Statistical Resistance and Reliability Analysis of Steel-Concrete Composite Beams

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Abstract: Through summing up, statistical parameters of steel material property based on new standards and statistical parameters of geometry property of steel-concrete composite beams are obtained. Testing datum of steel-concrete composite beam in bending state and its connecting piece in shearing state is roundly collected. Then indeterminateness statistical parameters of computation modes and resistance statistical parameters of steel-concrete composite beams are obtained.

Introduction

Steel-concrete composite beams can increase the effective use of space, improve the fire performance of steel structure and reduce the engineering cost so that it shows a wide application prospects. Statistical resistance of component is indispensable to structural reliability analysis， which is also the basic work of establishing the Unified Standard for The Reliability Design of Building Structure. In the past 30 years, aiming at mechanical properties and design method of steel - concrete composite beams, domestic scholars carry out a series of theoretical and experimental studies [4-12], but there is little literature on the resistance statistics of steel - concrete composite beam, so it is necessary to collect and collate the test datum of steel - concrete composite beams and apply mathematical statistics to the its resistance statistics.

The Statistical Parameter of Material Property of Steel-Concrete Composite

In the reference [1], the χ^2 test method is applied to test and analyze part of the latest data available from domestic steel mills, at the 5% significance level, its theoretical distribution is accepted as a normal distribution, and then the standard value f_{yk} whose assurance rate is 95% is calculated. On the basis of the above statistics, the material statistical parameters of steels of the new national standard were calculated in the reference [1]; table 1 [1] shows the obtained results.Figures in brackets are the obtained statistics in the reference [2], K_m represents the indeterminateness of the steel material.

Table 1 statistical parameters of steel material property based on new standard [1]

Steel	Range(t : mm)	μ_{Km}	δ_{Km}
Q235	$t \leq 16$ $16 < t \leq 40$ $40 < t \leq 60$ $60 < t \leq 100$	(1.070) 1.074 1.118 1.087	(0.081) 0.077 0.066 0.066

Q345	$t \le 16$ $16 < t \le 35$ $35 < t \le 50$ $50 < t \le 100$	(1.040) (1.025) 1.125 1.184	(0.066) (0.076) 0.057 0.083

In this paper, when the resistance statistical parameters of the composite beam were calculated, two steels of Q235, Q345 and three kinds of concrete strength of C30, C40, C50 were chosen, indeterminateness parameters of material properties are shown in Table 2.

Table 2 statistical parameters of material property of steel-concrete composite beams

Parameter	Steel		Concrete		
	Q 235	*Q* 345	*C* 30	*C* 40	*C* 50
f_y (f_{ck})MPa	235	345	20.1	26.8	32.4
f (f_c)MPa	215	310	14.3	19.1	23.1
μ_{Km}	1.087	1.094	1.41	1.35	1.32
δ_{Km}	0.075	0.093	0.190	0.160	0.135

Indeterminate Statistical Parameter of Geometric Size of Steel-Concrete Composite

Composite structure is a combination of steel, steel components or steel and concrete one, so the corresponding geometric size can refer to statistical parameters of the corresponding geometric size of steel components and reinforced concrete in the "Unified Standard for The Reliability Design of Building Structure". As shown in Table 3.Random variable K_A stands for the indeterminateness of geometric parameters of structural components.

Table 3 statistical parameters of geometry property K_A of steel-concrete composite beams [3]

Types of structural member	Item	μ_{KA}	δ_{KA}
Components of composite structure	Height, width of section	1.00	0.02
	Sectional effective height	1.00	0.03
	sectional area of longitudinal reinforcement	1.00	0.03
	Concrete cover thickness	0.85	0.30
	anchorage length of longitudinal reinforcement	1.02	0.09
	Steel sectional area	1.00	0.05
	Sectional area of the steel components	1.00	0.05

Indeterminate Statistical Parameters of Computation Modes of Steel-Concrete Composite

The Collection of Testing Datum. It is very important to statistically analyze the resistance of basic components of the structure and obtain indeterminate statistical parameters of the calculation model. The indeterminate statistical parameters of the calculation model are based on the ratio of t each component experimental and calculated values for its sample space. In this study, almost all the literature and experimental datum related to steel - concrete composite beam in the nearly 20 years are collected**.** Table 4 lists the number and data sources steel-concrete composite beams.

Table 4 the number and data sources steel-concrete composite beams

Stress state	Types of test pieces	Number	Data sources
In bending state	Cast-in-situ concrete flange steel-concrete composite beams	13	[5]
	Steel-concrete simply supported composite beams	8	[6]

	Steel - concrete laminated slabs composite beams	6	[9]
	Steel- profiled steel sheeting concrete composite beams	5 7	[11] [12]
In shearing state	Channel shear connector of steel-concrete composite beams	49	[7]
	Bendbor shear connectors of steel-concrete composite beams	44	[8]

Indeterminate Statistical Parameters of Computation Modes. random variable K_P usually represents indeterminate statistical parameters of computation modes. The expression of K_P is as follow:

$$K_P = \frac{R^S}{R} \tag{1}$$

Where: R^s represents the actual resistance value of the structural components (Advisable test value or accurate calculation of value), R represents component resistance value determined by the standard formula. So make a mathematical statistics on the basis of the samples in table 4,then the indeterminate statistical parameters of computation modes are obtained, that is to say the mean value μ_{Kp} and the coefficient of variation δ_{KP} of K_P are obtained (As shown in table 5).

Table 5 indeterminate statistical parameters of computation modes of steel-concrete composite beam

Types of structural components		Stress state	μ_{KP}	δ_{KP}
Composite floor structure	Cast-in-situ concrete flange steel-concrete composite beams (Positive moment zone)	In bending state	1.281	0.249
	Steel - concrete laminated slabs composite beams (Positive moment zone)		0.883	0.044
	Steel- profiled steel sheeting concrete composite beams		0.772	0.306
	Channel shear connector of steel-concrete composite beams	In shearing state	0.939	0.098
	Bendbor shear connectors of steel-concrete composite beams		1.677	0.122

Resistance Statistical Parameters of Steel-Concrete Composite Beam

Steel-concrete composite beam is a structural form that consists of two material, steel and concrete. So the resistance R can be represented as

$$\begin{cases} R = K_P \cdot R_P \\ R_P = R(f_{ci} \cdot \alpha_i), i = 1, \cdots, n \end{cases} \tag{2}$$

R_P stands for resistance of structural member which is determined by design calculation formulae. $R_P = R(\cdot)$, where $R(\cdot)$ is the resistance function; f_{ci} is the material properties of the i th material of structural components; α_i is geometry parameters corresponding to the i th material of structural components.

$$\mu_R = \mu_{K_P} \cdot \mu_{R_P} = \mu_{K_P} R\left(\mu_{f_{ci}}, \mu_{\alpha_i}\right) \tag{3}$$

$$\delta_R = \sqrt{\delta_{K_P}^2 + \delta_{R_P}^2} \tag{4}$$

$$K_R = \frac{\mu_R}{R_K} = \frac{\mu_{K_P} \cdot \mu_{R_P}}{R_K} \tag{5}$$

In this article, make the resistance statistic only for cast-in-situ concrete flange steel-concrete composite beams and steel - concrete laminated slabs composite beams in the positive moment zone and in full shear connection state. Statistical results are shown in Table 6.

Table 6 resistance statistical parameters of composite floor

Types of structural components	Parameters	*Q*235			*Q* 345		
		C 30	*C* 40	*C* 50	*C* 30	*C* 40	*C* 50
cast-in-situ concrete flange steel-concrete composite beams	K_R	1.445	1.425	1.416	1.484	1.450	1.437
	δ_R	0.264	0.265	0.265	0.268	0.268	0.268
steel - concrete laminated slabs composite beams	K_R	0.996	0.982	0.976	1.023	1.000	0.990
	δ_R	0.099	0.099	0.100	0.109	0.109	0.109

Conclusion

In this study, the test results of flexural capacity of cast-in-situ concrete flange steel-concrete composite beams, steel - concrete laminated slabs composite beams and steel- profiled steel sheeting concrete composite beams are collected; based on the above, then indeterminate statistical parameters and resistance statistical parameters of computation modes that steel-concrete composite beams are in bending state and shear connectors are in the shearing state are calculated.

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