Coincidental effects*: Several ageing effects are likely to simultaneously contribute to prevention of autogenous healing of the crack. These might include:

- thermal movement of the concrete due to the external annual temperature cycle or changes in pondwater temperature due to variability in fuel heat load or chiller availability, (the Inspector should be aware of any operational rules that are used to control temperatures of processes),
- post hardening concrete shrinkage,
- ground movement caused by annual changes in ground water table level,
- changes in loading applied to the structure, e.g. mobile fuel handling cranes or structural modifications.

51. *Potential consequential effects*: If the seepage is of uncontaminated water and the rate of seepage is small, there should be no significant consequential hazards from the water seepage. When assessing fuel ponds, the Inspector may consider the rate of seepage together with the safety case claims made on the water providing a fuel cooling or shielding safety function. If the pond water contains soluble radionuclides, the Inspector may consider the potential for activity to be released into the environment. If the crack occurs below ground, the Inspector may consider how activity may contaminate the ground and groundwater. Groundwater flows could transport activity a considerable distance from the source of the release. If the crack is above ground, the Inspector might consider the potential consequence of deposition of the contamination, e.g. upon the external surface as the seepage evaporates. The Inspector should consider the potential for activity to create a substantial dose rate in the vicinity of the crack over an extended timeframe.

52. *Regulatory expectation*: The Inspector should expect the dutyholder to demonstrate that all water retaining structures are monitored for evidence of water egress, with monitoring arrangements in place where releases may be contaminated. For some older facilities, it may not be possible to directly monitor potential releases through the base slab or below ground elements of structures. In such cases the Inspector should expect that the provision of monitoring facilities external to the structure (such as boreholes) has been considered to provider early detection of leakage. If external activity is detected at any point of egress, the Inspector may wish to seek assurance that the dutyholder has undertaken actions as necessary to mitigate against release of activity into the environment and to prevent build-up of activity to external faces or drainage features, for example by regular cleaning.

53. The Inspector should note that organic materials incorporated into the water retaining construction (e.g. waterbars, sealants, joints and membranes) could be adversely affected by radiation. The Inspector should be aware that a Building Research Establishment (BRE) document “A review of materials used as waterbars and sealants in pond structures” [2] was prepared in 2010 for ONR. This document considers the long-term effects of radiation upon organic based building materials.

3 MITIGATION ACTIONS

54. ONR-NS-TAST-GD-98, ‘Asset Management’ provides guidance to inspectors on the subject of Asset Management, including listing 10 key features of a sufficient asset management plan. Ageing management is considered to be a subset of the wider asset management topic, and hence only the relevant aspects which relate to ageing management of civil engineering SSC have been included herein.

55. The Inspector could expect dutyholders to develop an operational ageing management plan or equivalent arrangements. This may include, but not be limited to, the dutyholders Licence Condition 28 arrangements. SAP ECE.1 establishes the expectation that the

required safety functions and structural performance of civil engineering SSCs should be quantified and specified for the complete potential range of operational states. This should include:

- the associated required resilience for the SSC,
- the margins, such that civil engineering SSCs continue to provide their residual safety functions following the application of beyond design basis loads (including cliff edge considerations),
- that SSC should fail in a manner that suitably limits radiological consequences.

56. SAP ECE.20 establishes the expectation that EIMT should demonstrate that the structure continues to meet its safety functional requirements, taking into consideration changes in parameters assumed in the safety case. This should include ageing phenomena as identified in SAPs EAD.3 and EAD.4 for periodic measurement of material properties and parameters. The Inspector should be aware that this assessment of ageing should consider the expectations regarding independent arguments as presented in SAP ECE.2, including in-service degradation mechanisms and the potential for defects to develop into a failure mode.

57. SAP SC.6 recommends that the Safety Case should identify areas of maintenance to ensure continued safe operation and how these will be implemented, with ERL.1 establishing the expectation that safety claims on reliability will be supported by case by case analysis. SAP EAD.2 establishes the expectation that programmes for monitoring to detect ageing and degradation processes should be used to verify assumptions and assess whether the margins in place are adequate for the remaining life. ERL.4 establishes the expectations around margins of conservatism stated in the safety case to ensure the SSC's safety significance will continue to be recognised throughout its life, with EDR.1 establishing the expectation that SSCs will 'fail safe', identifying potential failure modes using a formal analysis where appropriate.

3.1 Prevention of ageing and defects

58. Whilst this annex provides guidance on the management of ageing and defects, the Inspector should expect that the focus is placed on preventing, avoiding and reducing the occurrence of defects or ageing effects, through well considered design and appropriate construction management.

59. The consideration of ageing starts at the design stage, the Inspector may seek confirmation that there is a clear understanding of the design life of the structure before any design starts. IAEA SSG 48 section 3.9 [3] provides considerations of ageing and detailed advice applicable to the design stage. The Inspector should expect the design to consider potential ageing mechanisms throughout the different phases of life, from construction, operation and demolition, alongside the relevant safety functional requirements placed on the SSC at each stage. The Inspector may wish to seek assurance regarding how the safety case records the assumptions and design justification(s) of margin(s) and allowance(s) for ageing effects. This includes the design considerations of potential changes to design parameters and material properties over time.

60. SAP EMT.6 places an emphasis on construction techniques to prevent defects and non-conformances. For any site, there may be unrevealed ageing mechanisms caused by legacy defects from inadequate workmanship during the construction phase, or inadequate design that has been ill-conceived or executed.

61. For further guidance, see:

- TAG 17 Annex 1 'Civil Engineering - Design'
- TAG 17 Annex 4 'Civil Engineering – Construction Assurance'
- Section 5.9.5 of TAG 17 'modifications'

3.2 Ownership of safety

62. SAP SC.8 establishes that ownership of the safety case should reside within the dutyholder's organisation with those who have direct responsibility for safety. The Inspector should be aware this role is often undertaken by the Design Authority (DA), as they have overall responsibility for ensuring that safety is maintained for the duration of the lifetime of facilities.

63. Ageing management often requires the use of specialist contractors to undertake one-off remediation works that fall outside the standard scope of the civil engineering activities on a site. Where this is the case, the Inspector should be aware of the dutyholder Intelligent Customer (IC) capability, to ensure that optioneering, design or repair works are undertaken by suitably qualified and experienced personnel (SQEP), and that the scope of works and associated contracts and specifications have been checked by a SQEP Intelligent Customer function.

64. For further guidance on the ownership of safety and Intelligent Customer function, see:

- ONR-NS-TAST-GD-079 'Licensee Design Authority Capability',
- ONR-NS-TAST-GD-049 'Licensee Core Safety and Intelligent Customer Capabilities',
- ONR-NS-TAST-GD-027 'Training and Assuring Personnel Competence'.

3.3 Ageing Management Plans

65. The Inspector should expect demonstration that the structures important to safety are sufficiently free of defects, so the safety functions are not compromised, in line with the expectations of SAP ECE.3. Paragraph 212 of the SAPs [1] states "effective management of ageing is needed so that the safety functions, systems and components are delivered throughout the period needed, which may be the full lifetime of the facility. This may be achieved through a specific ageing management programme or through other arrangements appropriate to the SSC". Issue I of the Western European Nuclear Regulators' Association (WENRA) Safety Reference Levels for Existing Reactors [4] defines an ageing management programme as "an integrated approach to identifying, analysing, monitoring and taking corrective actions and document the ageing degradation of structures, systems and components".

66. The operating organisation may not have all the relevant expertise to develop an ageing management plan, and consultation is likely to be required with the designer or Design Authority. The Inspector should expect demonstration that the ageing management plan has undergone periodic reviews to ensure it remains appropriate and effective. Features of an adequate ageing management plan or similar arrangements might include:

- the objective of the arrangements for the ageing management plan (e.g. to assure a defined safety function until a specified point in time),
- definition of who is responsible for the SSC being considered,
- definition of the safety function provided by the SSC being considered, including any assumptions from the safety case, and the potential consequence of failure, including claims of required resilience of the structures when subject to design basis and beyond design basis loadings (including cliff edge effects) during severe accidents,
- identification of relevant ageing and degradation mechanisms for each SSC (or group of SSCs) providing a safety function,
- actions to be undertaken in a timely manner to prevent or mitigate against ageing effects for the required lifetime of the SSC, including anticipated changes in environment at different operating states or after cease of operations, with consideration of the potential impact changes could have on the civil engineering SSCs, and if any action is required to prevent detrimental impact,

- requirements for suitably qualified and experienced persons (SQEP) to effectively undertake ageing management actions (potentially including training requirements or external resources),
- specific maintenance instructions for items requiring active maintenance, such as movement joints or bearings,
- arrangement for the storage of and readily available access to design, construction and inspection records, including output of any quality assurance activities and tests undertaken, and historical inspection and maintenance records,
- defined operating limits to ensure continuous provision of safety function (with assurance and demonstration through inspection and/or analysis) that sufficient margin remain (e.g. maximum loss of pre-stress, maximum number of load cycles, temperature limits, radiological exposure limit),
- projection of when safe operation may no longer be ensured,
- criteria to be monitored, recorded and, if appropriate, trended (including periodicity, action levels, availability and limits of instrumentation),
- actions to be undertaken following any design basis environmental conditions or accident event (e.g. inspection by SQEP),
- actions to be initiated in the event of unexpected occurrence or finding (including incident reporting system criteria).

3.3.1 Periodic Safety Review

67. The Inspector may judge whether relevant aspects of ageing management have been considered in periodic reviews in accordance with Licence Condition 15 arrangements, or when contemplating operating life extension (SC.7). Relevant considerations might include:

- assessment of current condition, highlighting any changes since construction or previous review, including changes in environment or parameters over time and whether these align with safety case and design assumptions,
- methods of validating the safety function of non-accessible components (e.g. buried structures, or where radiological dose is prohibitive),
- review of changes to design codes or relevant good practice, particularly when a potential inadequacy has been addressed with the original code / practice,
- review of relevant operational experience, both within and outside the nuclear industry, including civil engineering SSC structural response to design basis and beyond design basis events,
- review of any events and margin available to withstand an event given the potential impact on margin of aggregation of defects or ageing effects,
- analysis of any monitoring data trends, possibly to refine projections for continued achievement of safety functions for whole of lifetime required,
- review of climate change predictions against assumptions,
- review effectiveness of ageing management plan,
- evaluation of the need for research.

68. For more information on periodic safety reviews, see:

- ONR-NS-INSP-GD-015 ‘LC15 Periodic Review’,
- ONR-NS-TAST-GD-050 ‘Periodic Safety Reviews (PSR)’.

3.3.2 Reviews following changes in state

69. Changes in operating states, such as end of operations, may also initiate a review. The Inspector may judge whether relevant aspects of ageing management have been considered for such a change.

70. Relevant considerations for changes to site phases might include:

- changes in environmental exposure, including impact on existing ageing mechanisms or defects,
- changes in staffing levels and appropriate experience,
- alterations to fire boundaries and condition of revised personnel access arrangements,
- temporary demands placed upon structure (e.g. use of cranes to remove plant components or temporary storage of materials awaiting disposal).

3.3.3 Reviews of Operating Limits

71. Where the Operating Limits to ensure continuous provision of safety function are reliant upon active systems (e.g. cooling plant, pumps to limit operating depth), the consequences of failure of the active system must be adequately considered within the ageing management plan. This may take the form of arrangements in place for reactive measures, or additional layers of passive protection. The Inspector is reminded that although SSCs may provide passive protection, these require adequate EIMT to ensure the SSC will continue to perform the safety functional requirement in line with the safety case and original design intent. Common cause failure events, (e.g. earthquake, site wide loss of power) should be considered when making a judgement on the adequacy of arrangements and safety measures in place.

3.4 Identification of ageing effects

72. In the event that significant ageing effects are identified as part of a review or other EIMT activity, the Inspector should expect arrangements for a plan to be developed, defining actions to ensure the ongoing provision of the safety function. Features of such a plan might include:

- Identify any immediate actions required to avoid Risk of Serious Personal Injury, operational rule breach or other potentially unsafe situations,
- actions to be taken to investigate and identify the extent, cause and potential consequential effects of the ageing effect (e.g. research, intrusive investigation),
- requirements for an increase in detailed ongoing monitoring (e.g. installation of new instrumentation), including after repair or mitigation,
- requirement for re-assessment of structure, subject to improved understanding of performance or material properties, to include potential revision of requirements.
- specific condition assessment to assess ‘new’ activities (e.g. temporary openings to structures to remove plant), as existing ageing effects may lower resilience to changes in loading which may not have been captured in previous assessments,
- if structures are given enhanced or reduced operations, whether this impacts on how the civil engineering SSC should respond structurally to a design basis or beyond design basis event (including cliff edge effects), with consideration of adjacent structures, and whether the previous structural analysis regarding events was sufficient for new requirements, and whether additional strengthening is required to satisfy the safety function for the required lifetime,
- potential options for repair or mitigation, including consideration of likelihood of effectiveness of the repair method, and proposed lifetime of remedial measures,
- details of quality control and third-party supervisory requirements, and any verification methods required to demonstrate the repair or mitigation has achieved the desired effect. The Inspector should be aware of the dutyholders Intelligent Customer capability, where necessary, for repair works,
- provision of alternate load path or other mitigation in event of failure of safety function,
- measures to ensure appropriate dissemination of learning (e.g. revision to ageing management plan)
- actions to establish the full and potential extent of condition, i.e. where else might this issue be found.

3.5 Evidence of ageing effects

73. The Inspector should expect projections of when safety functions may no longer be met (e.g. when safe operations may no longer be ensured) to be based on the appropriate level of evidence. The Inspector should be aware of the assumptions and limitations of the raw data used in extrapolation, as such analysis is dependent upon the quality of the raw data, the number of independent data points and the assumptions made. The Inspector should expect projections for continued safe operations to be based on adequate collation of data, i.e. not just two data points. This is in line with the expectation of SAP ECE.13, that data used in analysis is applied so that the analysis is demonstrably conservative, with the uncertainties associated with the properties of material potentially affected by degradation to be taken into account.

74. In-service data collection methods can be used in demonstrating the adequacy of age deteriorated SSC. The Inspector may wish to seek assurance that raw data collected is correctly reflective of the design parameters as claimed or assumed in the safety case, in order to provide confidence in the continued safety performance of the SSC.

75. The Inspector should be aware of potential unrevealed ageing mechanisms which may not be identified as part of inspections, especially if inspections are limited to visual survey. Where a risk of an unacceptable potential consequence of an unrevealed ageing mechanism is identified, the Inspector may wish to seek assurance that the dutyholder has adequately considered whether invasive or instrumentation based management measures are required, and whether sufficient evidence is provided to justify ongoing safety.

3.6 Data Sources

76. Assessment of residual load capacity of ageing SSC or projections of remaining safe operational life need to draw upon all available relevant data sources. This might include:

3.6.1 Historical records of ageing effect

77. The Inspector should be aware of dutyholder records (usually Licence Condition 28 maintenance inspection records) as these can be used to trend or track progression of ageing effects e.g. evidence of SSC condition in last inspection. Such information could assist with gauging the rate of degradation and can be appropriate to be extrapolated to ascertain when structures may become unacceptable to continue operations. The Inspector should note previous comments regarding extrapolation of data.

78. The Inspector should be aware of historical data being used if it was not originally collected specifically for maintenance inspections, as it may have uncertain provenance.

3.6.2 Comparison with similar SSC

79. The Inspector should note that comparison with similar SSCs of a similar construction and age may be from within or outside the nuclear industry. The Inspector should give most regard to comparable SSC which have a similar age, materials, construction history, environmental exposure conditions and in-service demands, as all these factors can affect ageing mechanisms. For inaccessible SSC, this may be the only available option. The Inspector should take due account of the uncertainty of any comparison being made and the potential consequences of failure of the SSC.

3.6.3 Instrumental data

80. Where it may not be possible to quantify the effect of the ageing mechanism for a deteriorated SSC, it may be acceptable to demonstrate the safety of ongoing operations using data collection.

81. Demonstration of safety provided by instrumental data might take the form of:

- acoustic monitoring for un-grouted pre-stressing tendon corrosion,
- deflection of a structure subject to measurable loading effects,
- strain monitoring.

82. The Inspector must consider the ability of the models that use the gathered data to reliably predict the onset of failure with sufficient time to take appropriate mitigating actions to ensure safety.

3.7 Inaccessible areas

83. During the design phase, the Inspector is reminded of minimizing the number of inaccessible areas by design, in line with the expectations of SAP ECE.8. Where inaccessible areas cannot be avoided, then consideration should be given to how ageing will be managed in the ageing management plan. The use of remote monitoring techniques is one way in which this could be addressed.

84. For existing facilities, the Inspector may seek evidence that the dutyholder is taking reasonable steps to assess ageing of inaccessible areas. This might take the form of comparison of conditions to similar adjacent areas or the use of instrumentation to detect signs of distress. The Inspector should expect the dutyholder’s ageing management plan to provide detailed guidance on assessing the condition of inaccessible areas using indirect methods.

85. The Inspector should expect the dutyholders arrangements to ensure that full benefit is gained from opportunistic inspections, where concealed or buried areas are being exposed for other purposes.

86. When assessing the use of coupons to represent the ageing effects of inaccessible SSC, the Inspector should take due account of any differences in actual environmental exposure, material variance and other sources of uncertainty.

3.8 Nuclear-specific ageing

87. Whilst the ageing of civil engineering SSCs are widely known and reported across the civil engineering industry, there are some aspects of concrete degradation that are specific to the nuclear industry. These ageing mechanisms are less commonly reported on. The Inspector should specifically be aware of the effects of irradiation on concrete [5] when assessing operating facilities with extended lives and the degradation that occurs when concrete is exposed to radiation over time. The Inspector may seek assurance that these aspects are adequately addressed in the ageing management plan or equivalent arrangements.

3.9 Identification of remedial action required

88. When assessing arrangements, the Inspector may include due consideration of nuclear and conventional safety risks resulting from the planned actions. These should include but not be limited to:

- worker radiological dose uptake,
- interference or temporary isolation of any safety, safeguards or security systems,
- risks associated with access (e.g. confined space entry, falls from height).
- potential consequences of interruption to normal and ongoing operations or loss of throughput,
- potential for impacts on how the civil engineering SSCs may respond to design basis or beyond design basis events, including cliff edge effects e.g. disproportionate collapse,
- potential increase in waste risings and appropriate waste disposal routes.

3.10 Timely management of defects

89. SAP ECE.3 establishes the expectation that all civil engineering SSCs providing a safety function should be maintained at all times to a standard which reduces risk so far as is reasonably practicable and that civil engineering SSCs are sufficiently free of defects to maintain their safety function. 'Defects' in this context include those of workmanship during construction, maintenance and damage or ageing. ECE.16 establishes the expectation that materials should be shown to be suitable, allowing for defects or ageing effects which have the potential to adversely affect a civil engineering SSC. The Inspector needs to be cognisant of other potentially relevant factors when forming a regulatory judgement on the adequacy of arrangements for ageing management actions. Relevant factors to consider might include:

- safety function significance (priority should be directed toward components providing the highest safety functions),
- interruption to normal operations (e.g. there may be a suitable planned outage when the work could be undertaken with significantly less disruption),
- remaining service life of the affected SSC, and potential impact ageing or defects may have on the design basis and beyond design basis event response, including consideration of cliff edge effects, including ALARP considerations of time at risk arguments
- safety implications of undertaking the required remedial actions (e.g. access restrictions, worker dose uptake).

90. For consideration of optioneering regarding design of a suitable repair method, see:

- TAG 17 Annex 1 'Civil Engineering - Design'.

91. The Inspector should be aware that it may not be necessary to address an ageing effect immediately or at all if it can be demonstrated, with high confidence, that the ageing effect is being adequately managed. Features of degraded SSC management include (but are not limited to):

- the ageing mechanism is well understood, and future progression of the effect is predictable and,
- the affected components are subject to a programme of appropriate inspection and examination and,
- the affected components have sufficient residual margin against failure (including design basis, accidental and fault loading as claimed in the safety case) for the rest of the expected life,
- the predicted failure mode of the component would be evident, gradual and with sufficient time between evident signs of distress and predicted failure to allow for intervention to ensure safety.

92. If any of the above is not demonstrated, the Inspector should expect the ageing effect or potential consequences to be addressed in a timely way. Budgetary limits or inconvenience of undertaking the work should not be considered in the justification for not addressing an identified ageing effect which is adversely affecting a civil engineering SSC, unless these are demonstrably disproportionate to the improvement achieved in ongoing operational safety and safe operation can be achieved by other means. The Where partial or full repair are required in order to achieve the safety functional requirement(s) for the remaining life of the structure, the Inspector may wish to seek assurance that evidence indicates the extent of degradation, whether it is widespread or isolated incidents of degradation.

93. The Inspector may take into account the potential risk of consequential hazards developing if the ageing effect is not addressed as soon as reasonably practicable. Remediation costs tend to increase if action is not undertaken in a timely way. These factors are particularly significant where the ageing effect is leading to water ingress.

94. The Inspector should expect that the ageing and defects of civil engineering SSC are assessed on both an individual basis and holistically. The Inspector may consider the potential aggregation of such damage, with the potential impact these could have on the SSC as a whole, recorded as part of the arrangements.

3.11 Record Keeping

95. The Inspector may seek assurance that all decisions and activities associated with remediation of nuclear safety significant structures are adequately recorded and stored. Documentation on structural condition should be readily available should the structure experience unforeseen but sudden damage, e.g. earthquake or impact. The Inspector should be aware of the importance of adequate records for future use, specifically in the situation where further degradation, ageing or other damage is experienced and a justification is required for ongoing operation.

96. For further guidance regarding record management, see:

- TAG 17 Annex 1 ‘Civil Engineering – Design’,
- TAG 17 Annex 6 ‘Civil Engineering – Post Operations’,
- ONR-NS-TAST-GD-033 ‘Dutyholder Management of Records’.

4 DAMAGED STRUCTURES

97. A structure can be damaged at any point during the life of the site, from construction onwards. Damage can be defined [6] as an unfavourable change in the condition of a structure that can adversely affect current or future structural performance. The Inspector should note that the current or future structural performance of a damaged SSC may impact the SFRs and safety case claims placed on the structure. However, the damaged SSC may still meet all of the required safety claims, but with reduced margins from those originally anticipated within the design, in which case repair may still be required when margins are eroded and deemed not adequate. The damage might result from a number of causes, such as ageing effects, latent defects due to poor workmanship or damage due to movement or impact. As such, the Inspector may expect that repairs are undertaken to structures with a nuclear safety significance that have been subject to damage in order to restore their performance in order to satisfy the safety functional requirements placed upon them and comply with design intent.

98. In some cases, repairs or the replacement of damaged components may not be reasonably practicable, and the dutyholder may seek to justify the continued use of a structure in its current damaged state, based on damage tolerance arguments or on the basis of enhanced inspection or structural health monitoring. This section focuses on the case that damage cannot be repaired. There is limited relevant good practice (RGP) in this area.

4.1 Causes of Damage

99. Damage to structures typically occurs as a result of one or more of the following mechanisms, as described in BRE Digest 336 [7]:

- actions of external hazards and environmental effects –e.g. earthquakes, flooding, high winds, high/low temperature extremes etc.,
- actions of internal hazards – e.g. fire, impact loads, explosions,
- overloading – e.g. loads are beyond the design basis or were not included in the design basis such as those resulting from dropped loads,
- ground movement,
- groundwater changes,
- chemical deterioration processes – e.g. acids, alkali-aggregate reaction (refer to ageing effects section),

- electrochemical deterioration - e.g. chloride attack (refer to ageing effects section,
- biological attack – e.g. biological growth, fungal attack (refer to ageing effects section,
- electromagnetic or ionising radiation,
- latent damage caused by undetected errors in the design or construction,

4.2 Steps following damage identification

100. Where continued operation of the facility is an activity requiring ONR permissioning and / or the majority of the nuclear hazard can be removed by ceasing operations, the Inspector may expect that the dutyholder could reasonably demonstrate safety by:

- demonstrating the identified damage has not adversely affected the safety function of the SSC,
- adequate residual safety margin remains for the SSC (considering all operating states and safety claims made in relation to design basis events and accidents),
- the potential failure mode of the SSC does not adversely affect operational safety (including conventional health and safety),
- mitigating actions provided are sufficient to ensure ongoing safe operation of the SSC.

101. With the exception of SAP ECE.3, the civil engineering SAPs do not explicitly address damaged structures. Of particular note are SAPs EGR.10 and EGR.12 in relation to graphite core assessment, as these relate to the assessment of SSCs that, in some cases, are damaged and subject to progressive damage mechanisms and where it is not reasonably practicable to carry out repairs. Damaged structures can therefore be assessed considering these principles where relevant.

102. The Inspector should be aware that a number of the SAPs relating to Integrity of metal components and structures are relevant to damaged structures, including EMC.5 free from defects, EMC.6 means to establish defects of concern, EMC.28 margins, EMC.34 defect size.

103. When assessing damaged structures that continue to provide a nuclear safety function, the Inspector may wish to seek assurance of the adequacy of the process that the dutyholder undertakes to justify the continued use of a damaged structure. The principles of such a process include:

- gathering information on the structure,
- carrying out inspections and investigations to confirm the extent and causes of the damage,
- carrying out a structural assessment of the significance of the damage,
- determining whether a safe operating margin exists,
- providing a safety justification where continued use of the structure is proposed.

104. After it has been established that a structure is damaged, the Inspector may expect the dutyholder to follow a logical step-by-step approach to evaluate the damage and either justify the continuing use of the structure, reduce the loads, repair or modify it or take it out of use. The Inspector should expect the dutyholder to demonstrate they have taken a graded approach, including, where appropriate the original Categorisation and Classification scheme, considering SAP ECE.19.

105. Further details on suitable approaches are described in :

- BRE Digest 366: Parts 1 to 4: “Structural Appraisal of Existing Buildings” [7].
- “Appraisal of Existing Structures”, The Institution of Structural Engineers [8].

106. The general steps considered herein are:

- preliminary inspection,
- review of existing documentation (desk study),
- detailed investigation,
- assessment,
- reporting of assessment,
- damage tolerance assessment,
- safety case for future use of the structure
- demonstration of adequate safety.

107. When assessing the condition of a structure, the Inspector may wish to consider whether a similar event of damage or ageing could impact other structures on site, and whether the dutyholder has adequately assessed the risk.

108. The Inspector may wish to consider the potential for aggregation of multiple defects, non-conformances, ageing effects or damage on the holistic condition of a structure, e.g. whether there is a risk that the accumulation of several separate issues has an impact on the capacity of a structure. The Inspector is reminded of the expectations of ECE.19, specifically SAPs paragraph 358.

4.2.1 Preliminary inspection

109. A preliminary inspection by a suitably qualified and experienced person (SQEP) should be undertaken as soon as reasonably practicable after the damage has been detected or is suspected.

110. The Inspector should be aware that the objective of this preliminary inspection is to gain an initial understanding of the structure and its current condition and to identify any immediate safety concerns that would require urgent action. It is likely that only a visual inspection would be undertaken at this stage, but the Inspector may expect this inspection would be used to plan for more detailed subsequent inspections, investigations or tests. This, and subsequent inspections should be adequately documented.

4.2.2 Review of existing documentation (desk study)

111. The Inspector may expect the dutyholder to obtain and review all available documentation that would be relevant for the assessment of the structure, such as construction drawings, design reports (in particular design basis or design method statement type documents), specifications, calculations, modification proposals, previous inspection reports, maintenance records, old photographs and the health and safety file required by the Construction (Design and Management) Regulations (CDM), where applicable. The Inspector should be aware that information on drawings may not accurately reflect reality, especially when not marked “as-built”.

4.2.3 Detailed investigation

112. As part of the detailed investigation phase, the Inspector may seek evidence that the dutyholder has made reasonable efforts to confirm the accuracy of any available documented information. This work may require a range of activities appropriate to the structural type and nature of the defect. Typical activities could include visual inspection, a measured survey, ‘opening up’ works, excavation, non-destructive tests (NDT), sampling and testing of materials or installation of basic monitoring equipment.

113. When assessing detailed investigation proposals, the Inspector may consider whether the proposed activities, together with their extent, will obtain sufficient information for the assessment without further damaging or destabilising the structure. The Inspector should be aware that the preferred hierarchy of investigation is to initially use non-

invasive or non-destructive testing, with more invasive methods being used only where necessary. Any ‘opening up’ works should be reinstated or repaired as soon as reasonably practicable.

114. The Inspector should expect that, in addition to determining the accuracy of the readily available records for the structure, the detailed investigation should accurately identify the location, nature, cause and extent of the damage.

4.2.4 Assessment

115. The Inspector may seek confirmation that the structural assessment is carried out in stages of increasing complexity and rigour. When sufficient evidence has been produced that the structure is adequate, despite its damaged state, then the Inspector could consider that further levels of assessment may not be necessary. The Inspector should be aware that more detailed analysis could result in a requirement for further information and for this, an iterative approach may be appropriate between assessment and further detailed investigation.

116. The Inspector should be aware that existing design calculations, whilst useful, do not necessarily represent the structure as built, and do not take into account the way it was constructed or maintained, and may not reflect subsequent modifications. For these reasons, the Inspector may seek assurance that reliance on existing calculations is appropriately conservative, with investigative evidence to demonstrate this is the case.

117. Initial assessment is expected to consist of a review of the structure’s appropriateness for its intended use. The Inspector should expect this to include ascertaining the primary structural load paths and the effect of the observed damage on global and local strength, stability and robustness. The Inspector should expect the assessment to give due consideration to whether the damage is likely to be progressive and whether an increase in the current degree of damage or loading would be likely to lead to a disproportionate risk of failure (‘cliff edge’ effects). The type of failure mode expected is also of importance, in particular whether a ductile or brittle mode is expected, as this will influence the robustness of the structure. The Inspector may consider whether assessment to establish how the damaged structure will respond to design basis or beyond design basis events is appropriate. For all but the simplest of structures, the Inspector may challenge judgement-based assessments of damaged structures that are not based on calculations.

118. Where initial assessment has not been able to conservatively demonstrate adequacy, further detailed assessment will be required. The Inspector should expect that limit-state calculations will be undertaken based on a code specific to structural assessment, or if not available, based on an accepted design code. If the structure is shown to have an adequate margin of safety, then the Inspector may conclude that no further assessment calculations are required. The Inspector should be aware that the use of codes and standards alone is considered insufficient to justify structures where the defect is progressive, and due allowance must be made for further damage to occur over the remainder of the structure’s service life, and, where required, post-service decommissioning period or further, throughout a care and maintenance phase. Evidence will be required that there is a means to detect further damage in line with the expectations of SAP ECE.3, and the Inspector should expect that damage is demonstrated to fall within the assumptions made within the assessment calculations.

119. The Inspector may consider whether the analysis method is appropriate for the type of damage that has occurred. For example, localised chloride-induced corrosion of steel reinforcement in concrete may significantly reduce the reinforcement ductility and structures that are affected by this form of corrosion should not normally be justified based on plastic analysis (such as yield line methods).

120. The Inspector should be aware that the unmodified use of design codes to appraise an existing structure is often inappropriate. Although in some circumstances this approach may be overly conservative, for damaged structures it may lead to an over-estimate of residual strength. Partial safety factors used in design codes may need to be adjusted for use in a structural assessment. In the absence of a Eurocode dealing explicitly with assessment of existing structures, guidance on adjusting material strengths and partial material factors for assessment may be found in [7], [8], and [9].

121. The Inspector should be aware that the performance of existing buildings usually exceeds that suggested in design calculations, largely due to load-sharing and redistribution mechanisms that occur, but that are not accounted for in the design. The Inspector should expect structural assessment to account for these alternative load sharing mechanisms where they can be justified, based on thorough inspection and assessment of the structure. Where detailed analysis, including for plastic deformations is undertaken, such load sharing may have been accounted for already. The Inspector may wish to seek assurance that qualitative arguments around load sharing are consistent with predicted behaviour from any models used. An assessment may also account for actual geometry and material properties, which may be beneficial to the strength assessment.

122. Where there is damage or deterioration of the structure, the Inspector should be aware there may need to be an increase in partial material factor above the value used in design. The Inspector should be aware that it may also be necessary to reduce the characteristic strength value used for deteriorated material. The Inspector should note that larger partial safety factors will not compensate for greater brittleness or vulnerability (such as failure due to fatigue).

123. There is little guidance available on how strengths and partial factors should be adjusted to account for individual damage mechanisms. Some of the available advice in the literature is:

- Alkali-Silica Reaction (ASR) – BA 52/94 [**Error! Reference source not found.**9],
- Assessment of effects of corroded or damaged reinforcing bars – BA38/93 and BA51/95 [9],
- Scour and hydraulic actions – BD 97/12 [9],
- Damage to reinforced concrete (resulting from seismic events) – FEMA 306 [10].

124. The Inspector should expect that specific allowances for deterioration are made directly in the calculations, such as loss of material strength or of material. An approach using worst credible strength is preferred to one using characteristic strength, if a structure has suffered damage or deterioration in such a way that the actual strengths are known or thought to be less than the assumed characteristic values. The Inspector should expect values for worst credible strengths to be underpinned by testing. Advice is given in BD 44 (for concrete) [9] for strength values for use in initial assessment when no test data are available.

125. The Inspector should expect the assessment to make due allowance for the age of the structure, all potential aspects of damage (including other minor damage(s) that are not the original basis of the damage assessment) and its anticipated future design life. The Inspector should expect that any assumptions made on future deterioration are suitably conservative and underpinned by proposals for enhanced monitoring and inspection of the structure to confirm that assumptions made are validated by physical evidence.

126. The Inspector should expect the assessment to account for applicable external hazards, fault and accidental loads and should include for all design basis events and the potential for cliff edge effects.

127. In addition to a strength assessment, the Inspector should expect the assessment to address whether the global and local stability of the structure remains adequate. The

Inspector should expect that structural robustness (i.e. the ability of the structure to withstand beyond design basis events without disproportionate effects on nuclear safety) is considered in the assessment and should assess whether codified rules for disproportionate collapse are complied with.

128. The Inspector may consider whether the assessment adequately includes consideration of whether any of the multiple arguments used to provide defence in depth in accordance with the original safety case (SAP ECE.2) have been invalidated by the damage.

4.2.5 Reporting of assessment

129. The Inspector may expect a formal report to be prepared to record the scope, content and outcome of the structural damage assessment. This report should have a firm conclusion as to whether the structure is suitable for continued use in its damaged state.

130. The Inspector should expect the report to address, as applicable, the following areas [as reported in [7]:

- consequence of failure,
- nature of the damage / defects and the rate of deterioration or change occurring,
- predicted residual service life,
- possibility of hidden damage or defects,
- adequacy of the condition data,
- justification for the material properties used,
- justification for the partial factors for materials and loading,
- sensitivity of the structure to the applied loading,
- recent load history and performance under service loads,
- type and rigour of assessment completed,
- re-evaluation of the structure’s load-carrying capacity,
- whether any measures are needed to restrict access or operation,
- whether any reasonably practicable measures can be taken to prevent further damage,
- whether there are any reasonably practicable strengthening measures,
- timing and extent of intensified inspection and monitoring.

4.2.6 Damage tolerance assessment

131. Where structural assessment indicates that the damage to the structure is likely to be progressive, then one possible approach to substantiation is by use of damage tolerance arguments. In this approach, an analysis is undertaken to determine, at a particular confidence level, the point at which the safety function would no longer be fulfilled. The Inspector should expect this limit (an established damage tolerance level) to be related to suitable measurable parameters such as deflection, corrosion levels or damage extent. The Inspector should expect the confidence limits used to establish the damage tolerance level to be justified and be appropriate to the importance of the nuclear safety function. The Inspector should expect that the confidence level would be at least 95%, for the safety function to be fulfilled for the remainder of the life of the structure.

132. The Inspector should expect a safe operating limit on the damage tolerance level to be determined by reducing the established damage tolerance level by the application of a safety margin. The Inspector should anticipate the margin applied to reflect all significant uncertainties in the assessment. These uncertainties are likely to include the extent of the damage, the accuracy of the methods used to establish the damage tolerance level, the degree of sampling applied, the expected rate of deterioration, and the accuracy with which the development of the deterioration mechanism can be established during the remaining life of the structure. The Inspector may wish to seek assurance that an appropriately conservative overall approach to the estimation of uncertainty has been taken in determining the safe operating limit.

133. In order to underpin the safety justification that the damage to the structure is within its safe operating limit, the Inspector should expect an appropriate inspection and test regime will be established. The Inspector should expect the methods used to include direct examination of defects using a technique qualified for the defect type, size and orientation of concern. The Inspector may wish to receive assurance that the frequency of the inspections and tests are based on suitable evidence as to the expected rate of deterioration of the structure.

4.2.7 Safety case for future use of the structure

134. When assessing a safety case for the continued use of a damaged structure, the Inspector may seek evidence of a clear strategy that looks ahead to the end of life of the structure (or to the point where it will be repaired). The Inspector may wish to seek assurance that robust methods and appropriate acceptance criteria are used to demonstrate on a continuing basis that the assumptions made in assessing the adequacy of the structure remain valid. The Inspector should be aware that acceptance criteria based solely on compliance with codes and standards are not likely to be acceptable.

135. For structures important to safety, the Inspector should expect the safety case to clearly demonstrate that defects can be tolerated without compromising the required safety functions and performance requirements, in line with SAP ECE.3. Further, that the existence of defects that could compromise safety functions in the future can be detected for the remaining service life, in line with the expectations of ECE.17 and EMC.6. The Inspector should expect the effect of defects on safety functions to be assessed for normal operations, fault and accidental conditions. The possibility of disruptive failure, without adequate forewarning should be demonstrated to be remote, in line with the expectations of SAPs ERL.4, ECE.2, ECE.6 and EMC.11 which state that failure modes should be gradual and predictable.

136. The safety case should consider how further damage can be prevented and whether there are diverse methods of preventing failure of the SSC if the damage should worsen, in line with the expectations of SAP EKP.3 for defence in depth and EDR.4 for no single failure criterion (and where the safety function is that of leak tightness, ECV.1, DC.1 and RP.5).

137. The safety case should identify the expected remaining service life of the structure, in line with the expectation of SAPs ECE.1 and ECE.6. Where assessment, and the development of load factors, is based on assuming a reference period (i.e. the chosen period of time which is used as a basis for assessing values of variable actions or time-dependent material properties) less than the minimum usually taken for new design (generally a minimum of 50 years), the Inspector may seek evidence that this approach has been adequately justified. The Inspector may consider whether any reduced reference period is realistic and whether the resulting annual probability of failure will not exceed the required target value based on the consequences of structural failure [7].

138. In line with SAP ECE.20, the safety case should describe how the structure will be monitored to detect further deterioration. The Inspector should be aware that reliance solely on visual inspection, even at an enhanced frequency, is unlikely to provide the required degree of confidence needed for the substantiation of damaged structures. The Inspector may, in addition to inspection, seek evidence of a programme of future monitoring and testing.

139. The Inspector should be aware that the type of monitoring or testing going forward will depend on a number of factors, such as the degree of confidence in the extent of the damage and its likely modes of propagation and uncertainty around the rate of change. The Inspector may wish to seek assurance that the dutyholder has considered the installation of structural health monitoring systems that provide continuous or periodic data directly from equipment on the structure, as these can give an early warning of

further changes. This Inspector should be aware that such equipment can also be used to trend data in order to underpin the safety case assumptions in relation to damage progression.

140. The Inspector may wish to seek assurance regarding whether monitored values are compared to action levels which, in turn, should be established on the basis of the admissible probability of failure. An operating envelope should be defined where applicable, in line with the principles of SAP ECE.3 for defects to not compromise safety functions, and EMC.21 and EMC.24 for use of operation envelopes in the safety case. The Inspector should expect the steps to be taken when approaching or exceeding the action levels are determined and described in the safety case.

141. Testing should preferably be non-destructive, where such methods can be adequately calibrated, to avoid further damaging the structure. Where invasive testing and investigation cannot be avoided, the Inspector may wish to seek evidence that the dutyholder has made allowance for any resulting damage to the structure in determining its safe capacity.

142. The safety case should clearly address the risk of ‘cliff edge’ effects, in line with the expectations of SAP ECE.6 and EHA.18 and EHA.7. The Inspector should be aware this is particularly important where brittle failure conditions or rapid further deterioration could result where loads are slightly greater than the design basis. For such cases, the Inspector should focus on whether there is sufficient evidence that these mechanisms have been correctly identified and that the type of monitoring adopted is capable of providing early detection of further damage development. The safety margin adopted in such cases is likely to be larger than for more defect tolerant situations, but the Inspector may wish to seek assurance that the parameters used to assess the safety margin are appropriate to the expected failure mechanism. For example, the measurement of deflection may provide an acceptable way of determining performance in many cases where a structure is capable of post-yielding behaviour, but will not be suitable where sudden brittle facture may occur.

4.2.8 Demonstration of adequate safety

143. For damaged structures where the nuclear hazard cannot be mitigated by ceasing operations, the Inspector may wish to seek assurance that the dutyholder has demonstrated that risks have been reduced so far as is reasonably practicable by:

- demonstrating that all reasonably practicable measures to improve the situation have been undertaken,
- actions to remove the hazard in a safe but timely way are being pursued,
- appropriate accident response arrangements to minimise the consequences of a failure of the SSC have been developed and, where appropriate, deployment has been practiced.

5 RELEVANT STANDARDS AND GOOD PRACTICE

144. This section provides a summary of the relevant guidance for inspectors to be aware of, along with sources for further information that provide useful background. Inspectors are advised to check whether these guides are the most up to date, given the review period of the TAG.

145. Note the lists provided are not full and comprehensive lists. The Inspector should only use the guidance that is relevant to the scenario being assessed and seek other appropriate guidance to suit the circumstances.

5.1 AGEING MECHANISMS

5.1.1 ONR Technical Assessment Guides (TAGs) and Technical Inspection Guides (TIGs)

- ONR-NS-TAST-GD-017 Civil Engineering & Annexes,
- ONR-NS-TAST-GD-098 'Asset Management',
- ONR-NS-TAST-GD-050 'Periodic Safety Reviews (PSR)',
- ONR-NS-TAST-GD-049 'Licensee Core Safety and Intelligent Customer Capabilities',
- ONR-NS-TAST-GD-079 'Licensee Design Authority Capability',
- ONR-NS-TAST-GD-080 'Challenge Culture Capability (including an Internal Regulation function), and the provision of Nuclear Safety Advice',
- ONR-NS-TAST-GD-051 'The Purpose, Scope and Content of Safety Cases',
- ONR-NS-TAST-GD-048 'Organisational Change',
- ONR-NS-TAST-GD-057 'Design Safety Assurance',
- ONR-NS-TAST-GD-065 'Function and Content of the Nuclear Baseline',
- ONR-NS-TAST-GD-026 'Decommissioning',
- ONR-NS-TAST-GD-027 'Training and Assuring Personnel Competence',
- ONR-NS-TAST-GD-033 'Dutyholder Management of Records'.

5.1.2 UK Regulations

- Construction (Design and Management) Regulations 2015 (CDM2015).

5.1.3 Associated UK HSE Guidance (L Series, HSG Series and RR Series)

Legal (L) Series

- L153 Managing Health and Safety in Construction Approved Code of practice for CDM 2015,
- L101 Safe work in confined spaces. Confined Spaces Regulations 1997 Approved Code of Practice, Regulations and guidance.

Health and Safety Guide (HSG) Series

- HSG65 Managing for Health and Safety 2013, HSG 159 Managing Contractors,
- HSG268 The health and safety toolbox: how to control risks at work 2014.

Research Report (RR) Series

- HSE RR823 'Managing Ageing Plant, A Summary Guide', provides a basis for relevant good practice, but it has been predominantly written for metallic containment systems such as tanks, pressurised vessels and pipelines,
- HSE RR912 Research Report: Management of Ageing A framework for nuclear chemical facilities 2012 provides generic advice relating to ageing management.

5.1.4 International Guidance (IAEA, WENRA and ENSREG)

146. General ageing management standards for the nuclear industry are defined within IAEA Safety Standard, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA SSG-48 [3].

- Design considerations are in Section 3.9 of [3].

147. More specific standards relating to concrete structures within IAEA Ageing Management of Concrete Structures in Nuclear Power Plants [11]. A figure depicting a recommended approach to ageing management is included as Figure 1, copied at the end of this annex.

148. A number of other IAEA documents make reference to the requirement for ageing management but the majority of the information relevant to civil SSC is summarised in [3]and [11].

149. IAEA Safety Report Series 82 – 'Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned' (IGALL) [12] provides a technical basis and practical guidance on managing ageing of SSC. It includes:

- A generic sample of ageing management review tables,
- A collection of proven ageing management plans,
- A collection of typical time limited ageing analyses.

150. This Safety Report [12] provides a common, internationally agreed basis on what constitutes an acceptable ageing management plans and serves as a roadmap to available information on ageing management. The information is supplemented by a database [13] which is subject to ongoing development. Access to the database requires registration.

151. An ageing management plan is defined as "a set of plant activities relating to understanding, prevention, detection, monitoring and mitigation of a specific ageing effect on a structure, component or group of components. Plant activities include maintenance, in-service inspection, testing and surveillance, as well as operational conditions and technical support programmes." The report [12] identifies the following IGALL ageing management plans for civil structures:

- AMP 301 In-service Inspection for Containment Steel Elements,
- AMP 302 In-service Inspection for Concrete Containment,
- AMP 303 Safety Class 1, 2 and 3 Piping and Metal Containment Components Supports,
- AMP 304 Containment Leak Rate Test,
- AMP 305 Masonry Walls,
- AMP 306 Structures Monitoring,
- AMP 307 Water-control Structures,
- AMP 308 Protective Coating Monitoring and Maintenance Programme,
- AMP 309 Non-metallic Liner,
- AMP 310 Ground Movement Surveillance,
- AMP 311 Containment Monitoring System,
- AMP 312 Concrete Expansion Detection and Monitoring System,
- AMP 313 Containment Pre-stressing System.

152. The report [12] identifies the following civil engineering related time limited ageing analysis (TLAA) and refers to the database for more information:

- TLAA301 Concrete Containment Tendon Pre-stress,
- TLAA302 CANDU/PHWR Concrete Strength Reduction Due to Creep and Shrinkage,
- TLAA303 Cumulative Fatigue Damage of Containment Liners and Penetrations,
- TLAA304 Foundation Settlement Due to Soil Movement.

153. WENRA Safety Reference Level for Existing Reactors [4] highlights regulatory expectations regarding ageing management in Issue I: Recommendations relating to ageing management of civil SSC have been included in this annex.

154. WENRA Decommissioning Safety Reference Levels [14] provides regulatory expectations regarding ageing management for non-operational and waste storage sites. The expectations relating to ageing management correspond to those for active facilities. The Inspector should note the specific Decommissioning Safety Reference Levels of DE-42, DE-43 and DE-44.

155. The European Nuclear Safety Regulators Group (ENSREG) publication “ONR - ENSREG Topical Peer Review on Ageing Management” [15] is the UK's report on the first European Union topical peer review. The report contains assessments by both dutyholder and ONR of the effectiveness of the ageing management programmes for operating reactors and partially constructed sites. The report includes an assessment of the general arrangements for ageing management plans and specific sections that consider how these arrangements have been applied to SSCs. The sections of relevance to civil engineering are:

- Section 7 - Concrete Containment Structures,
- Section 8 - Pre-stressed concrete pressure vessels (AGR).

The report identifies areas of strengths and weaknesses and outlines an action plan where improvements are required.

5.1.5 Design Standards and industrial guidance

- BS ISO 55001:2014 [16] is a current British Standard for the management of assets. It was based on and replaces Publicly Accessible Standard (PAS) 55 [17]. While not specific to the management of ageing assets, it does provide extensive guidance upon the management of assets in service,
- The superseded PAS 55 [17] provides further guidance beyond that included in the BS, including guidance for assets at the end of their serviceable life.

156. Additional normative references to the above, including but not limited to:

- ICE manuals. The most applicable relevant good practice relating to civil SSC originates from UK Highways Agency and Local Authorities who are responsible for the management of numerous concrete and steel bridge structures. Most information takes the form of technical reports and proceedings, and hence is not listed here,
- Effective Ageing Management of Concrete Structures, Tcherner et al., Journal of Advanced Concrete Technology [18] discusses and provides details of an approach to ageing management for new and existing concrete structures forming part of a nuclear facility. It considers that a key aspect of ageing management is a rigorous and systematic assessment of structures, commonly referred to as a condition assessment. The paper provides the methodology for carrying out condition assessments of concrete structures. It uses as a basis the IAEA guidance on ageing management,
- Standard ASCE/SEI 41-17 is concerned with the seismic evaluation and retrofit of existing buildings,
- ACI365.1R-17, Report on Service Life Prediction [19] lists some existing knowledge of concrete degradation mechanisms and empirical methods for estimating the service life of reinforced concrete structures. It provides guidance for, and promotes the use of, modern quantitative methods for life estimation. It also provides guidance on in-service inspections to provide data for the use of either methodology,
- For an extensive list of references to Relevant Good Practice relating to asset management available up to the beginning of 2015, refer to the ‘Establishment of Relevant Good Practice in Asset Management - Proposed Asset Care and Maintenance Relevant Good Practice’ [20],
- For consideration of irradiation of concrete, a useful summary of the current knowledge is contained in a paper by Rosseel et al [21].

5.2 DAMAGED STRUCTURES

5.2.1 ONR Technical Assessment Guides (TAGs)

157. ONR Technical Assessment Guides (TAGs) provide guidance to inspectors carrying out assessments of dutyholders safety cases. A number of TAGs provide advice that is relevant to damaged structures, the most significant of which are summarised below.

158. ONR-NS-TAST-GD-016 (Integrity of Metal Structures, Systems and Components) contains advice in relation to metal components. The key advice, adapted to damaged structures more generally, can be summarised as:

- the Inspector may wish to seek confirmation that due account has been taken of defects or degradation in the analysis of the structure for fault loads and external hazards and that appropriate acceptance criteria have been specified. Acceptance criteria based on meeting the requirements of codes and standards are not likely to be acceptable for degraded or defective structures,
- where a safety case requires specific assurance on the likelihood of structurally significant defects at particular locations, it can only be supported by direct examination using a technique qualified for the defect type, size and orientation of concern.

159. TAG 17 (this document) advises that the Inspector may consider whether the safety case has addressed the consequences of a defect becoming worse and whether adequate records of defects are being maintained. Reference is made to [22 volumes 1 and 2] in the bibliography, which provides advice with respect to the evaluation of defects in concrete structures.

160. ONR-NS-TAST-GD-020 (Civil Engineering Containments for Reactor Plants) contains particular advice in relation to damaged pre-stressing tendons on AGR reactor pressure vessels. Advice derived from this TAG and adapted for damaged structures is:

- the general expectation is that damage once detected should be addressed by replacement or repair where this is reasonably practicable. Where this expectation is not met, the potential consequences should be fully understood and a programme of further mitigation prepared on an ALARP basis,
- examinations and tests should be undertaken to determine the cause of damage and its extent should be established,
- where damage is detected, specific case-by-case safety cases will be required, supported as appropriate by numerical analysis,
- when assessing a defect specific safety case, the assessor should bear in mind the accumulated body of defects justified in previous defect specific safety cases,
- the Inspector should have an expectation that the dutyholders arrangements will address the causes of any damage or defect to prevent further degradation,
- if monitoring activities observe changes in damaged areas the assessor should be satisfied that the cause of the changes is understood and that potential adverse trends are acceptable for continued use,
- where damage has been detected and cannot be repaired, or the damaged item replaced, the safety case should consider multiple independent arguments (SAP ECE.2). The safety case should consider how further damage can be prevented, whether there are diverse methods of preventing failure of the SSC if the damage should worsen and how the SSC will be monitored to detect further deterioration, with an operating envelope being defined where applicable.

161. ONR-NS-TAST-GD-029- Graphite Reactor Cores provides advice to inspectors on damage tolerance assessment (DTA) and it is considered that this could be applied more widely as a basis for the assessment of damaged structures. Advice on the acceptability of damage tolerance arguments is given and three potential approaches to DTA are described.

5.2.2 ONR Technical Inspection Guides (TIGs)

162. A number of the nuclear site licence conditions are considered applicable to the justification of damaged structures. Guidance on the application of the Licence Conditions can be found in the relevant ONR Technical inspection Guides (TIGs). The most significant of these licence conditions include:

- ONR-NS-INSP-GD-014 'LC 14 - Safety Documentation',
- ONR-NS-INSP-GD-015 'LC 15 - Periodic Review',
- ONR-NS-INSP-GD-028 'LC 28 - Examination, inspection, maintenance and testing'.

5.2.3 UK Regulations

163. A review of the legislative requirements with respect to the assessment of damaged structures is given in [7], though this review does not cover nuclear facilities. The review is focused on the Building Regulations [23], which apply only to offices and canteens on nuclear licensed sites (not used in the emergency arrangements).

164. There are no other explicit requirements defined for the structural assessment of existing buildings apart from those general duties that arise in relation to health & safety related legislation (primarily The Health and Safety at Work Act (1974) and subsequent Acts).

165. Workplace legislation introduces responsibilities in respect of through-life structural performance of buildings. An amendment to the Workplace (Health, Safety and Welfare) Regulations 1992 introduced Regulation 4A, states: "Where a workplace is in a building, the building shall have a stability and solidity appropriate to the nature of the workplace."

166. The CDM Regulations 2015 may be applicable if the assessment involves invasive investigations, temporary works or structural modifications or is part of a larger project.

5.2.4 Associated UK HSE Guidance (L Series, HSG Series and RR Series)

Legal (L) Series

- L153 Managing Health and Safety in Construction),
- L101 Safe work in confined spaces. Confined Spaces Regulations 1997 Approved Code of Practice, Regulations and guidance.

Health and Safety Guide (HSG) Series

- HSG65 Managing for Health and Safety 2013,
- HSG 159 Managing Contractors,
- HSG268 The health and safety toolbox: how to control risks at work 2014.

Industry Guidance (INDG) Series

- INDG411 A quick guide for clients on CDM 2015.

5.2.5 International Guidance (IAEA, WENRA and ENSREG)

167. The WENRA Safety Reference Levels for existing reactors [4] provide the following requirement in relation to degradation of structures, which can be considered relevant to damaged structures:

- I2.1 – "The licensee shall assess structures, systems and components important to safety taking into account relevant ageing and wear-out mechanisms and potential age related degradations in order to ensure the capability of the plant to perform the necessary safety functions throughout its planned life, under design basis conditions."

5.2.6 Design standards and industrial guidance

168. Within the wider technical literature, step by step approaches to carrying out structural assessments (or appraisals) of damaged structures are given in [7] and [9]. These cover both the investigation and inspection phases as well as techniques for evaluation of structural capacity. Detailed advice with respect to fire damage assessment is in [9]. Further advice on the use of non-destructive testing (NDT) techniques to detect and evaluate damage is given in [24].

169. There are no structural Eurocodes that cover the assessment and retrofitting of existing structures, although these are under development. A pre-normative document has been published [6] which presents preliminary proposals for consultation. The purpose of this development work is to bring together the different national approaches to a broadly accepted and coherent set of harmonised European technical rules for the assessment and retrofitting of existing structures, complementing those for the design of new structures. It is expected that the work will develop a probabilistic approach to assessment using partial safety factors similar to the current design approach. A review of existing national standards is presented, including for the UK. The review specifically excludes additional requirements for nuclear structures. The draft document includes useful advice with respect to determining material properties and partial factors for use in structural assessment.

170. Of particular value are the “Design Manual for Roads and Bridges” (DMRB) [9] suite of standards used by the Highways Agency, Transport Scotland and the Welsh Government. Those standards that provide guidance that may be of relevance to damaged structures are cited in [**Error! Reference source not found.**]. The standards contain much useful information regarding appropriate material properties and partial factors for assessing older structures.

171. Structural Health Monitoring (SHM) is a process of in-service damage identification and health evaluation for an engineering structure through an automated monitoring system. It is considered that this type of system may be useful, particularly for larger structures and guidance is given in [24]. SHM can be used for tracking the responses of a structure over a sufficient duration to determine anomalies, to detect deterioration and to assess damage for decision making. It can also be used to predict future performance and establish lifetimes.

172. Detailed advice is given in [24] on different approaches to detecting the global and local response of the structure to damage, with a particular focus on vibration based damage detection methods from structural dynamic response measurements. Structural damage assessment techniques are described, in particular the data-based and model-based approaches which are considered complementary. Data-based techniques are based on previous measurements from the SHM system to assess the current damage state. They utilise a form of pattern recognition and do not require the development and use of a behaviour model of the system. Model-based techniques (commonly using finite element modelling) are especially useful for predicting responses to new loading conditions or damage states. The applicability of each method is considered, together with its advantages and disadvantages.

5.2.7 Federal Emergency Management Agency

173. The Federal Emergency Management Agency (FEMA) is an agency of the United States Department of Homeland Security. FEMA has produced guidance with respect to assessing damage due to seismic events on building structures, examples of which are FEMA 306 [10] and FEMA 307 [25], which are applicable to concrete and masonry structures. FEMA 307 [25] includes background and theoretical information to be used in conjunction with the practical evaluation guidelines and criteria given in FEMA 306 [10].

174. FEMA advice is given on carrying out the assessment process, including categorising and evaluating the damage. Although a lot of the advice is specific to seismic loading

and assessment, most of the investigation techniques and elements of the basic assessment methodology can be applied more widely to damaged structures in general.

175. A section in [10] provides guidelines for the use of typical tests, inspections and assessments to assess the consequences of earthquake damage to buildings. The damage evaluation begins with the selection of an appropriate performance objective. The performance objective serves as a benchmark for measuring the difference between the anticipated performance of the building in its damaged and pre-event states, described as relative performance analysis.

176. The proposed structural analysis methodologies in [10] are based on the inelastic behaviour of structures. These techniques generate a plot, called a capacity curve, that relates a global displacement to the lateral force imposed on the structure. The capacity of the structure is represented by the maximum global displacement at which the component damage is on the verge of exceeding the tolerable limit for a specific performance level. Whilst this approach is specifically useful for structures suffering damage due to significant displacement, the principles could be adapted more generally.

177. As outlined in [**Error! Reference source not found.**], damage investigation is expected to report on two related categories of information on the structural damage consequences to the building. First, there is a compilation of the physical effects on all the structural components (such as cracking and spalling). Second, the damage is classified according to component type, behaviour mode, and severity. Using these data, it is considered possible to quantify the changes attributable to the damage with respect to basic structural properties of the components of the building, including stiffness, strength, and deformation limits.

178. A series of component damage classification guides are given in [10]], with advice on identifying the causes of various types of damage in reinforced concrete walls and on the classification of severity of damage and estimation of component modification factors to allow for damage. The modification factors refer to the difference in capacity between a pre-event component and a post-event component and are based on a review of the research. Proposed alterations to calculation methods set out in design code ACI 318-95 are given for the assessment of damaged reinforced concrete walls.

Office for Nuclear Regulation

6 REFERENCES

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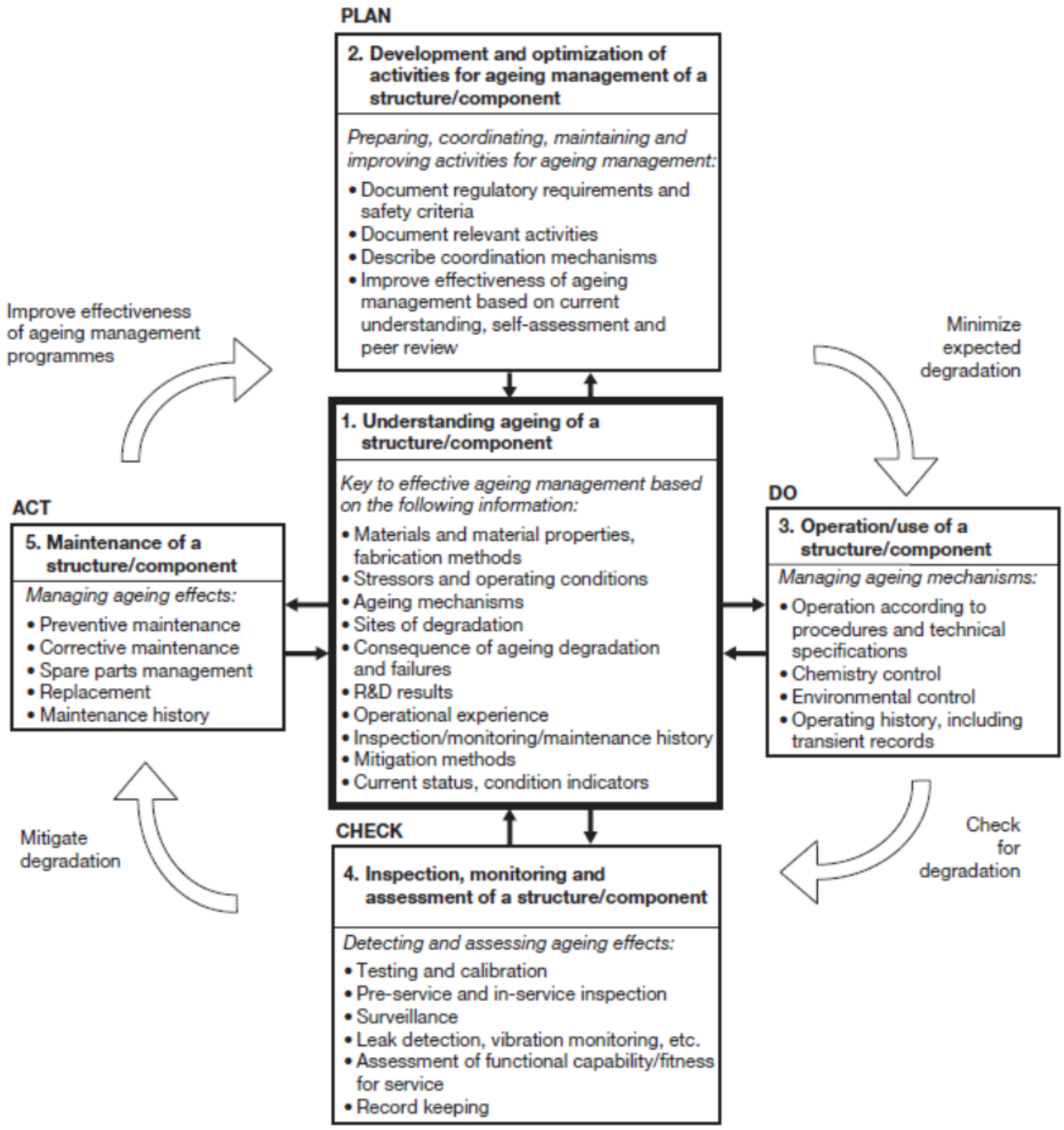

FIG. 1. Systematic approach to managing ageing of a structure or component.

TABLE 1 – EXAMPLE AGEING EFFECTS, POTENTIAL RESULTS AND DIRECT EFFECTS

Ageing Effect	Potential result	Direct Effects on Safety Function
Dimensional change*: - Thermal movement - Moisture movement - Post hardening concrete shrinkage - Creep (concrete and cementitious materials) - Swelling of masonry (moisture absorption)	Shrinkage cracking	Loss of containment. Loss of shielding Rainwater or groundwater penetration into facilities Losses of water from ponds (potentially transporting contaminates)
	Overstress of adjacent structural components	Cracking, deformation or failure to adjacent structural components Reduction in capacity secondary load paths Unanticipated structural restraint
	Opening of movement joints	Losses of water from ponds (potentially transporting contaminants) Strain on sealants and waterbar materials
	Excessive deflection	Ponding or standing water Loss of serviceability Damage to supported services Cracking to weatherproof envelope
	Ground heave Settlement of structures	Damage to below ground services. Can lead to further ground movement. Damage to groundwater or ground gas protection measures Loss of serviceability Cracking to weatherproof envelope
Cementitious chemical reaction (including biologically induced): - Carbonation - Conversion of high alumina cement - Alkali aggregate reaction - Sulphate attack on concrete - Thaumasite sulphate on concrete - Metallic component in aggregate reaction (pyrites and related reactions)	Loss of corrosion protection to embedded reinforcement	Corrosion of embedded reinforcement, leading to expansion of corrosion products and cracking and loss of reinforcement cross section.
	Loss of structural integrity	Disintegration of structural component
	Expansive cracking	Strain damage to reinforcement.
	Spalling of concrete	Conventional health & safety risks to personnel. Damage to waterproof envelope. Creation of debris in controlled environments.
Material property change due to stress**: - Metal fatigue (due to load or temperature variation). - Hydrogen embrittlement. - High strain crack migration. - Weld strain induced failure.	Loss of pre-stress to concrete	Development of tensile cracks. Unexpected deformation. Reduced load resistance.
	Cracking of metallic components	Brittle fracture leading to component failure.
	Loss of ductility. Increased vulnerability to low temperature cracking.	Brittle fracture leading to component failure with little evidence of distress before failure.

Ageing Effect	Potential result	Direct Effects on Safety Function
	Stress or strain corrosion	Increased rate of ageing effects
Metallic corrosion***: - Brown/red rust (oxygen rich environment). - Chloride induced corrosion. - Anaerobic (black) corrosion (including organically induced). - Bimetallic corrosion.	Loss of steel section	Reduced load resistance.
	Formation of expansive corrosion products	Cracking to surrounding materials (e.g. concrete), spalling or unpredicted loads. Increased fractional forces (bearings, moving components).
	Increase in surface roughness	Increased fractional forces (bearings, moving components).
Exposure to accidental loading: - Impact. - Fire. - Excessive loads.	Thermal induced dimensional change	See above section on direct effects from dimensional change*
	Material property change due to stress	See above section on direct effects from material property change due to stress**
	Reduction in material yield point	Development of tensile cracks. Deformation. Reduced load resistance.
	Loss of material from surface	Reduced load resistance. Increased rate of ageing effects.
Degradation of corrosion protection system: - Lack of maintenance. - Impact or abrasion. - Fire. - Aggressive environmental factors.	Initiation of metallic corrosion	See above section on direct effects from metallic corrosion***
Exposure to in-service environment: - Foot traffic. - Abrasive environments. - Moving, breaking or accelerating wheel loads	Loss of surface	Increased rate of ageing effects. Release of particulates (e.g. asbestos, fibres)
	Compaction or deformation	Loss of insulation properties, leading to condensation. Settlement of finishes. Rutting, leading to cranking or ponding of surface water
Ground movement: - Consolidation. - Ground water or leakage water induced. - Excess pour water pressure.	Ground failure	Slope instability. Inundation with wash out material.
	Settlement of structures	Damage to below ground services. Can lead to further ground movement. Damage to groundwater or ground gas protection measures. Loss of serviceability. Cracking to weatherproof envelope.
Calcite or other unreacted cementitious product leaching:	Surface calcite deposition	Locking of movement joints. Blocking of drains. Hard to remove surface staining (which may contain radioactive elements).
Freezing of entrained moisture in cold weather:	Frost pop outs to concrete	Increase in carbonation depth locally.
	Delamination to brickwork	Loss of masonry face. Increase in water absorption. Creation of debris.

Ageing Effect	Potential result	Direct Effects on Safety Function
	Ground swell or heave	Cracking to flexible pavements.
Exposure to in-service environment: - Ultraviolet radiation (sunlight). - Ionising radiation.	Reduced ductility	Brittle fracture leading to component failure. Inability to accept in-service movements.
	Reduced tensile or bond strength	Reduced load resistance. Debonding with adjacent materials. Brittle fracture. Tensile cracking (e.g. roofing materials).
Lack of maintenance: - Bird, rodent or insect infestation. - Establishment of vegetation. - Rot (timber-based materials)	Direct physical damage	Abrasion, erosion or consumption of material. Opening up of joints, cracks and other vulnerabilities. Inability for persons to access working areas for maintenance.
	Creation of debris	Blocking drains and rainwater outlets leading to standing water.
	Chemical damage (guano, decomposition products)	Staining. Increased rate of ageing effects.