**Developing a novel hybrid GWO-LGB model for improving concrete creep compliance prediction**

**(Widely used existing creep models)**

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***S.1. ACI 209 creep model [1]***

The compliance, , that represents the total stress-dependent strain by unit stress is

|  |  |
| --- | --- |
|  | (1) |

where is the age of concrete, in days; is the age of concrete at the time of loading, in days; is the elastic modulus of concrete at the time of loading, in MPa; is the creep coefficient as the ratio of the creep strain to the elastic strain at the start of loading, at concrete age due to a load applied at the age .

|  |  |
| --- | --- |
| (MPa) | (2) |
|  | (3) |

where is the unit weight of concrete, in kg/m3; is the mean concrete compressive strength at the time of loading, in MPa; is the mean concrete compressive strength at the time , in MPa; is the mean concrete compressive strength at 28 days, in MPa; and are constants, which are functions of the type of concrete and the method of curing, as Table S1.

|  |  |
| --- | --- |
|  | (4) |

where is constant, in days; is constant; is the ultimate creep coefficient.

To totally consider the shape and size effect

|  |  |
| --- | --- |
|  | (5) |
|  | (6) |

where is the volume to surface area ratio, in mm.

For standard conditions, in the absence of specific creep data for local aggregates and conditions, it is proposed that . Otherwise,

|  |  |
| --- | --- |
|  | (7) |
|  | (8) |

Where is the age of loading coefficient; is the ambient relativity humidity coefficient; is the size coefficient; is the slump coefficient; is the fine aggregate coefficient; is the air content coefficient.

|  |  |
| --- | --- |
|  | (9) |
|  | (10) |

where is the relative humidity in decimals

|  |  |
| --- | --- |
|  | (11) |
|  | (12) |

where is the slump of the fresh concrete, in mm.

|  |  |
| --- | --- |
|  | (13) |

where is the ratio of fine aggregate to the total aggregate by weight, in percent.

|  |  |
| --- | --- |
|  | (14) |

where is the air content, in percent.

**Table S1** Type of concrete and the method of curing

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type of cement** | **Moist cured concrete** | | **Steam cured concrete** | |
| **a** | **b** | **a** | **b** |
| I, II\* | 4.00 | 0.85 | 1.00 | 0.95 |
| III | 2.30 | 0.92 | 0.70 | 0.98 |

***S.2. GL 200 model [2]***

The creep compliance function, , is expressed as

|  |  |
| --- | --- |
|  | (15) |
|  | (16) |
|  | (17) |
|  | (18) |
|  | (19) |
|  | (20) |

where is the strength development parameter, see Table S2.

**Table S2** Strength development parameter

|  |  |  |
| --- | --- | --- |
| **Type of cement** |  |  |
| I | 0.335 | 1.0 |
| II | 0.4 | 0.75 |
| III | 0.13 | 1.15 |

***S.3. fib 2010 model [3]***

The creep compliance function, , can be calculated as

|  |  |
| --- | --- |
|  | (21) |

where is the 28 day concrete modulus of elasticity and is the concrete modulus at loading time.

|  |  |
| --- | --- |
|  | (22) |
|  | (23) |

The variable is a constant dependent on the cement type and concrete strength, see Table S3.

The 28-day creep coefficient is a summation of the basic and drying creep coefficient.

|  |  |
| --- | --- |
|  | (24) |
|  | (25) |
|  | (26) |

The variable is effective thickness and is the adjusted age of loading.

|  |  |
| --- | --- |
|  | (27) |
|  | (28) |

The parameters and are given by

|  |  |
| --- | --- |
|  | (29) |
|  | (30) |

The values are all dependent on cement type or size.

To take into account the effects of a constant temperature different from 20oC while loaded

|  |  |
| --- | --- |
|  | (31) |
|  | (32) |
|  | (33) |
|  | (34) |
|  | (35) |
|  | (36) |
|  | (37) |

**Table S3**

|  |  |
| --- | --- |
| **Cement type** |  |
| I | 0.25 |
| II | 0.38 |
| III | 0.20 |

**References**

[1] ACI 209R-92, Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures, American Concrete Institute, Farmington Hills, MI, 1992.

[2] N.J. Gardner, M.J. Lockman, Design Provisions for Drying Shrinkage and Creep of Normal-Strength Concrete, ACI Mater. J. 98 (2001). https://doi.org/10.14359/10199.

[3] FIB, fib Model Code for Concrete Structures 2010, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, 2013. https://doi.org/10.1002/9783433604090.