## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | | | | | – Morris, Understanding Biodeterioration of Wood in Structures<br>– CFS, *Canadian Woods*<br>– CAN/CSA-O80 Series<br>– CWC, *Wood Highway Bridges* |
| | UV exposure | Surface degradation, coating breakdown | Exposure to sunlight | Protective coatings and stains | CWC, *Wood Reference Handbook* |
| | Drying-induced shrinkage perpendicular to grain | Splitting or checking; damage to other components; floor misalignment; nail popping | High initial moisture content used in a dry environment; seasonal moisture content changes; inappropriate fastening that restricts drying; shrinkage movement of members; accumulated thicknesses perpendicular to grain (beams, stringers, plates) | Use dry wood, protective coatings; design for drainage and shrinkage and to allow wood movement to ensure that wood is not constrained in tension | – NRC, Commentary E on NBC, Part 4<br>– CBD 244<br>– CWC, *Wood Design Manual*<br>– FPI, *Mid-Rise Wood Frame Construction Handbook*, Chapter 5: Design for Vertical Differential Movement<br>– CWC, *Introduction to Wood Design*<br>– CWC, About Moisture and Wood<br>– CWC, Building Performance Series No. 1, Moisture and Wood-Frame Buildings |
| **Masonry** (for references, see Clause H.4.4)<br>See Table entries for<br>• stone<br>• clay brick<br>• concrete block and mortar<br>See also entries for steel and stainless steel. | | | | | CMCA, Textbook of Canadian Masonry |

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### Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| Stone<br>• porous to varying degrees<br>• crack susceptible at planes of weakness<br>• inorganic | Acid attack | Reduced strength; disintegration; disfigurement | Presence of carbonates in stone (e.g., limestone or sandstone); acid rain; drainage; orientation | Choice of stone; integral mortar; protective coating; protection from precipitation; drainage details | – ASTM C97, C1492, C1496, C1528, STP1394, MNL 21<br>– Amoroso and Fassina (1983)<br>– BS 7543<br>– Natural Stone Institute |
| | Salt crystallization | Spalling, occasionally efflorescence | Water and salts in mortar or adjacent materials (e.g., ground) | Protection from wetting; details promoting drainage; capillary break between masonry and source of salt | – Schaffer (2004)<br>– Doehne (2002)<br>– ISO 19208<br>– ASTM STP1394, MNL 21<br>– Natural Stone Institute |
| | Freeze-thaw | Spalling, cracking | Saturation or near-saturation of materials and concurrent freeze-thaw cycles | Choice of stone; protection from wetting; details promoting drainage and drying | – ASTM C1528, STP1394, MNL 21<br>– Natural Stone Institute |
| | Thermal hysteresis | Bowing and/or dislodging of panels | Type of stone (marble); thickness of stone | Use thicker section or choose stone with demonstrated history of performance | – ASTM C97, STP1394, MNL 21<br>– Grelk et al., Durability of Marble Cladding — A Comprehensive Literature Review<br>– Natural Stone Institute |
| Clay brick<br>• porous to varying degrees<br>• crack susceptible<br>• inorganic | Freeze-thaw | Spalling, cracking | Saturation or near-saturation of materials and concurrent freeze-thaw cycles | Manufacturing process; protection from wetting; details promoting drainage and drying; moisture barriers; breathable coatings if coatings are used; integral mortar joints, well tooled | – CSA A82<br>– Brick Industry Association Technical Notes |

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## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | Salt crystallization | Efflorescence, subflorescence, occasionally spalling | High moisture content and presence of salts in brick, mortar, or adjacent materials | Low salts in bricks and mortar; protection from wetting; details promoting drainage and drying; integral mortar joints, well compacted; capillary break between material containing salt (e.g., soil) and the masonry | – CSA A82<br>– CBD 2<br>– BRE 359<br>– Brick Industry Association Technical Notes |
| | Moisture expansion | Cracking, bowing | Bricks expand after manufacture | Aging prior to use; movement joints | Brick Industry Association Technical Notes |
| | Movement due to moisture and/or temperature variations | Cracking, bowing | Moisture and/or temperature changes; restraint of free movement | Movement joints | – CAN/CSA-A371<br>– NRC, Commentary D on NBC Part 4<br>– BRE 359<br>– Brick Industry Association Technical Notes |
| Concrete block and mortar<br>• cement-based<br>• porous to varying degrees<br>• inorganic<br>• rigid | Freeze-thaw | Spalling, disintegration (surface scaling), delamination, internal cracking | Saturation or near-saturation of material with concurrent freeze-thaw cycles, aggravated by chlorides (de-icing agents and fertilizers) and poor drainage | Block unit and mortar: use aggregate resistant to degradation; increase cement content; increase level of compaction (tooling for mortar); use admixtures; maximize water for block unit; minimize water for mortar<br>Masonry: protect from precipitation; detail to promote drainage and drying | – Federal Highway Administration, Publication No. FHWA-HRT-07-021, 2007<br>– Tate and Thomson, Effect of Air Entrainment on Freeze-Thaw Durability of Type S Portland Cement-Lime Mortars |

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**Table D.1 (Continued)**

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | Sulphate attack | Expansion, disintegration, spalling | Sulphates in groundwater or sea water | Sulphate-resistant cement; optimize mix design; high cement ratio; high compaction; air entrainment; improve drainage | – CSA A23.1<br>– CBD 136 |
| | Acid attack | Reduced strength, disintegration | Acids in industrial buildings — amount in contact; permeability | Protective coatings | – FIB, CEB Bulletin 182<br>– Kerkhoff, Effects of Substances on Concrete and Guide to Protective Treatment |
| | Moisture ingress | Efflorescence, disintegration, spalling, surface formation of calcium carbonate | Vapour transfer, permeability, uncontrolled movement of water through the masonry | Protect masonry from precipitation during construction and in service; protect masonry from ingress of water from the top and from groundwater at the base and from behind; detail to promote drainage and drying | Drysdale and Hamid (2005) |
| | Biological attack | Reduced strength, disintegration | Contact with sewage (generation of acids) | Protective coatings; cleaning | FIB, CEB Bulletin 182 |
| | Shrinkage | Cracking of mortar or masonry, potential damage to adjacent building elements | High w/c ratio in mortar; high linear drying shrinkage of the block unit | Mix design of mortar and block; construction sequence; frequency and placement of control/ movement joints; amount and distribution of reinforcement; curing and moisture control prior to use | – CSA A23.1, A165 Series, CAN/CSA-A371<br>– NCMA, TEK-10 Series |

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## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | Creep | Deformation, damage to adjacent building elements; misalignment of building elements | Long-term exposure to high loads resulting in high levels of stress below the yield strength of the material; long-term exposure to high temperatures | Reduce stresses; apply loads at later age of masonry; place movement joints | Brooks, Factors in Creep of Masonry |
| | Temperature movements | Cracking and/or bowing of masonry | Temperature changes; restraint of free movement | Reinforcement; control/ movement joints | – CSA A23.1, S304.1<br>– NRC, Commentary D on NBC Part 4<br>– NCMA, TEK-10 Series |
| | Salt crystallization | Efflorescence, subflorescence, spalling | Soluble salts in the block units and mortar; soluble salts in groundwater or other adjacent sources absorbed by the masonry | Use low-alkali cement; protect masonry from precipitation and from ingress of water from the top and from groundwater at the base and from behind; detail to promote drainage and drying<br>Use dampproofing and waterproofing to prevent entrance of groundwater | NCMA, TEK 08-03A |
| **Concrete** (for references, see Clauses H.4.5 and H.4.8)<br>See also entries for steel and stainless steel. | | | | | |
| • porous to varying degrees<br>• cracks due to shrinkage<br>• inorganic | Freeze-thaw | Spalling, disintegration, cracking | Saturation or near-saturation of material and concurrent freeze-thaw cycles, aggravated by chlorides and poor drainage | Air entrainment; air void spacing factor; exposure class; choice of aggregates; protection from precipitation; details promoting drainage and drying; | – CBD 116<br>– CSA A23.1<br>– ACI 201.2, 302.1 |

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## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | | | | proper finishing procedures on flatwork | |
| | Sulphate attack | Expansion, followed by disintegration | Sulphates in groundwater, bricks, coal stockpiles, or sea water; type of aggregate and cement used in concrete | Type of cement, mix design, drainage | – CSA A23.1<br>– CBD 136<br>– ACI 201.2 |
| | Alkali-aggregate reaction — alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR) | Expansion, followed by disintegration | Silica or dolomite aggregates, with moisture | Type of aggregates or cement additives; control of moisture; type of cement (lower alkali content); use of supplementary cementing materials | – CSA A23.1<br>– ACI 201.2, 221.1 |
| | Acid attack | Strength, disintegration | Acids in industrial buildings — amount in contact; permeability | Protective coatings | FIB, CEB Bulletin 182 |
| | Moisture ingress | Efflorescence; mortar disintegration; formation of calcium carbonate | Vapour transfer; permeability | Mix design; protection from precipitation; details promoting drainage and drying; type of cement | CAN/CSA-A179 |
| | Biological attack | Strength, disintegration | Contact with sewage (generation of acids) | Protective coatings; cleaning | FIB, CEB Bulletin 182 |
| | Drying shrinkage | Cracking, damage to adjacent building elements | High water/cement (w/c) ratio, paste content; type and gradation of aggregate; restraint; relative humidity; drying time; member size and shape | Mix design; construction sequence; proper control joints and joint layout; amount and distribution of reinforcement; curing and moisture control prior to use; use of larger coarse aggregate; | – CSA A23.1, A165 Series, CAN/CSA-A371<br>– ACI 224 |

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## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | | | | optimized aggregate gradation; moderate w/c ratio; use of shrinkage-reducing admixtures (SRAs) | |
| | Autogenous shrinkage | Cracking in early age high-strength or high-performance concrete | Low w/c ratio (under 0.42); types of supplementary cementing materials used | Immediate water curing; reduced paste content; increase in maximum aggregate size | ACI 231 |
| | Creep | Deformation, damage to adjacent building elements | Long-term exposure to high loads resulting in high levels of stress below the yield strength of the material; long-term exposure to high temperatures | Design (greater thickness, pre-stressing); movement joints | ACI 209 |
| | Temperature movements | Cracking, bowing | Temperature changes; restraint of free movement | Reinforcement; control/ movement joints | – CSA A23.1, S304.1<br>– NRC, Commentary D on NBC Part 4 |
| | Thermal stress cracking | Early cracking within the building element | Mass concrete elements that can create large temperature differentials; mix design (high cement content); initial placing temperature; lack of thermal protection; restraint | Mix design (high-volume replacement of cement with supplementary cementing materials); type of cement; thermal protection to reduce temperature gradient within the element; reduced initial placing temperature; reinforcement | – CSA A23.1<br>– ACI 207.2 |
| | Abrasion | Surface disintegration | Heavy traffic; wind-driven particles; | Protective toppings; choice of aggregate, | – Annex F of CSA A23.1, CSA S413 |

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## Table D.1 (Continued)

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | | | compressive strength of concrete surface | additives; low to relatively low w/c ratio; proper curing | – ACI 201.2 |
| | Delayed ettringite formation (DEF) | Visible displacement and cracking | Internal concrete temperature greater than the limits given in CSA A23.1; exposure to cyclic wetting and drying in service | Type of cement used in the mix; use of supplementary cementing materials; reduced initial placing temperature | – CSA A23.1<br>– ACI 201.2 |
| **Metals** (for references, see Clause H.4.2) | | | | | |
| Metals (all) | Galvanic corrosion | Many | Electrolyte (moisture-filled porous material); dissimilar metals electrically connected | Choice of materials; electrical disconnection of adjoining metals | – Ahmad (2006)<br>– Landolfo, Cascini, and Portioli (2010) |
| | Differential thermal movements | Cladding damage | Metals of different coefficients of thermal expansion connected to produce constraint stresses | Design to accommodate movement; choice of metals | NRC, Commentary D on NBC Part 4 |
| Steel<br>• non-porous<br>• inorganic | Corrosion: atmospheric environment | Connector failures; appearance; damage due to rust expansion | Sustained moisture; oxygen, aggravated by acids and hygroscopic impurities | Drainage (avoid water traps); ventilation; protective coatings | – BS 5493<br>– DIN EN ISO 12944-1<br>– CBD 170 |
| | Corrosion: marine environment | Corrosion of piles in splash zone | Sustained moisture; oxygen, aggravated by chlorides | Corrosion protection of steel through the use of cold applied tapes, liquid polymer–based coatings, fibre-reinforced plastic (FRP) wraps | BS 5493 |
| | Corrosion: soil environment | Pile and pipe failures | Sustained moisture; oxygen or anaerobic | Type of soil (test for resistivity, bacteria, etc.); | ANSI/AWWA C105/A21.5 |

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**Table D.1 (Continued)**

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | | | bacteria, aggravated by soluble salts; stray electric currents | protective coating; cathodic protection | |
| | Corrosion: concrete environment | Failure of reinforcement or delamination of concrete | Sustained moisture; oxygen; chlorides; pH reduced by carbonation | Protective barriers; concrete mix; drainage details; proper exposure class; addition of calcium nitrite admixture (corrosion inhibitor); concrete cover | – CSA A23.1, S413<br>– CBD 224, 225<br>– ACI 201.2 |
| | Corrosion: masonry environment | Failure of connectors (main body, buckling); cracking/spalling of masonry due to expansion of corrosion by-products; staining | Sustained moisture; oxygen; preservative types | Zinc coating thickness; stainless steel | – CAN/CSA-A370, CAN/CSA-A371<br>– Ailor (1982)<br>– CIB 127 |
| | Corrosion: timber environment | Failure of connectors and surrounding wood | Sustained moisture; oxygen | Drainage (avoid water traps); ventilation; protective coatings | – FPL, *Wood Handbook*<br>– BRE 301 |
| | Fatigue | Structural failure | Cyclic loads | Welding details; structural design | – CSA S6.1<br>– CIB 128 |
| Weathering steel | Corrosion: atmospheric environment (red rust) | Connector failures, damage due to rust expansion | Retention of water between surfaces; sea water | Detailing to avoid accumulation of water between surfaces | ASTM G101 |
| Stainless steel | Pitting or crevice corrosion, intergranular corrosion, stress corrosion cracking | Connector failures | Type of stainless steel, aggravated by warm chlorinated atmospheres, high stress | Type of stainless steel SS304<br>SS316 | ASTM A240, A666 |

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**Table D.1 (Continued)**

| Material | Mechanism | Failure | Conditions for process | Mitigation | References*† |
|---|---|---|---|---|---|
| | (orange pitted appearance) | | | | |
| Hot-dipped zinc galvanized steel | Corrosion: atmospheric environment (white powdery appearance) | Failure of connectors, structural members; downgrading of appearance | Sustained moisture; oxygen; chlorides; pH reduced by $SO_2$ | Stainless steel | ASTM A123/A123M, A153/A153M, A385/A385M |
| | Corrosion: concrete environment | Failure of reinforcement or delamination of concrete | Sustained moisture; oxygen; chlorides; pH reduced by carbonation | Stainless steel | ASTM A767/A767M |
| | Corrosion: masonry environment | Failure of connectors; cracking of masonry | Sustained moisture; oxygen; chlorides; pH reduced by carbonation and $SO_2$ | Stainless steel | ASTM A123/A123M, A153/A153M |
| | Corrosion: timber environment | Failure of connectors and surrounding wood | Sustained moisture; oxygen | Stainless steel | ASTM A123/A123M, A153/A153M |
| Aluminum alloys | Corrosion (dark pitted appearance) | Downgrading of appearance; connector failures | Type of alloy, surface finish; contact with alkaline solution, copper, or copper-containing solution; contact with some other metals | Drainage (avoid contact with alkaline solutions or drainage from large, dissimilar metal surface area); anodization; protective coatings | – BRANZ 213<br>– ASTM B234, B580 |
| Copper and alloys | Dezincification of brass (green to dark pitted appearance) | Failure of fasteners by loss of strength or cracking; downgrading of appearance; connector failures | Type of brass | Material selection (brass with less than 20% zinc) | ASTM B36/B36M, B152/B152M |

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