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Alternative estimation of the modulus of elasticity for dam concrete

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Abstract

The modulus of elasticity of dam concrete is hard to determine directly from tests due to the need for large specimens and testing machines. As an alternative, it is possible to predict experimental data of the elasticity module of fresh dam concrete through an evaluation of the results of standard specimens with the size of ϕ150×300 mm and assumptive acceptances of elasticity modules of aggregate in consideration of composite material models. A comparison was made between the 13 different composite material model results obtained in our study and the experimental data of Vilardell et al. [J. Vilardell, A. Aguado, L. Agullo, R. Gettu, Estimation of the modulus of elasticity for dam concrete, Cem. Concr. Res. 28 (1) (1998) 93–101]. As a result of this comparison, the models likely to yield the lowest number of errors were determined. Therefore, parallel (Voigt) and series (Reuss) models were found more appropriate for a reasonable prediction of elasticity modules of the dam concrete.
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Keywords: Concrete; Modulus of elasticity; Composite material models

1. Introduction

The modulus of elasticity of concrete is a parameter required in structural analysis to determine the strain distributions and displacements, particularly when the design of the structure is based upon elasticity considerations. Standard specimens of elasticity modulus, measured through an exposure to a uniaxial compressive loading, have dimensions at least three times as large as those of the maximum aggregates. The concrete used dam constructions is often made up of a binder inclusive of cement and a high amount of fly ash and aggregates with a maximum size that ranges from 80 to 200 mm [1]. The compressive strength of such concretes needs to be measured through large specimens, ϕ450×900 mm, for instance. Due to practical difficulties in performing such tests, dam concrete is usually wet-screened, removing aggregates larger than about 40 mm, and standard cylinders of ϕ150×300 cm are cast and tested in compression [2], but this may cause overestimation of the compressive strength. One study suggested that the strength of the dam concrete should be taken as 85% of the wet-screened concrete when there is a lack of specific test data [3].

Various composite material models have been devised to determine concrete properties. Detailed information and equations of these models are also available [4–10]. For the applications of these models, the basic assumptions are as follows: concrete is a three-dimensional combination of two homogeneous and isotropic phases; the matrix phase and the coarse aggregates, and each phase behaves linearly in the linear elastic regime of the concrete [5]. Both models are almost identical to each other. Predictions were made for only Hirsch and Counto models from among composite models for dam concrete in the study by Vilardell et al. [1]. Considering the fact that these models are not capable of accounting for composite properties of parallel and series models on their own and that they produce near-true results, this study might have used the model of Hirsch and Counto.

In our study, models of Parallel (Voigt model), Series (Reuss model), Popovics, Illston, Mehmel-Kern, Hashin-Hansen, Hobbs, Maxwell, Bache and Napper-Christensen were also applied in order to determine the models likely to producing the most near-true values as an alternative to the models used in the experimental tests made by Vilardell et

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al. Consequently, through using various composite material models in estimation of elasticity modulus of dam concrete in order to determine the models likely to yield the lowest number of errors, apart from determine the number of errors. Therefore, prediction possibilities of using composite material models in determination of modulus of elasticity were sought and some suggestions were made accordingly.

2. Prediction of E-moduli for dam concrete

Due to the difficulty in testing large test specimens, it has been suggested that the results obtained from ϕ150×300 mm in size mortar and wet-screened dam concrete specimens should be evaluated together with the assumptive acceptances of elasticity modulus of aggregates by means of composite models so that estimation of elasticity of modulus of dam concretes can be achieved. Prismatic concrete specimens in sizes of 450×450×900 mm were produced from dam concrete with the maximum aggregate size being 120 mm. Cylindrical concrete and mortar specimens in sizes of ϕ150×300 mm were produced from 40 and 5 mm with the maximum aggregate sizes respectively through removing large aggregates from dam concretes when still fresh [1]. They obtained experimental data under these conditions.

The modulus of elasticity for dam concrete are best estimated with both simulations D(M) and D(WS), using the experimental data from the mortar and wet-screened concrete. By taking the matrix phase as the mortar and the aggregate phase as the gravel of 5–40 mm, the prediction of the wet-screened concrete modulus, which is denoted as WS(M), can be acquired from the models. Likewise, with the matrix phase taken as the mortar and the aggregate phase taken as the gravel of 5–120 mm, estimation can be achieved for dam concretes, which is denoted as D(M). As an alternative, the wet-screened concrete may be considered to be the matrix phase and the gravel of 40–120 mm to be the aggregate phase with a view to predicting the modulus of the dam concrete, which is denoted as D(WS). In the calculations, E_c, E_m and E_a, are the elastic moduli of the composite, matrix and the aggregate, respectively, and V_m and V_a are the volume fractions of the matrix and aggregate. WS(M) and D(M) are the modulus of elasticity of concrete estimated.

These calculations include volume fractions appearing in Table 1. 0.3, 0.5 and 0.8 were assumed for x in the calculations made with the Hirsch model. This parameter of x is the ratio of boundaries corresponding to upper and lower terms dependant upon the phases forming composite.

Table 1
Volume fractions considered for the composite models predictions

Code	V_m	V_a
WS(M)	0.555	0.445
D(M)	0.405	0.595
D(WS)	0.725	0.275

Table 2
Results of composite models for different aggregate moduli and for different ages for 90 days ages wet-screened, dam and wet-screened dam concrete

Days	E_a GPa	Code	Experimental Data [1]	Parallel Model (Voigt)	Series Model (Reuss)	Hirsch-Dougill (x=0.3)	Hirsch-Dougill (x=0.5)	Hirsch-Dougill (x=0.8)	Popovics	Illston	Mehmel-Kern	Counto	Hashin-Hansen	Hobbs	Maxwell	Bache-Nepper-Christensen
90	35	WS(M)	35.1	**31.226**	30.869	30.975	31.046	31.154	15.629	31.153	31.064	31.072	31.036	31.036	31.097	31.045
		D(M)	43.0	**32.246**	31.886	31.993	32.065	32.173	16.139	32.160	32.098	32.081	32.058	32.058	32.118	32.068
		D(WS)	43.0	**35.073**	35.072	35.072	35.072	35.072	17.551	35.072	35.072	35.072	35.072	35.072	35.072	35.072
	50	WS(M)	35.1	37.901	**34.988**	35.814	36.387	37.280	18.965	37.041	36.412	36.480	36.188	36.188	36.687	36.386
		D(M)	43.0	**41.171**	38.078	38.956	39.564	40.513	20.599	40.201	39.763	39.615	39.415	39.415	39.945	39.650
		D(WS)	43.0	**39.198**	38.233	38.517	38.709	39.001	19.612	39.005	38.672	38.805	38.651	38.651	38.816	38.687
	65	WS(M)	35.1	44.576	**37.697**	39.527	40.849	43.007	22.301	42.199	40.739	40.896	40.222	40.222	41.391	40.892
		D(M)	43.0	50.096	**42.525**	44.545	46.001	48.374	25.060	47.408	46.364	46.000	45.519	45.519	46.816	46.348
		D(WS)	43.0	**43.323**	40.183	41.076	41.694	42.656	21.674	42.497	41.447	41.882	41.382	41.382	41.919	41.581

Table 3
Prediction error percentages of different composite models of different aggregate moduli for 90 days ages for wet-screened, dam and wet-screened dam concrete

Days	E_a GPa	Code	Experimental Data [1]	Parallel Model (Voigt)	Series Model (Reuss)	Hirsch-Dougill (x=0.3)	Hirsch-Dougill (x=0.5)	Hirsch-Dougill (x=0.8)	Popovics	Illston	Mehmel-Kern	Counto	Hashin-Hansen	Hobbs	Maxwell	Bache-Nepper-Christensen
90	35	WS(M)	35.1	**−11.04**	−12.05	−11.752	−11.549	−11.242	−55.472	−11.25	−11.498	−11.475	−11.578	−11.578	−11.405	−11.551
		D(M)	43.0	**−25.01**	−25.846	−25.597	−25.430	−25.178	−62.468	−25.21	−25.353	−25.393	−25.447	−25.447	−25.306	−25.423
		D(WS)	43.0	**−18.44**	−18.436	−18.436	−18.436	−18.436	−59.185	−18.44	−18.436	−18.436	−18.436	−18.436	−18.436	−18.436
	50	WS(M)	35.1	7.98	**−0.32**	2.035	3.665	6.212	−45.969	5.53	3.739	3.930	3.098	3.098	4.522	3.663
		D(M)	43.0	**−4.25**	−11.446	−9.404	−7.990	−5.784	−52.096	−6.51	−7.527	−7.873	−8.336	−8.336	−7.104	−7.792
		D(WS)	43.0	**−8.84**	−11.086	−10.424	−9.978	−9.301	−54.391	−9.29	−10.066	−9.755	−10.114	−10.114	−9.730	−10.030
	65	WS(M)	35.1	27.00	**7.40**	12.613	16.379	22.526	−36.464	20.22	16.066	16.514	14.594	14.594	17.924	16.500
		D(M)	43.0	16.50	**−1.105**	3.592	6.979	12.497	−41.721	10.25	7.823	6.976	5.859	5.859	8.875	7.787
		D(WS)	43.0	**0.75**	−6.551	−4.474	−3.038	−0.800	−49.596	−1.17	−3.612	−2.601	−3.762	−3.762	−2.515	−3.299

For isotropy of the concrete, x should equal 0.5. As was mentioned before, results of elasticity of modulus of mortar and wet-screen concrete specimens are the experimental results of standard specimens. With the river gravels having dissimilar mixes of mineralogies, mostly limestone, it is possible to have a range of modulus of elasticity values [1]. For the calculations of predictions of modulus of elasticity of dam concretes, three moduli of aggregates (35, 50 and 65 GPa) were used.

3. Results

Differences between the estimative results of elasticity modulus of dam concretes and those of experimental data for 13 different composite models obtained as a result of the calculations of the equations given in Ref. [4] through computation have been presented in Tables 2 and 3. In the calculations, four different concrete ages (7, 28, 90 and 180 days) and three supposedly accepted different moduli of aggregate were considered. The results appearing in Tables 2 and 3 show only the results of the age of 90 days, which is accepted as a usual reference age for dam concretes. Results in bold numbers are the closest estimations to experimental data. We verified our study modeling results through achieving a comparison with those obtained by Vilardell et al. [1]. Estimation results obtained from concrete composite models were compared with those experimental data. Prediction error percentages of different composite models of different aggregate moduli for 90 days ages for wet-screened, dam and wet-screened dam concrete have been given in Table 3. Results in bold letters are those producing the lowest errors.

4. Evaluation of the results

Tables 2 and 3 reveal that all the models give similar results close to experimental results when E_a=35 GPa is

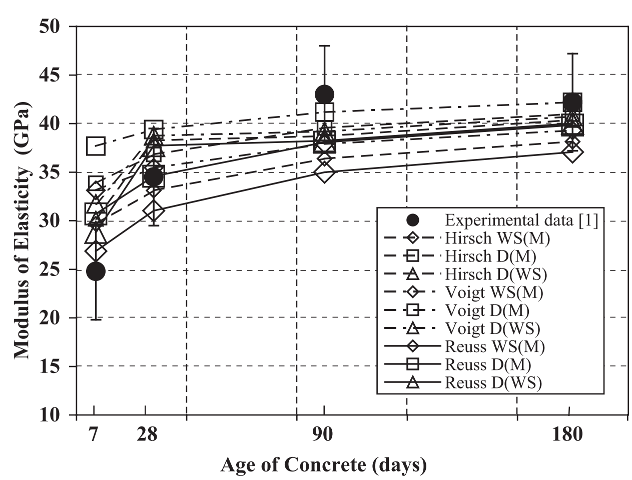

Fig. 1. Predictions with the Hirsch, Voigt and Reuss Model for E_a=50 GPa.

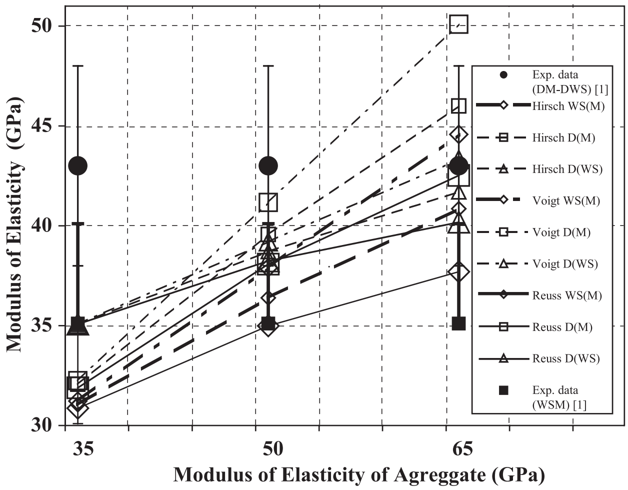

Fig. 2. Predictions with the Hirsch, Voigt and Reuss Model for age of 90 days.

adopted. Deviations are also seen in the calculations in regard to experimental results (10% in WS(M), 25% in D(M) and 18% in D(WS). When E_a reaches 50 GPa, the series model was found more suitable for WS(M), while the parallel model was found to be more appropriate for D(M) and D(WS). When the value of E_a reaches 65, series model was found to be more appropriate for WS(M) and D(M), while the parallel model was found to be more appropriate for D(WS). On the other hand, the Popovics model produced inappropriate results through considerable deviations. Comparisons were made between the estimation results of parallel, series and Hirsch–Dougill (x=0.5) models in Figs. 1 and 2 with respect to four different ages of concrete and three elasticity of aggregate moduli. As can be seen in Fig. 1, while values for 7 days are above those of experimental data, values for 28 are close to those of experimental data. On the other hand, when values for 90 and 180 days are examined, calculation results are below those of experimental data. When computational results of 90 days, the reference age for dam concrete, are analyzed, the parallel (Voigt) and series (Reuss) models give much better results in comparison with those obtained through the Hirsch–Dougill model (x=0.5).

Results of the effects of three different elasticity modulus of aggregate upon the estimation of elasticity modulus of dam concretes are given in Fig. 2. When an analysis of WS(M) is made, it can be seen that when E_a=35 GPa is provided, computational results are below experimental results and close to one another. When E_a=50 GPa is provided, computational results are above those of experimental data. However, when E_a=65 GPa is provided, computational results are above those of experimental data and in a scattered position. As for D(M) and D(WS), it can be seen that when E_a=35 GPa is provided; computational results are below experimental results and close to one another. When E_a=50 GPa is provided, computational results are below those of experimental data. However, when E_a=65 GPa is provided, computational results are scattered around those of experimental data.

When analyzing results in terms of the Hirsch–Dougill (x=0.5) and Counto models, the Hirsch–Dougill model produces close results when E_a equals 35 GPa for all three x values, while the Counto model also produces close values. When E_a equals 50 and 65 GPa, the Hirsch–Dougill model produces different results depending on x values. The most appropriate results for the Hirsch–Dougill model are x=0.3 for WS(M) and x=0.8 for D(WS). The Counto model produces the similar results as those of the Hirsch–Dougill model when its values is accepted as x=0.5.

5. Conclusion and suggestions

When E_a equals 35 GPa, results of WS(M) were determined to be closer to those of experimental data when compared to the results of D(M) and D(WS) for all composite models. However, regarding E_a 50 GPa, values of WS(M) were more appropriate for in the Series model in comparison with those of the other models. As for D(M) and D(WS), the parallel model produced more appropriate results. When E_a equaled 65 GPa, values of D(WS) were closer to those of experimental data than those of D(M) and WS(M). These results seem to suggest that as the elasticity of aggregate modulus increases, distribution of computational values increases. We, therefore, conclude using only Hirsch–Dougill and Counto models in the prediction of elasticity of modulus of dam concrete may not always produce accurate results. For this reason, we assume that the models of parallel (Voigt) and series (Reuss) may prove more reasonable for this purpose.

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