Specifying Splitting Tensile Strength for Lightweight Concrete to Improve and Simplify Design

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Lightweight concrete may have reduced tensile strength compared to normalweight concrete. If the tensile strength is reduced, aspects of design related to tensile strength, such as shear and development length of reinforcement, are usually affected.

The American Association of State Highway and Transportation Officials' (AASHTO's) bridge design specifications have included provisions that reflect this potential reduction to the properties of lightweight concrete since at least 1983. However, a variable had not been assigned to the reduction factor. Therefore, the factor had to be defined wherever it was needed and, without a variable assigned, the factor could not be inserted into equations. The current version of the *AASHTO LRFD Bridge Design Specifications*[1] contains a major revision to provisions addressing lightweight concrete that was adopted in 2015. The revision defined the concrete density modification factor, λ, in Article 5.4.2.8 and included the variable in all equations where it was appropriate.

For normalweight concrete, $\lambda = 1.0$. In Article 5.4.2.8, two approaches are provided to determine the value of λ for lightweight concrete. The first option is based on the ratio of a specified splitting tensile strength, f_{ct}, of lightweight concrete to the computed splitting tensile strength of normalweight concrete. This option is rarely used, but it can provide significant benefit when shear or development lengths are important factors in design.

Prior to 2015, the second option for determining λ, which is used when the splitting tensile strength is not specified, was based on the type of lightweight concrete: 0.85 for sand-lightweight concrete and 0.75 for all-lightweight concrete. The 2015 revision changed this approach by defining λ using the unit weight of concrete w_c, which is a great improvement for designers.[2] AASHTO LRFD specifications Eq. 5.4.2.8-2 is:

$$0.75 \le \lambda = 7.5\, w_c \le 1.0$$

Recent tests of lightweight concrete for a range of compressive strengths and types of lightweight aggregate[3,4,5] have shown that the splitting tensile strength of lightweight concrete often exceeds the computed tensile strength of normalweight concrete, which is not defined in the specifications, but can be determined by solving AASHTO LRFD specifications Eq. 5.4.2.8-1 (with $\lambda = 1.0$) for f_{ct}:

$$f_{ct} = \left(\frac{1}{4.7}\right)\sqrt{f'_c} = 0.213\sqrt{f'_c}\,(\text{in ksi})$$

An example of results from research is presented in **Table 1**, which shows splitting tensile strengths for a series of lightweight concrete bridge deck mixtures made with three types of lightweight aggregate and a normalweight control mixture.[4] Using a design compressive strength of 4.0 ksi for the deck concrete and the expression for f_{ct} shown previously, the predicted splitting tensile strength for normalweight concrete would be 0.426 ksi. All values of splitting tensile strength for the lightweight concrete in Table 1 are comfortably above this value; only the splitting tensile strength of the normalweight concrete is close to the predicted value. For this study, constituent proportions for the mixtures were held constant and the lightweight concrete compressive strengths were less than the normalweight concrete strength. Proportions of the lightweight concrete mixtures could have been adjusted to produce compressive strengths equal to the control. As shown in the last two columns of the table, the measured tensile strengths of the lightweight concretes were greater than the predicted tensile strengths computed using measured compressive strengths, whereas the measured tensile strengths of the normalweight concrete mixture were below the predicted value. These data indicate that, for these lightweight concrete mixtures, f_{ct} could be specified equal to the predicted splitting tensile strength using $\lambda = 1.0$.

Table 1. Splitting tensile and compressive strength test results (ksi) and comparison of test results to predicted splitting tensile strength for lightweight and normalweight bridge deck concrete mixtures (test data from Ref. 4)

	f_{ct}		f'_c		$\frac{f_{ct}}{(0.213\sqrt{f'_c})}$	
NWC	0.438		5.505		0.880	
Type of LWC	Sand	All	Sand	All	Sand	All
Slate LWA	0.490	0.461	5.135	4.685	1.021	1.005
Clay LWA	0.520	0.493	5.200	4.675	1.076	1.075
Shale LWA	0.510	0.465	4.980	4.550	1.079	1.029

Key: NWC = normalweight concrete; LWC = lightweight concrete;
LWA = lightweight aggregate. The types of LWC are defined in Ref. 4.

A second example of test results, in this case taken from production of prestressed lightweight concrete girders, is presented in **Table 2** for three projects that all used the same mix proportions and type of lightweight aggregate.[5] As shown in the last three rows of data in the table, the measured splitting tensile strengths of lightweight concrete were greater than the predicted tensile strengths computed using specified compressive strengths. Again, these data indicate that, for this lightweight concrete mixture, f_{ct} could be specified equal to the predicted splitting tensile strength using $\lambda = 1.0$.

Table 2. Twenty-eight-day splitting tensile strength test results for three projects (from Ref. 5)

Project		AWS	Skagit	SR162
Count		3	10	4
Average f_{ct}	(ksi)	0.700	0.696	0.663
Minimum	(ksi)	0.675	0.613	0.643
Maximum	(ksi)	0.740	0.800	0.680
Range	(ksi)	0.065	0.187	0.037
Standard deviation	(ksi)	0.035	0.058	0.015
Average 28-day f'_c	(ksi)	11.578	10.832	11.845
Predicted f_{ct} using average f'_c	(ksi)	0.724	0.700	0.732
Specified f'_c	(ksi)	9.000	9.000	9.200
Predicted f_{ct} using specified f'_c	(ksi)	0.638	0.638	0.645
Average test f_{ct} / Predicted f_{ct}		1.097	1.090	1.027

Key: AWS = Airport Way South; Skagit = Skagit River Bridge decked bulb-tee girders; SR162 = Puyallup River Bridge WF74G.

Conclusion

Data show that the splitting tensile strength of lightweight concrete can reasonably be expected to approach or exceed the predicted splitting tensile strength of normalweight concrete. Therefore, it is reasonable for designers to specify f_{ct} for lightweight concrete to be equal to the predicted splitting tensile strength for normalweight concrete when shear or development lengths are important aspects of design. Specifying $f_{ct} = 0.213\sqrt{f'_c}$ eliminates the penalty for using lightweight concrete by setting $\lambda = 1.0$.

References

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