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UNCERTAINTY QUANTIFICATION AND SENSITIVITY ANALYSIS ON CYCLIC CREEP PREDICTION OF CONCRETE

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Abstract. *This paper presents a methodology for uncertainty quantification in cyclic creep analysis. Several models- , namely BP model, Whaley and Neville model, modified MC90 for cyclic loading and modified Hyperbolic function for cyclic loading are used for uncertainty quantification. Three types of uncertainty are included in Uncertainty Quantification (UQ): (i) natural variability in loading and materials properties; (ii) data uncertainty due to measurement errors; and (iii) modelling uncertainty and errors during cyclic creep analysis. Due to the consideration of all type of uncertainties, a measure for the total variation of the model response is achieved. The study finds that the BP, modified Hyperbolic and modified MC90 are best performing models for cyclic creep prediction in that order. Further, global Sensitivity Analysis (SA) considering the uncorrelated and correlated parameters is used to quantify the contribution of each source of uncertainty to the overall prediction uncertainty and to identifying the important parameters. The error in determining the input quantities and model itself can produce significant changes in creep prediction values. The variability influence of input random quantities on the cyclic creep was studied by means of the stochastic uncertainty and sensitivity analysis namely the Gartner et al. method and Saltelli et al. method. All input imperfections were considered to be random quantities. The Latin Hypercube Sampling (LHS) numerical simulation method (Monte Carlo type method) was used. It has been found by the stochastic sensitivity analysis that the cyclic creep deformation variability is most sensitive to the Elastic modulus of concrete, compressive strength, mean stress, cyclic stress amplitude, number of cycle, in that order.*

1 INTRODUCTION

Creep of concrete under a sustained static load is a well-known phenomenon. Much research has been carried out in this context [1-2]. Under actual operating condition many structures are subjected to dynamic loading in addition to static loading. The effect of traffic loads on bridge and pavement, vibrating machinery on floor system, wave load on offshore structures and wind load on slender buildings are familiar examples. Such structures under repeated loads must be designed to control deformation due to static and dynamic creep. Numerous researches on the cyclic creep in concrete found the increase in creep under cyclic loading as cyclic creep and it is important to realize that cyclic creep is measured relative to creep under sustained load equal to the mean cyclic stress and not the creep under a sustained load equal to the upper cyclic stress [2]. Actually, time-dependent nonlinearity also grows during cyclic loading especially under higher strains. Cyclic creep is a nonlinear phenomenon.

Many studies have examined the stress-strain behaviour of drying and confined concrete under cyclic compression and tension and numerous concrete models have been proposed in the last years but very few studies addressed the long term time-dependent behaviour of concrete under cyclic load. Since probably the first works attempting to characterize the behaviour of concrete under a rapidly fluctuating (1 Hz) stress of given duration were published [3-4] a significant research effort has been devoted to that field and found the irreversible deformation to increase with the number of cycles. The decrease of the non-elastic deformation with an increase in the age at application of cyclic load, this behaviour is similar to that under static loading. Many others mathematical and experimental models have been documents in the literatures like [5-12].

The investigation of uncertainties for time-dependent behaviour of plain concrete under sustained loading much research has been carried out but under cyclic loading very less work has been done. The study on the uncertainties in creep and shrinkage effects has been continuously an area of significant efforts. The external or parameters uncertainty and internal (model uncertainty, measurement uncertainty and uncertainty of the creep phenomenon) uncertainty has given to the references [13-20].Uncertainty Quntification (UQ) of creep models under sustained loading by using the Latin Hypercube Sampling were proposed [21]. However, most of the existing UQ and Sensitivity Analysis (SA) techniques assume input variables independence, and a few studies have focused on the UQ and SA of the correlated input variables and degradation materials behaviour under cyclic loading, which is usually the common case in concrete structures.

Different UQ and SA techniques will perform better for specific type of models. One method of UQ and SA of models by considering the uncorrelated and correlated parameters is proposed by [22 and 28]. The distinction between uncorrelated and correlated contribution of uncertainty for an individual variable is very important and output response and input variables is approximately linear in this method. One of the most important and basic concepts is that results of any scientific experiment always has a degree of uncertainty which is known as experimental uncertainty. The problem of quantifying the contribution of systematic error and measurement uncertainty considered for the calculation of the uncertainty. In fact, since its first edition [24] of the Guide to the Expression of the Uncertainty in Measurement (GUM), and still in the last one [25], the GUM attempts to completely set aside the concepts of the true value and measurement error, whose connection with that of measurement uncertainty is considered (Clause E.5.1). GUM uncertainties are standard deviation of probability distribution and as a degree of belief, quantified by means of a subjective probability distribution (Clause 3.3.5). The GUM Supplement 1 [26] is based on one general concept of propagating probability density function (PDF) where in order to obtain PDF for the measured of the Monte Carlo method (MCM) use was suggested. Consequently, the law of propagation of uncertainties is based on a construction of a linear approximation of the model function [27]. The GUM uncertainty framework- GUF [26] and MCM are approximate methods where the first methods are exact and second one is never exact. Apart from that MCM is more valid than the GUF for large class of problems [26].

In this work, a statistical framework is discussed for cyclic creep function. As a first step, four cyclic creep models in plain concrete are discussed briefly: BP model [6-7], modified MC90/EC2 [8-9], Whaley and Neville model [5] and modified Hyperbolic function [10-12]. Subsequently, the influences of input parameters are discussed in 2 steps. The Monte Carlo simulation with Latin Hypercube Sampling (LHS) technique is used for determining the UQ and SA, measurement, phenomenon , model uncettainties, which explained in step 3. In step 4 explain the overview of UQ and SA [22-26] and measurement UQ according to GUM methods. Further, using the stochastic UQ and SA, it is determined the uncertainty level of different models and analysed the quality of model and to what degree does the randomness of an input quantity influence the variability of the output. The present paper has considered the amount of degradation with respect of both strength and stiffness of the concrete.

2 CYCLIC CREEP MODELS

Several experimental and mathematical models have been developed for estimating cyclic creep strain. The most widely used mathematical models are the BP models, Whaley and Neville model. Modified MC90/EC2 and modified Hyperbolic function, experimental cyclic creep models: Gaede 1962, Kern et al. 1962, Neville et al. 1973, Sutter et al. 1975, Hirst et al. 1977. This study also includes these four mathematical models.

Based on the test data Whaley and Neville model [5] has shown that the cyclic creep strain can be expressed as the sum of the two strain component, a mean strain component and a cyclic strain component. We consider uniaxial stress decribe as:

$$\sigma = \sigma_0 + \frac{1}{2}\Delta sin(2\Pi\omega t) \tag{1}$$

where, σ_0 = mean stress, $\frac{1}{2}\Delta$ = cyclic stress amplitude, and ω = circular frequency.
The mean strain component is the creep strain produced by the static mean stress $(\sigma_m) = \left[\frac{\sigma_{max}-\sigma_{min}}{2}\right]$. The additional cyclic creep component was found to dependent on both mean stress (σ_m) and the stress range $(\Delta) = [\sigma_{max} - \sigma_{min}]$. They proposed the following predictive equation for the total cyclic creep strain:

$$\epsilon(t - t_0) = 129\sigma_m(1 + 3.87\Delta)t^{\frac{1}{3}} * 10^{-6} \tag{2}$$

$$\Phi(t - t_0) = \frac{1}{\sigma}\left[\epsilon_{el}(t_0) + \epsilon(t - t_0)\right] = \frac{1}{E_c(t_0)} + \frac{\epsilon(t - t_0)}{\sigma} \tag{3}$$

where, $\epsilon(t - t_0)$ is the cyclic creep strain, σ_m is the mean stress expressed as a fraction of the compressive strength, Δ is the stress-range expressed as a fracton of the compressive strength, and $\Phi(t - t_0)$ is the creep functuion.

The above the static and dynamic components of dynamic creep as a function of time. It can be expressed as a function of number of cycles also:

$$\epsilon(t - t_0) = 129\sigma_m t^{\frac{1}{3}} + 17.8\sigma_m \Delta N^{\frac{1}{3}} \tag{4}$$

The above equation is fit for $\sigma_m < 0.45$ and $\Delta < 0.3$. The cyclic creep specimens 76 mm x 76 mm x 203 mm cast vertically, fog-cured for 14 days at 20±1°C. During enclosed in polyethylene bags containing some water nut water was not in direct contact with the specimens. The cyclic load varied sinusoidally at 9.75 (Hz) cycles per second.

BP model [6] takes into consideration both shrinkage strain and mechanical strain. According to the BP model, cyclic creep function $\Phi(t - t_0) = \frac{\epsilon}{\sigma_{mean}}$, where ϵ is the strain mean level of cycle, is as follows:

$$\phi(t - t_0) = \left[\frac{1}{E} + C_{oc}(t - t_0) + C_d(t - t_0 - t_d)g\sigma - C_p(t - t_0 - t_d)\right] f\sigma \tag{5}$$

where,

$$C_{oc}(t - t_0) = \frac{\varphi_1}{E_0}(t_0^{-m} + \alpha)(1 + k_w \varphi_\sigma \sigma_{pp}^2 \omega^n (t - t_0)^n \tag{6}$$

and this equation modified:

$$\Phi(t, t_0, \sigma) = q_1 + F(\sigma)\left[C_{oc}(t, t') + C_d(t_{dc}, t' t_0) + C_p(t_{dc}, t', t_0)\right] \tag{7}$$

In which t_{dc} can be calculated as:

$$t_{dc} = t' + (t - t')\left[1 + 10\omega^{\frac{1}{4}}\Delta^2 F^3 \sigma_{max}\right] \tag{8}$$

Here ω is the frequency (Hz), k_ω is the empirical constant and the the function $F(\sigma_{max})$ is the nonlinearity over proportionality factors.

The long-time material model presented in the 1990 CEB Model Code (MC90) [8] was chosen as the model. Static creep tests within the previously mentioned and the modified by [9] cyclic creep function is defined as:

$$\Phi(t - t_0) = \frac{1}{E_c(t_0)} + \frac{\varphi_c(t - t_0)}{E_c(28d)} + \frac{\varphi_{cc}(t - t_0)}{E_c(28d)} \tag{9}$$

In these expression $\varphi_c(t - t_0)$ is the static creep ratio and φ_{cc} is the cyclic creep ratio, t' the concrete age at loading and t the actual time. The cyclic creep ratio is defined as:

$$\varphi_{cc}(t - t_0) = \beta(t_0)\beta(f_{cm})\beta(S_m)\beta(\Delta)\varphi_{cc}\beta(N, \omega) \tag{10}$$

In this expression f_{cm} is the average compressive cylinder strength at 28 days, S_m the ratio between the mean stress and the concrete strength at the start of testing, Δ the relative stress amplitude, N is the number of load cycles and ω is the frequency $N = (t - t_0)\omega$:

$$\beta(N, \omega) = N^n - 1 = ((t - t_0)86400\omega)^n - 1, with, n = 0.022 \tag{11}$$

The general expression for cyclic creep term is then written as:

$$\varphi_{cc}(t - t_0) = 1.39\beta(t_0)\beta(f_{cm}(1 + 10.5(S_m - 0.4)^2))\Delta(N^n - 1) \tag{12}$$

This expression is basically derived for high strength concrete and it is applicable also plain concrete with different constants parameters.

The hyperbolic function form German code 1045-1 or DAfStb booklet 525 [DIN5] modified by [10] and give the final equation as:

$$\varphi(t-t_0) = \left(\frac{t-t_0}{a+(t-t_0)}\right)^b \varphi_\infty(t_0) = \left(\frac{t-t_0}{a+(t-t_0)}\right)^b * c * \frac{1}{d+t_0^e} \tag{13}$$

$$c = \varphi_{RH} * \beta(f_{cm}) = \left(1 + \frac{1-\frac{RH}{100}}{0.10 * h_0^{\frac{1}{3}}} * \left(\frac{35}{f_{cm}}\right)^{0.7}\right) * \left(\frac{35}{f_{cm}}\right)^{0.2} * \left(\frac{16.8}{(f_{cm})^{\frac{1}{2}}}\right) \tag{14}$$

The constant a, b, d, and e are determined from cyclic creep experimental data. For concrete compressive strength 52.00 MPa, the value of a, b, d and 318.22, 0.30, 0.10 and 0.20 found, respectively.

3 SOURCES OF UNCERTAINTY

This section describe to include the different sources of uncertainty in the cyclic creep prediction. These sources of uncertainty can be classified into three different types-physical or natural uncertainty, data uncertainty and model uncertainty as shown in Fig.1.

Fig.1 shows the different sources of error and uncertainty considered in this paper for the sake of illustration of the proposed methodology. There are several otheres sources of uncertaint that are not considered here. Each of these different sources of uncertainty is briefly discussed below.

3.1 Physical or Natural Uncertainty

Physical or natural uncertainty refers to the uncertainty or fluctuations in the environment, test procedures, instruments, observer, etc. Hence, repeated obervations of the same physical quantity do not yield identical results. This paper considers the physical uncertainty in loading, environment and materials properties. The uncertainty in the systematic errors to the measuement, human error, the variability in others materials properties such as Poisson ratio, supplementary cementaing materials, the curing time period, temperatures, etc. is not considered.

3.2 Data Uncertainty

Experimental data are available in literature to characterize the distribution of materials properties such as young modulus of elascity, compressive strength of concrete, etc. These data may be sparse and cause uncertainty regarding the probability distribution type and parameters, these errors are not considered in this paper and the quantification of these errors is trivial; these errors will be considered in future work. The measurement uncertainty calculated from the GUM [23-25] and Monte Carlo method. Bayesian model screening is implemented using Monte Carlo methode, which is described in literature [25]. The study found that the experimental error between 0.08 - 0.13 is reasonables for diffeent test.

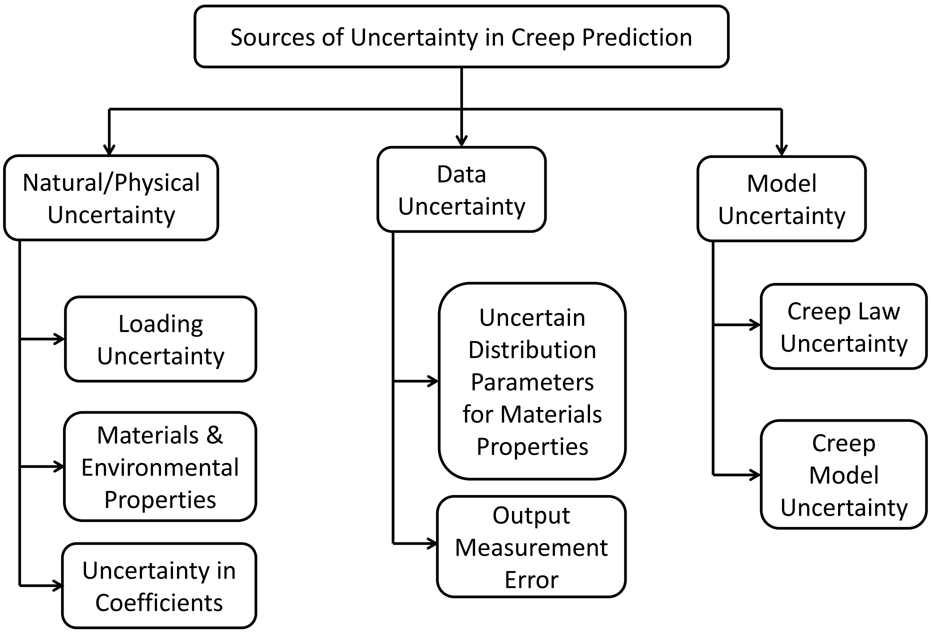

Figure 1: Sources of Uncertainty in Creep Prediction

3.3 Model Uncertainty

More than 10 different creep prediction laws have been proposed in the literatures. Each of these models has its own limitation and uncertainty. The uncertainty in cyclic creep prediction can be subdivided into two different type: creep model error and uncertainty in model coefficients. This error is assumed to represent the difference between the model prediction and the experimental obervations. The variation from the experiments are determined by [28-29] for the comparison with measurements data. The statistical analysis of cyclic creep data no body done and there is no data existing data bank for cyclic loading. The all pervious comparison based on RILEM data bank for sustained loading. The effect of cyclic loading to calculate variation in experiments are neglected so far might be non-negligible for big structures, such as bridge with many lanes or with dense traffic of heavy trucks. Assuming the $CV_{\psi,\alpha} \approx 0.08$ and $CV_{\psi,\beta} \approx 0.05$. The coefficient of variation of the creep phenomenon α and the measurements β determined the coefficient of variation of the model uncertainties. The model uncertainty factor is normally distributed with an expected value of $E(\psi_{cr,cyc}) = 1$. Discretization error is not considered in this paper; this error will be considered in future work. There appears to be an influence of frequency of loading on cyclic creep, creep generally decreasing with an increase in frequency so that under very rapid cycles the behaviour of concrete becomes more elastic. Furthermore, uniform cycling causes less creep than an irregular pattern within the same range of stresses. Table 1 list the comparision of the total coefficient of variation of four models based on using statistic input variables. In all these comparision, model BP is found to be the best model. The MCM calculation method of measurement uncertainty is discussed in Section 4.1.

Table 1: Model uncertainty

Model	BP	mod.MC90	mod. Hyperbolic	Neville
$CV_{\psi,cr,cyc}$	0.283	0.306	0.300	0.380

4 UNCERTAINTY QUANTIFICATION IN MODEL PARAMETERS

4.1 Bayes Method

This section explain the Bayesian technique used to uncertainty anylsis for measurement: MCM using the experimental data. A fundamental parameter in order to obtain reliable results through MCM is the number M of trails or evaluation be performed by the model. M value 10^6 is often considered approprite in order to provide a coverage interval of 95 percentage ; however, the random nature of the process and the nature of the probability distribution of the output quantity Y have an influence on the value needed for M, which will very in each case. Each value of standard uncertainty y_r $(r = 1, ..., M)$ is obtained by performing a random sampling of each of the probability density functions of the input quantities X_i and evaluating the model with the values found. The M values of Y thus obtained must be arranged in a non-decreasing order. The output quantity and the associated standard uncertainty can be calculated as follows:

The average:

$$\bar{y} = \frac{1}{M}\sum_{r=1}^{M} y_r \tag{15}$$

and the standarddeviation is taken as the standard uncertainty $u(y)$ associated with y:

$$u^2(\bar{y}) = \frac{1}{M-1}\sum_{r=1}^{M}(y_r - \bar{y})^2 \tag{16}$$

4.2 Global sensitivity analysis

The objective of SA is to identify critical inputs variables of a model and quantifying how input uncertainty impacts model outcomes. The sensitivities are solved at nominal values, cannot take account of the variation effect of the input variables, and thus those sensitivities are local. Compared with the local sensitivity, the uncertainty importance measure is defined as the uncertainty in the output cab be apportioned to different sources of uncertainty in the model input, and the importance measures is also called global sensitivity. [22-23] Methods are used in this paper and method is approximately linear output response and input variables. For a model $y = (x_1, x_2, x_3, ...x_i...x_k)$ and the main effect of each variables, the model can be simplified as follows:

$$y = \beta_0 + \sum_{i}^{K} \beta_i x_i + e, \tag{17}$$

Where $\beta_0...\beta_k$ are regression coefficients and e is the error. The partial variance (V_i) and total variance (V) can be estimate for uncorrelated variables as follows. The sensitivity indices can be calculated as follows:

$$S_i = \frac{V_i}{\hat{V}} \tag{18}$$

$$S_i^U = \frac{V_i^U}{\hat{V}} \tag{19}$$

$$S_i^C = \frac{V_i^C}{\hat{V}} \tag{20}$$

where, V_i, V_i^U, V_i^c are the partial variancs, uncorrelated variance and correlated variance, respectively.

5 UQ AND SA OF CYCLIC CREEP FUNCTION

5.1 Input Parameter and Parameters Correlation

The cyclic creep models uncertainty factors compressive strength of concrete (f_c), young modulus of elasticity (E_c), relative humidity (RH), water-cement ratio (w/a), sand-aggregate ratio (a/c), geometry factor (ks), cement content (c), frequency of loading (ω), mean stress (σ_m), stress amplitude (Δ), number of cycle (N) are assumed to be random quantities. All statistic properties of concrete given in Table 2. For the determination of dynamic modulus of concrete, E_d, dynamic compressive shear strength of concrete, f_d, are contradictory part for the analysis of the cyclic creep function because these quantities are depend on the strain rate, and number of cycle. Numerous empirical relationships are available in the literatures. However, "Lifetime-Oriented Structural Design Concepts" and "Deterioration of Materials and Structures" [31] published the overview of degradation of concrete under cyclic loading and are used in this paper. The deformation of concrete at any instant are defined as follow:

$$Totalstrain = elasticstrain + creep + shrinkage \tag{21}$$

If the elastic strain under a constant stress is assumed to diminish with time, then merely assume that creep is increased by a corresponding amount to insure that the total strain is correct. Under cyclic loading, is the precise interpretation of elastic strain very important, because change in elastic strain due to change in elastic modulus are generally small compared with the sum of others quantities. The correlation of $\rho = 0.4$ and $\rho = 0.8$ further additional small range of correlation $\rho = 0.1$ are determined, but neglected in the stochastic analysis due to insignificance. These models are not intended (e.g. temperature effect on creep).

Table 2: Statistic properties of the input variables for mathematical cyclic creep model

Variables	Mean	Std.	CoV	Distribution	Models	Sources
$f_{c,28}$	52.00 MPa	3.12	0.06	Log-normal	1,2,3,4	34
f_d	50.70 MPa	3.00	0.06	Log-normal	1,2,3,4	30
$E_{ci,28}$	34144 MPa	3414.4	0.10	Log-normal	1,2,3,4	30
$E_{cm,28}$	29394 MPa	2994.0	0.10	Log-normal	1,2,3,4	34
E_d	33290 MPa	3329.0	0.10	Log-normal	1,2,3,4	30
Humidity (RH)	0.65 [-]	0.026	0.04	Normal	1,2,3	32
Cement content	362 kg/m^3	36.20	0.10	Normal	1,3	33
Water-cement ratio	0.50 [-]	0.10		Normal	1	33
Sand-cement ratio	5.16 [-]	0.516	0.10	Normal	1	33
Fine-aggregate ratio	0.50 [-]	0.05	0.10	Normal	1	33
Geometry factor, ks	1.15 [-]	0.057	0.05	Normal	1,2,3	33
Frequency	9.0 Hz	0.72	0.08	Normal	1,2,3,4	Assumed
Mean stress	$0.40f_c$	0.016	0.04	Normal	1,2,3,4	Assumed
Stress amplitude	$0.20f_c$	0.008	0.04 6	Normal	1,2,3,4	Assumed
Number of cycles	10^6	40000	0.04	Normal	1,2,3,4	Assumed
a	318.22	31.82	0.10	Normal	3	Assumed
b	0.30	0.03	0.10	Normal	3	Assumed
d	0.10	0.010	0.10	Normal	3	Assumed
e	0.20	0.02	0.10	Normal	3	Assumed

1 = BP, 2 = modified MC90/CE 2 , 3 = modified Hyperbolic , 4 = Neville

The input variables correlation of the model Neville, modified MC90/CE2, modified Hyperbolic function and BP are shown in Tables 3-6.

Table 3: Correlation matrix Neville

Variables	f_c	E_c	σ_m	Δ
f_c	1	0.8	0	0
E_c		1	0	0
σ_m			1	0
Δ		Symm.		1

Table 4: Correlation matrix mod. MC90/EC

Variables	RH	ks	f_c	E_c	σ_m	Δ	N
RH	1	0	0	0	0	0	0
ks		1	0	0	0	0	0
f_c			1	0.8	0	0	0
E_c				1	0	0	0
σ_m					1	0	0
Δ						1	0
N			Symm.				1

Table 5: Correlation matrix mod. Hyperbolic model

Variables	RH	ks	f_c	E_c	a	b	d	e
RH	1	0	0	0	0	0	0	0
ks		1	0	0	0	0	0	0
f_c			1	0.8	0	0	0	0
E_c				1	0	0	0	0
a					1	0	0	0
b						1	0	0
d							1	0
b			Symm.					1

Table 6: Correlation matrix BP

Variables	RH	c	w/c	a/c	ks	f_c	ω	Δ
RH	1	0	0	0	0	0	0	0
c		1	-0.4	-0.4	0	0.4	0	0
w/c			1	0	0	-0.4	0	0
a/c				1	0	-0.4	0	0
ks					1	0	0	0
f_c						1	0	0
ω							1	0
Δ			Symm.					1

5.2 Uncertainty of cyclic creep strain

The mean value of the predicted cyclic function of the four models for short time is presented in Fig 2. Because the initial elastic strains were not reported, because, due to pronounced short-time creep duration, they had to be assumed, and so the compressions are relevant only to the part of strain representing the creep increase due to the part of strain cycling. Significant errors have often been caused by combining the creep coefficient with an incompatible value of the conventional elastic modulus. Thus analysis must properly be based on the cyclic creep function. In Fig. 2 the data of all four models shows quit different values in the first hour of testing and at 100 hours the difference showed small despite the use of a similar concrete and testing condition. This may be fluctuation in time to the physical mechanism of creep. The modified MC90/EC2, Neville and modified hyperbolic model are based only on the set of data and may not be applicable for conditions substantially different than these during the experiments.

Fig. 3 and 4 shows that the result of the uncertainty analysis of four different models. The both Fig. showed that the correlated and uncorrelated contribution of input variables have important contribution to the uncertainty in model output. The uncorrelated input variables uncertainty of Neville model is very small, only the contribution of four variable. On the other hand the input variables are notable effect on the output because there in more variables and complex model and model uncertainty is small. The correlated and uncorrelated input variables for model Neville shows largest uncertainty $CV_{par,crcyc}(t-t_0) = 0.08$ at t = 1 h and uncertainty $CV_{par,crcyc}(t-t_0) = 0.06$ at t = 100 h, the uncertainty goes to decreasing with the increasing the time under load. The uncorrelated input quantities uncertainty of

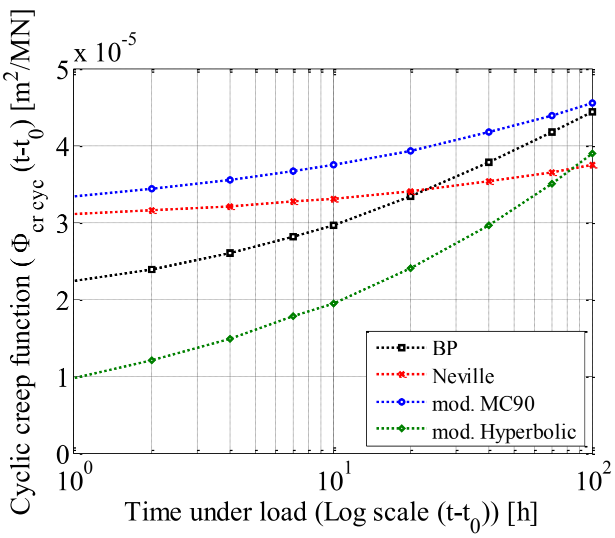

Figure 2: Mean value of creep function

model mod. MC90 and mod. Hyperbolic $CVpar, crcyc(t-t_0) = 0.10$ and almost independent with time. Model BP has strongly time-dependent uncertainty varying in the range of $CV_{par,crcyc}(t-t_0) = 0.11 \cdots 0.08$. Taking into the input variables real correlation of model Neville the input variables increase significantly $CV_{par,crcyc}(t-t_0) = 0.08$ may cause this effect strong correlation of strength and young modulus of elasticity. Comparing the total uncertainty of the models from Fig. 4, we conclude that the model and measurement paly the important role on the uncertainty behaviour of models. In comparison of all models, BP has the lowest total uncertainty $CV_{par,crcyc}(t-t_0) = 0.30$ and model Neville has highest total uncertainty $CV_{tot,crcyc}(t-t_0) = 0.40$. The models mod. MC90, mod. Hyperbolic and Neville are based on the experimental data and also, assumed strain-time equation do to always satisfactory fit the experimental data, so that long-term values cannot be estimate with confidence. Generally, the time over which creep have actually been measured the better the prediction. The CV in the initial time of loading shows higher and decreasing with increasing the time. Because the initial time more uncertainty in measurement. The most important variable at short-time creep is model uncertainty factor for all models.

Total model quality (MQ) can be used to balance the better response of the model to its uncertainty in order to select the model that is most for a certain response. Fig. 5 show the time-dependent model quality. MQ dependent total uncertainty considering the correlated input quantities. The MQ is slight time dependent. For this reason the time interrogation according to the [32] and results given in Fig 5. In all these comparisons, model BP is found to be the best. CEB-MC90/EC2 model [8], which modifies his original model MC90/EC 2 [9] by co-opting key aspects of cyclic loading (the mean stress and stress amplitude function and dependence on the number of cycles would simply mean a loading frequency), comes out as the second best. Considerably worse but the third best overall is seen to be the modified Hyperbolic model. Since the current Neville model, labelled Neville, is the simplest, introduced in 1973 on the basis of Neville's research [2], it is not surprising that it comes out as the worst because based on only four variables and there is no consideration of concrete composition and environmental variables.

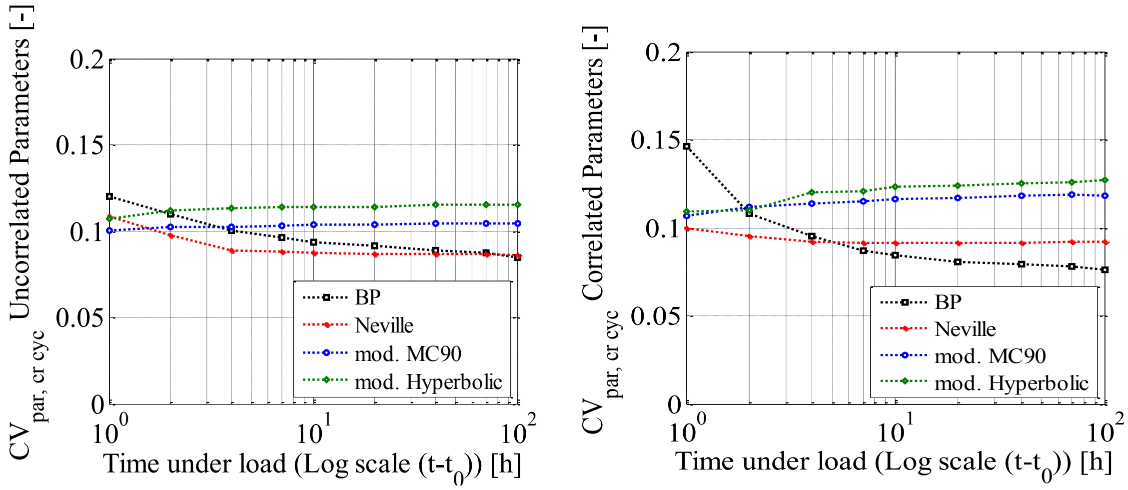

Figure 3: Input variables uncertainty of cyclic creep prediction

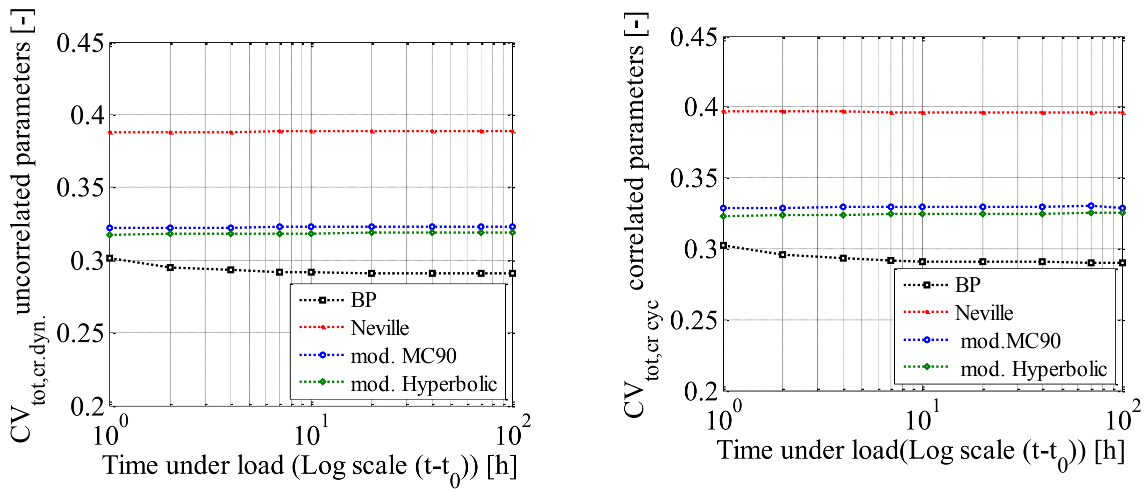

Figure 4: Input variables and model uncertainty of cyclic creep prediction

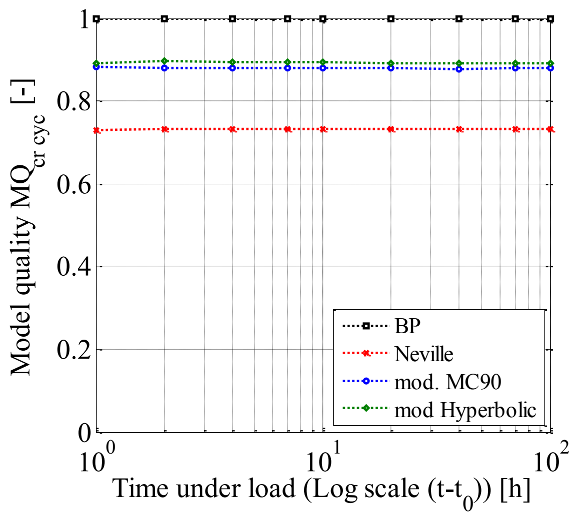

Figure 5: Model quality (MQ) of cyclic creep prediction

5.3 Sensitivity analysis of the cyclic creep strain

SA require to find out the dominant effect of the variability of input random variables on the cyclic creep strain. Figs 6-9 show the results of the sensitivity analysis of uncorrelated and correlated variables. For the calculation of the sensitivity the model uncertainty is not considered. It is assumed that the sensitivity indices are up to $\sum_{p'=1}^{pK} S_p = 1$. The normalization is necessary due to consideration of correlation, which may the results of sensitivity indices $Sp \geq 1$. This arise the difficulties in the comparison between the uncorrelated and correlated indices. High value of sensitivity S_p means highly influential on the uncertainty. For example $Sp = 1$ means only this quantities affect the output. The input quantities sensitivity of model Neville is presented in Fig.6. All input quantities are approximately time-independent. The reason behind this is the expression is depend on the value of the mean stress, stress amplitude, compressive strength an modulus of concrete and there is other input quantities considered in this model and this quantities is assumed constant with respect to time. The strength and modulus is not exactly constant over the time but it is much complicated to consider. It is seen that the most sensitive quantities turn out to be elastic modulus and followed by compressive strength. The mean stress and stress amplitude is not much influence as compared above two quantities. The variables correlation is strongly influence the sensitivity indices. However, E_c and f_c are most influence quantities.

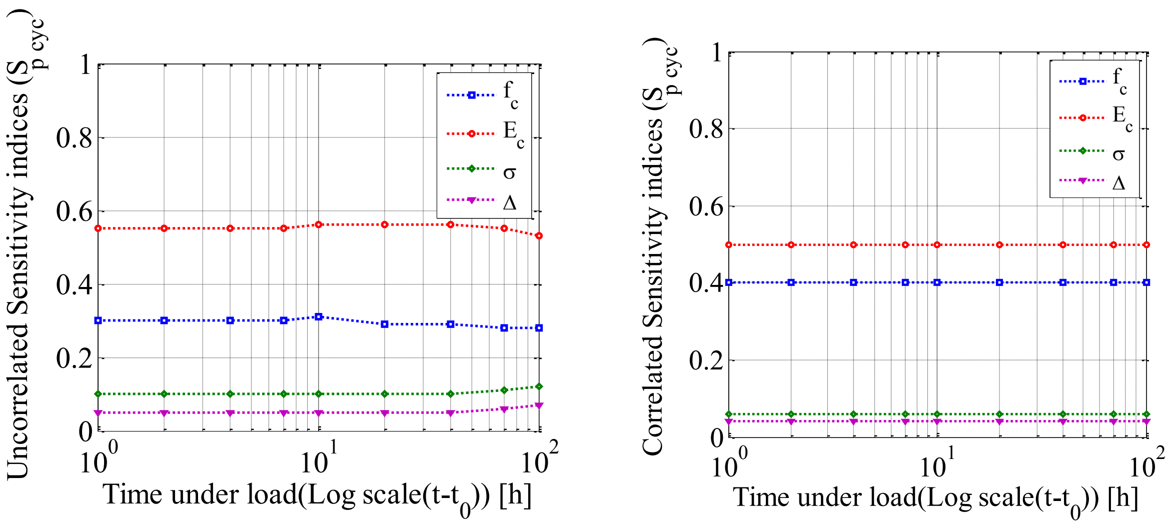

Figure 6: Uncorrelated and correlated sensitivity indices of model Neville

Model modified hyperbolic shows also constant sensitivity indices of all input quantities over the time. In this model the time is account only this $\left(\frac{t-t_0}{a+(t-t_0)}\right)^b$ quantities and the influence of both a and b is much smaller as compared the other quantities. The elastic modulus most influenced variable and followed strength of concrete. The correlation showed the valuable influences the sensitivity indices. The Fig. 7 shows the sensitivity indices of all input variables of modified hyperbolic.

The sensitivities of model modified MC90 remain approximately constant over the time. The humidity influence the time function by factor β_H, but the influence is relatively small. The sensitivity indices of E_c, f_c and σ_m fluctuate over the time. The main reason for this is these variables affect by the time under loading but the influence is small. As compared the sensitivity

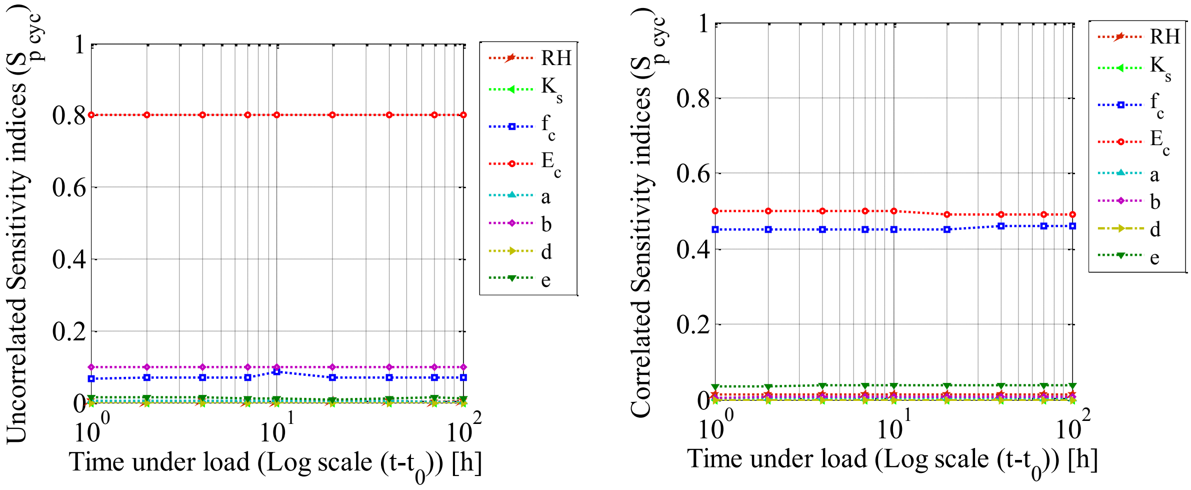

Figure 7: Uncorrelated and correlated sensitivity indices of model modified Hyperbolic

indices between the uncorrelated and uncorrelated, it seem clearly large difference for most influent quantities. In the case of input quantities uncorrelated, E_c is the most dominating input quantities. Oh the other hand, the E_c and f_c are sensitive quantities turns out due to the strong correlation. The numbers of cycle, mean stress and stress amplitude have small influence.

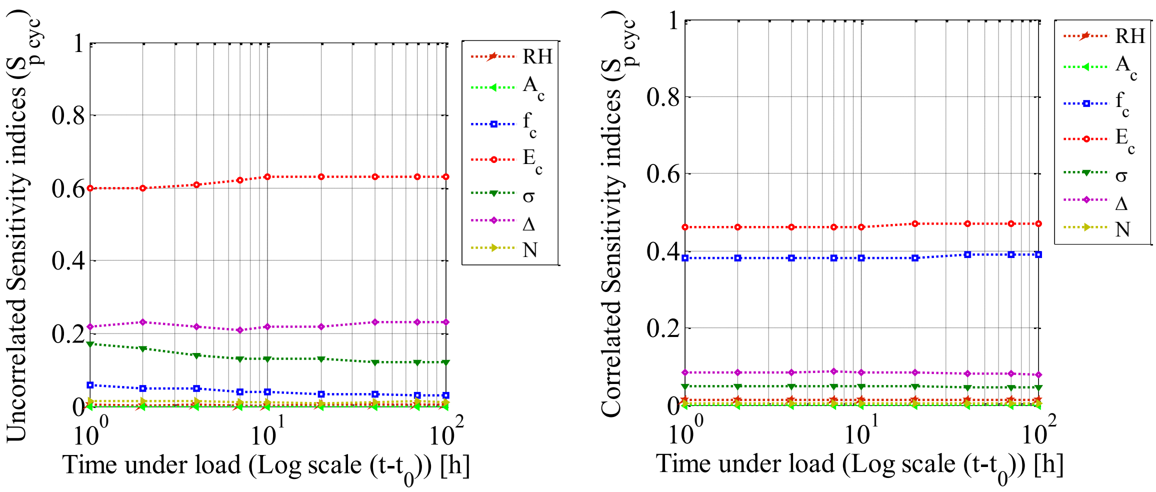

Figure 8: Uncorrelated and correlated sensitivity indices of model modified MC90/CE2

The model BP seen a more time dependent sensitivity indices over the time. The main reason behind this is the more combination of time function with the input quantities. It is seen that the most sensitive quantities turn out to be concrete strength. In the second place the content of the cement when quantities are assuming the uncorrelated. Further, the stress amplitude and frequency is the third and fourth influence quantities. The influence of water-cement ratio, aggregate-sand ratio and humidity also considerable. The concrete strength is most dominating quantities when considering the quantities correlation. The second dominant quantity is the cement content and stress amplitude. The sensitivity indices of cement content and stress amplitude small decrease with increasing time. The cyclic parameter is seen that the considerable influence.

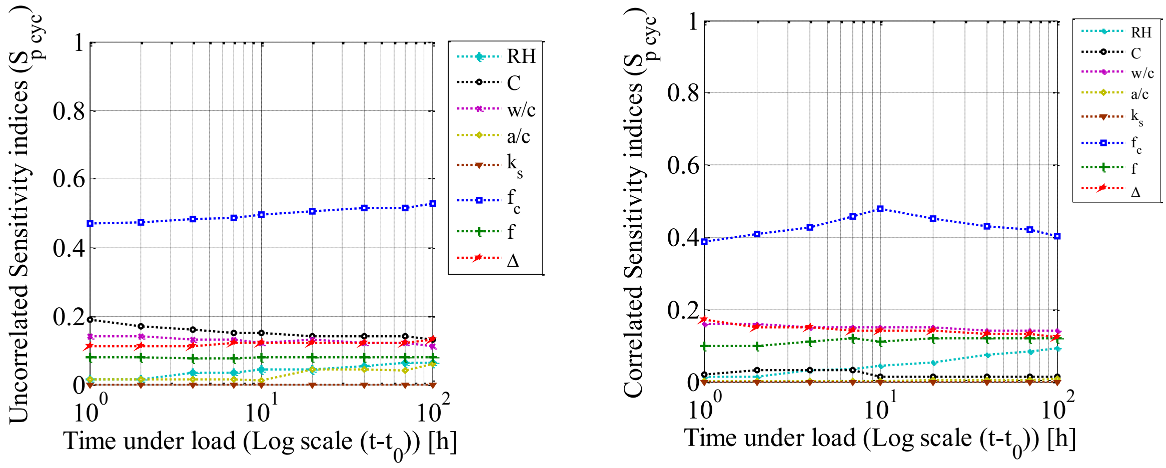

Figure 9: Uncorrelated and correlated sensitivity indices of model BP

6 CONCLUSION

In the present study, a probabilistic framework is suggested for the predicting the cyclic creep of plain concrete considering four different cyclic creep models. Different sources of uncertainty- physical variability, data uncertainty, and model error/uncertainty- were included in the cyclic creep analysis. Different types of model error cyclic creep model error. The input quantities which drive the cyclic creep such as, elastic modulus, concrete strength, mean stress, cyclic stress amplitude, number of cycle, humidity, cement content, water-cement ratio, sand-cement ratio, geometric factor have been considered as random variables. The uncertainty and sensitivity analysis is computed using the LHS sampling technique. It is seen from the uncertainty analysis the complex cyclic creep model BP has the good MQ and less uncertainty but the simple model Neville has higher uncertainty and lower model quality. In contrast, the complex model needs computational effort and more input variables. Stochastic sensitivity analysis is performed to determine the predominant factor amongst the input variables, which influences the cyclic creep prediction. It is observed that cyclic creep is more sensitive to the elastic modulus and strength of concrete, followed by mean stress, stress amplitude, frequency, cement content, humidity, water- cement ratio, in that order. Further, the present study of cyclic creep models brings some interesting point. The most of the creep analysis is only sustained load; the cyclic loading effect is neglected. Cyclic effect, neglected so far, might non-negligible for long span bridge with many lanes or with a dense traffic of heavy trucks. This may cause the excessive time-dependent deflection of concrete structures. The concrete structure can lose their stiffness by (i) the degradation of concrete, (ii) the creep of concrete etc. The relation between the frequency of the structure and its age is important fo the study of the long-term bahaviour of materials, possibly for the detection of its damage. Significant is the change of the modulus of elasticity of concrete dur to cyclic creep. Also, the proposed approach for UQ and SA is applicable to several engineering disciplines and the domain of cyclic creep analysis was used only as an illustration to develop the methodology. In general, the proposed methodology provides a fundamental framwork in which multiple models can be connected through a Bayes network and the confidence in the overall model prediction can be assessed quantitatively.

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