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Probabilistic Parametrical Assessment of FRC Specimens

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Abstract. Significant progress has been made in the last years towards understanding the short and long – term performances of fibre reinforced cementitious materials and this has resulted in a number of novel and innovative uses. One of the main problems concerns the great quantity of random parameters– the placement of fibres, their orientation and quantity in a determined section etc. In consequence, full – probabilistic methods could be recommended for the analysis and evaluation of FRC. It can be assumed that for some structures probabilistic parameters derived from actual material tests could be used. A series of 9 specimens with the same reinforcement was used for a standard 4-point bending test. Using the obtained results, probabilistic normal distributions for the necessary input data were defined. The diagram of the experiment can then be recalculated probabilistically using the method SBRA. The ductility of the material can be expressed energetically. The final result is a histogram of the flexural toughness of the specimen that can be used for further calculations and evaluations.

Introduction

The worries with inferior fracture toughness of concrete are alloyed to a large extent by reinforcing it with fibres of various materials. The resulting material with a random distribution of short, discontinuous fibres is termed FRC. FRC has so far been successfully used in slabs on grade, shotcrete, architectural panels, precast products, offshore structures, structures in seismic regions, crash barriers, footings, hydraulic structures and so forth. The newest application often addresses high-performance fiber-reinforced cementitious composites (HPFRCCs). Issues related to fibre – matrix interaction reinforcement mechanisms, standardized testing, resistance to dynamic load, and transport properties are of primary importance.

All materials used in constructions have several qualities with a certain degree of randomness, For FRC, however, the random parameters are not limited to those that were already examined [1]. Completely new randomness values appear, such as the quantity of fibres in a determined section, their orientation etc.

Probabilistic Assessment of ASTM C 1609 Bending Tests

The main parameter of fibre-reinforced concrete that is obtained from experiments is the resistance in tension. The most common testing method is a four-point bending experiment configuration, since tension tests would be technically complicated. The experiment procedure is defined by the standard ASTM C 1609 [2] [3]: a uniform sample with no dents is loaded quasi-statically with constant deformation growth until a limit deformation is reached; therefore, the resulting diagram has a clear peak defined as Crack Limit State CLS. The same testing procedure is recommended in the Czech Republic [4].

Defining Input Data

In this case, 9 specimens were tested. During the experiment, six parameters were evaluated: the maximum force (F_{max}), the corresponding deformation (e_{Fmax}) and the forces F_1, ..., F_4, where the index states the corresponding deformation in millimetres.

The results of the experiments are shown in Fig. 1. Energy can be easily used to define the ductility of the material, where graphically energy can be defined as the surface underneath the curve. An identical approach is used by the Technical Report for Concrete Industrial Ground Floors [5]. The definition of the area as the most simplified shape (taking into account only the origin, the CLS point and the ultimate deformation) was already performed [6] and the main conclusion was the necessary parametric definition of the curves.

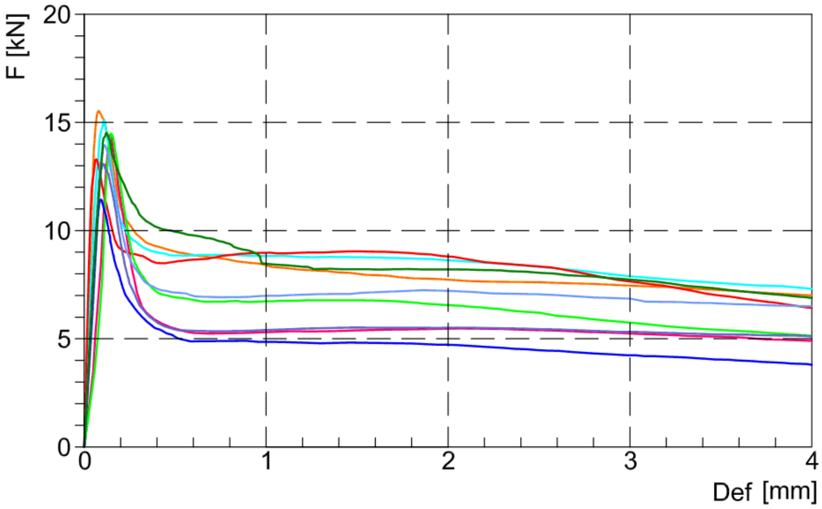


Fig. 1. Experiment results for 9 specimens.

The main statistical parameters of the six evaluated coordinates are listed in Table 1. The distributions were idealized as normal distributions (see Fig. 2). A compromise had to be done to limit the minimal and maximal values of the forces. If the standard 6σ-law was used, some forces would gain negative values.

Table 1. Statistical parameters of the experimental results.

	e_{Fmax} [mm]	F_{max} [kN]	F_1 [kN]	F_2 [kN]	F_3 [kN]	F_4 [kN]
μ	0,1067	13,9622	7,4078	7,0522	6,8756	6,4144
σ	0,0267	1,1616	1,6672	1,4847	1,3828	1,2615
min	0,0267	11,3933	1,9577	2,1743	2,2993	2,4150
max	0,1867	16,8790	2,7329	2,5081	2,4301	2,3731

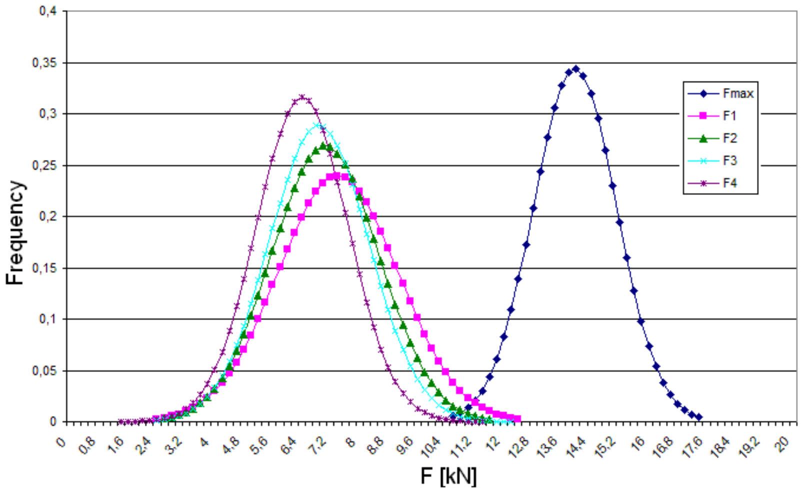


Fig. 2. Distributions of the forces.

The modelled curves should correspond as much as possible to the experimental results. These curves show that initially there is no significant connection between the maximal force F_{max} and the force that leads to a quasi-constant growth of deformation. However, from the deformation of about 1 mm the curves of all the specimens are almost parallel and their tangent is does not change significantly. It is appropriate to introduce functions that would parametrically define the points on the curve. The mathematical description follows:

$$F_i = F_{\max \mathrm{var}} \frac{\mu_i}{\mu_{F \max}} + \frac{\sigma_i}{\sigma_{F \max}} \left(F_{\max,\mathrm{var}} - \mu_{F \max} \right) . \qquad (1)$$

Calculation of the Flexural Toughness

For the probabilistic calculation of the area under the curve (flexural toughness), the SBRA method [7] was used. The main assumptions are the following:

- for every step of the probabilistic calculation a random value of the maximal force F_{max} and the corresponding deformation e_{Fmax} will be chosen using said normal distributions
- the initial segment of the curve from the origin to the maximal force is considered linear
- the forces F_1, ..., F_4 are functions of F_{max} as stated in equation (1)

The graphic representation of possible points of the curves is represented in Fig. 3.

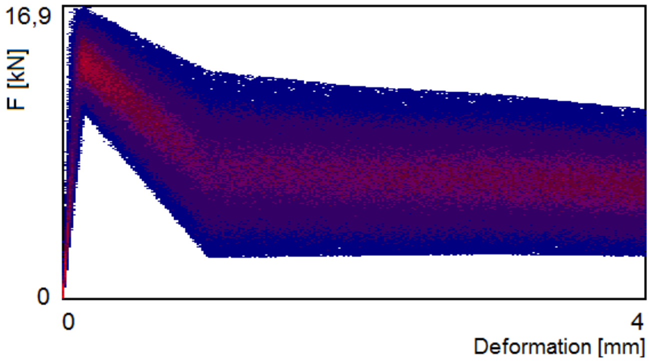
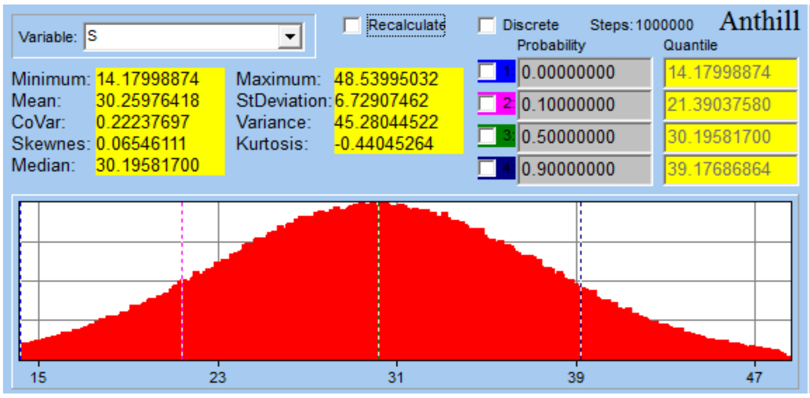


Fig. 3. Probabilistic expression of test results.

Using the described assumptions, any simplified modelled curve is a function of two parameters: the maximal force F_{max} and the corresponding deformation e_{Fmax}. The remaining forces are determined parametrically. The area under the curve can be then calculated in every single step using equation (2). The final histogram of the flexural toughness can be found in Fig. 4.

$$A_{var} = \frac{e_{F\max} \cdot F_{\max}}{2} + F_1 \cdot \left(1 - e_{F\max}\right) + \frac{(F_{\max} - F_1) \cdot (1 - e_{F\max})}{2} + F_2 + F_3 + \frac{F_1 + F_4}{2} \quad . \tag{2}$$



Variable: S

Steps: 1000000

Minimum: 14.17998874
Mean: 30.25976418
CoVar: 0.22237697
Skewnes: 0.06546111
Median: 30.19581700

Maximum: 48.53995032
StDeviation: 6.72907462
Variance: 45.28044522
Kurtosis: -0.44045264

	Probability	Quantile
☐ 1:	0.00000000	14.17998874
☐ 2:	0.10000000	21.39037580
☐ 3:	0.50000000	30.19581700
☐ 4:	0.90000000	39.17686864

Fig. 4. Histogram of flexural toughness.

Conclusion

In the above stated case, the difference between the mean value of the flexural toughness' histogram and the average test result is 2.8% (see Table 2). Given the relatively small set of specimen, the precision of this result can be considered satisfactory.

Table 2. Comparison of results.

	mean	median
$T_{B,graph}$ [J]	31,1288	31,1288
$T_{B,probab}$ [J]	30,2598	30,1958
ΔT_B [J]	0,869	0,933
ΔT_B [%]	2,792 %	2,997 %

The utilization of fully – probabilistic methods to assess fibre reinforced members and structures would be right for the development of both existing empirical procedures and theoretical models as a basis for experiments and evaluation of their outcomes.

Acknowledgement

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