Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 1460603, 9 pages
https://doi.org/10.1155/2021/1460603

Research Article

On the Relation between Strength and Stiffness of Cable Tray

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Received 12 July 2020; Accepted 16 March 2021; Published 8 April 2021

Academic Editor: Fazal Mohamed

In order to realize the optimal design of the cable supporting system for the purpose of material saving and energy saving and green manufacturing, the strength-stiffness ratio is proposed in the paper in nondimensional form, which defines quantitatively the relation between the static load strength and stiffness of the cable tray. On the premise of ensuring service safety, the correlation between the strength and stiffness of the cable tray under static load is discussed extensively through the theoretical analysis of the mechanical model. The weakest link in the carrying capacity of the cable tray as well as the issue that needs to pay attention is proposed in the process of design and the test of the cable tray. A reasonable strength-stiffness ratio will help to make full use of the potential of material strengths. The value of the strength-stiffness ratio is obtainable by means of the finite element method or by the loading test of the cable tray. It is shown through the analysis that the value of the strength-stiffness ratio being setting in the range close to but less than 1 will make comparatively reasonable material utilization and will help the deflection test going smoothly to obtain a relatively safer allowable working load for the cable tray.

1. Introduction

With the rapid development of electrification and informatization in industry, the cable bridge has become an indispensable basic element in industrial transportation and civil architecture, which have not only a wide range of demand but also considerable product yield and output value [1]. In case of accident during the service life, it will cause big losses to economy and society since the maintenance of the cable tray would be quite difficult. Therefore, the basic requirements for cable tray should cover the long-term safety and the reliable service performance, including the bearing capacity with the seismic resistance and the corrosion resistance. In recent decades, the developments have been achieved theoretically, experimentally, and numerically according to various service requirements for cable trays. For example, the nonlinear response was studied with the damped behavior under seismic excitations [1–4]. The dynamic analysis was developed from the initial string model based on the assumption from inextensible to extensible elastic beam models, considering the effect of bending stiffness, sag, inclination, and lateral components [5, 6]. A reduced cable-support coupled model was proposed to investigate the modal resonant dynamics of cables with a flexible support [7]. The nonlinear dynamic behavior of clustered tensegrity structures was analyzed using a positional formulation by the finite element method [8]. A design methodology was developed for the seismic qualification of safety-related cable tray support systems [9]. In the case of antielectromagnetic interferences, the ampacities of cables laid on trays were calculated by solving heat transfer equations [10–12] and computed using the finite element method [13, 14]. There were the reports about the mutual electromagnetic coupling between cables in enclosed and open trays [15], the transfer impedance of an enclosed cable tray in terms of the ratio of width to height as well as the connecting scheme between cable trays [16, 17], the analytical interpretation of electromagnetic interference between open cable trays of solid-bottom type [18], etc. For flame retardant capability of cable tray, there have been growing interests in understanding and predicting the fire development since the cable tray fire in 1975 at Browns Ferry

Nuclear Power Plant. Most of the work were concentrated on experimental and numerical analyses of cable tray fires, in either open atmosphere or in confined and mechanically ventilated compartments [19–22], as well as the fire behavior of the cable tray arrangements [23, 24]. The models for flame spread behavior were developed to estimate the heat release rate for the vertical cable tray fire [25] and to predict the fire development of the cable tray based on the computational fluid dynamics [26].

In addition to the requirements mentioned above, however, new demands come into being for the cable tray, such as the large span, the lightweight, and the ease of construction [27] along with the progress in industrial technologies, especially with the idea and recognition of the resource-conserving and the environment-friendly societies. It should be pointed out that various meshless methods advance very fast in the regime of numerical simulations [28–30] in recent years, which can yet be regarded expectantly as an effective means in the simulation of cable trays. Since that the strength and stiffness are, as a matter of fact, always the most basic requirements of the cable tray, the relation between strength and stiffness of the cable tray will be discussed in the paper from a new point of view. In general, the strength refers to the capacity of a component to bear loads without damage, while the stiffness refers to the capacity of a component to resist deformation, of coarse the two concepts should not be confused. In terms of the requirements of normal service, both the strength and stiffness of the cable tray must be satisfied absolutely at the same time.

Actually, the safety concerns of strength always take precedence over those of stiffness either in theory or in practice for any bearing component. However, it can be seen obviously the diversity of the requirements for stiffness in a large number of components in engineering. For example, the restrictions on deformation are very strict for machine tool spindles. In contrast, all kinds of springs require greater deformation capacity to realize the function of energy storage or vibration isolation. Although the deformation of different components is varied in size and form, the essential prerequisite for those components is to meet the requirement of strength.

In the manufacturing process of the cable tray, on the other hand, it is often the case that the deformation or the deflection measurement will be carried out for inspecting the qualification of products, or for determining the safe working load as the basis of design, since the implementation of measuring deformation is more convenient than that of stress. What needs to be emphasized is that a structure works inevitably at elastic state on the whole under the normal service load correspondingly with a definite relationship existing between the load and deformation. From this point of view and following the concepts of energy and material saving and green manufacturing, the definition of the strength-stiffness ratio of bending beam is proposed for the cable tray in the paper. The relation between strength and stiffness of the cable tray is studied theoretically and comprehensively in-depth in order to promote the optimal design of the cable tray under the premise of ensuring safety and to improve the economic and social benefits of products.

2. Strength-Stiffness Ratio of Cable Tray

The various open cable trays can be classified as the ladder-type, the perforated-type, and the solid-bottom type, as shown in Figure 1, which can be applied for installing large-sized cables for power transmission and medium- or small-sized cables for instrumentation and control equipment, respectively.

Generally, the cable tray horizontally mounted can be simplified as the continuous beam of equal span with uniformly distributed load. For safety and ease of operation, the simply supported beams with uniformly distributed loads are taken as the mechanical model for the horizontally arranged cable tray in the design and test processes in various standards [31–34]. According to the bending beam theory in the mechanics of material, the cable tray in service must conform to both the strength and stiffness conditions, of which the strength condition can be written as

$$\sigma_{\max} = \frac{Mh}{I_Z} \leq [\sigma] = \frac{\sigma_{0.2}}{n}, \tag{1}$$

where $\sigma_{\max}$ and $M$are respectively the maximum stress and the bending moment on the dangerous section of the bending beam; I_z refers to the axial moment of inertia of the cross-section of beam; h_0 represents the side height of the cross-section, and h stands for the maximum distance from the cross-section to the neutral axis, as shown in Figure 2. There are in general $h \geq 0.5h_0$, but $h = 0.5h_0$ only, if the cross-section is symmetric about the neutral axis. $[\sigma]$ and $\sigma_{0.2}$ are respectively the allowable stress and the conditional yield stress of the material and n is the safety factor. The stiffness condition of the bending beam can be written as follows: where y_0 denotes the dimensionless deflection at the mid-point of the span, which is defined as the ratio between the deflection and the span l of the beam. The allowable dimensionless deflection $[y]$ is a control parameter in consideration of various factors such as the deformation limitation, the instability, the safety factor, and the experience from services. For the cable tray, the allowable deflection is set as $[y] = 1/200$ [32, 33], where the safety factor of the stiffness condition is the same with that of the strength condition of the cable tray. Obviously, to satisfy both the strength condition (1) and the stiffness condition (2) is always a basic concern to bear in mind throughout in the design of the cable tray.

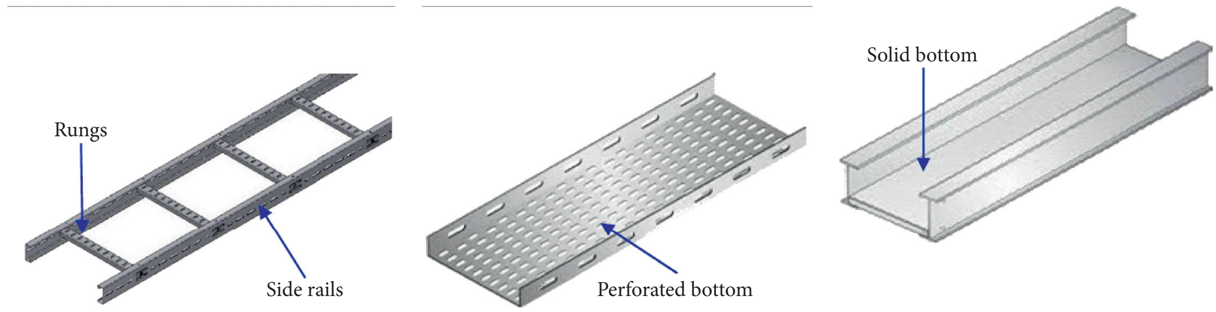
$$y_0 \leq [y], \tag{2}$$

On the other hand, the cable tray needs to be loaded to the limit state in the load test during the process of the quality control and the product acceptance. The limit conditions for the strength and stiffness are defined respectively in the paper as the inequalities when the strength or stiffness gradually reaches the limit state during the load test of the cable tray as follows:

$$\frac{Mh}{I_Z} \leq \sigma_{0.2}, \tag{3}$$

$$y_0 \leq y_{\max}, \tag{4}$$

where $y_{\max} = n[y]$ stands for the limit of dimensionless deflection. Either the strength or the stiffness of the cable



(a) (b) (c)

Figure 1: Types of cable trays. (a) Ladder-type. (b) Perforated-type. (c) Solid-bottom type.

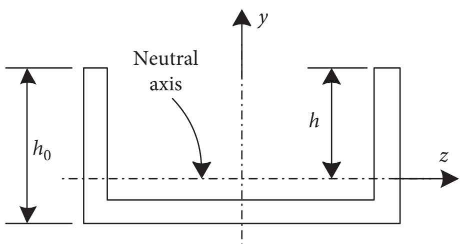


Figure 2: Schematics of cross-section and neutral axis of beam.

tray reaches its limit state; the inequality (3) or (4) takes the equal sign correspondingly. Obviously, the cable tray on the whole should be in an elastic state under normal service condition, which is also true during the load test until the moment where the load just reaches the limit state. In the elastic state, there are definite relations between the force and the deformation of the component, under which the material conforms to Hooke's law. Thus, the allowable strain $[\varepsilon]$ and the conditional yield strain $\varepsilon_{0.2}$ of the material can be defined respectively as follows:

$$[\varepsilon] = \frac{[\sigma]}{E}, \tag{5}$$

$$\varepsilon_{0.2} = \frac{\sigma_{0.2}}{E}, \tag{6}$$

where E denotes the Young's modulus of the material. In (5), the allowable strain $[\varepsilon]$ and the allowable stress $[\sigma]$ can be regarded as the material parameters in consideration of the safety factor. These two parameters are linked by Hooke's law. Rewrite the strength and stiffness conditions (1) and (2) and the limit conditions (3) and (4) in dimensionless form for the cable tray as follows:

$$\frac{Mh}{I_z[\sigma]} \leq 1, \tag{7}$$

$$\frac{y_0}{[y]} \leq 1, \tag{8}$$

$$\frac{Mh}{I_z \sigma_{0.2}} \leq 1, \tag{9}$$

$$\frac{y_0}{y_{\max}} \leq 1. \tag{10}$$

Based on the theory of the bending moment and the deflection of beam in statics [35], the ratio of strength and stiffness of the cable tray can be defined as follows by dividing the left sides of (7) and (8) along with equation (5):

$$\beta = C_\beta \frac{h[y]}{l[\varepsilon]}. \tag{11}$$

The strength-stiffness ratio can also be written in the following form:

$$\beta = \frac{\sigma_{\max}[y]}{y_0[\sigma]}, \tag{12}$$

where (h/l) is the height-span ratio of the cable tray. C_β represents the characteristic coefficient of the beam, which can be determined by the support form and the loading manner of the beam. It should be pointed out that the definitions of the strength-stiffness ratio given in equations (11) and (12) are exactly the same, wherein equation (11) is suitable for theoretical analysis, while equation (12) is convenient for getting the ratio by numerical calculation or load test in engineering. Since the cable tray on the whole works in elastic states, the strength-stiffness ratio can be obtained similarly using the limit conditions by dividing the left sides of equations (9) and (10) along with equation (6). It needs to be pointed out that the strength-stiffness ratio expresses the relationship between the strength and stiffness of the cable tray in a dimensionless form, but it is not directly related to the load. The characteristic coefficient of beam is defined as follows:

$$C_\beta = \frac{y''^{\max l2}}{y_{\max}}. \tag{13}$$

where $y_{\max}$ and $y''_{\max}$ indicate respectively the maximum values of the deflection and its second derivative of the beam. Note that the positions of the maximum deflection and the maximum second derivative of the beam do not necessarily coincide with each other. As is well known that, according to the beam theory, y'' is the approximate value of the curvature corresponding to the local deformation at the place in direct proportion to the bending moment in the cross-section of the beam. The distribution of bending moments depends on the loading manner and the support form of the beam. Since the deflection y can be obtained by integrating y'' twice in combination with the boundary conditions, C_β reflects the loading mode and the effects of support of the beam. From a mathematical point of view by comparing the y'' with y, there is the integral relation or the differential relation on the contrary between the two. In this sense, C_β can be regarded as a reflection of the relation between the local and the overall deformations of the beam, since y'' correlates to the characteristics of local bending deformation, while y more reflects the characteristics of the overall deformation of beam.

The three mechanical models of the beam under uniformly distributed load are compared comprehensively in Table 1, including the expressions of the characteristic coefficient of the beam, the strength-stiffness ratios, the maximum bending moment, and the midpoint deflection, where the position of the maximum bending moments is indicated in brackets. Among the three mechanical models, the simply supported beam acts as the basic mechanical model of the cable tray specified by the industrial standard [32–34]. The single-clamped beam represents the approximate model of the side span, while the clamped-clamped beam serves as the approximate model of the central section span of the continuous beam with equal span. The latter two models are both the statically indeterminate beams. It shows from Table 1 that the value of C_β varies in a large range, showing the effects of the constraint on the overall deformation of the beam. Of the three beams, the constraint of the simply supported beam is the weakest while that of the clamped-clamped beam is the strongest. The deflections of the single-clamped and the clamped-clamped beams are only 2/5 and 1/5 respectively of that of the simply supported beam, showing that there would be greater safety for the stiffness of the actual cable tray, compared with the mechanical model of the simply supported beam. It can be found by comparing the data in Table 1 that in terms of strength, although the maximum bending moment of simply supported beam is the same with that of single-clamped beam, the maximum bending moments occur at different positions for the two beams. The maximum bending moments of the single-clamped and the clamped-clamped beams occur both at the sections where the supports are located, indicating that the maximum bending moment of the cable tray as a continuous beam with equal span occurs at the sections at the supports, especially at the section of the second support of the side span. There are two other factors we need to pay attention to. Firstly, there is the stress concentration at the position in contact with the support of the cable tray, which is superimposed with the maximum bending stress on the section at the support. Secondly, it is often the case that the joints are just placed at the junction of the cable tray, at which the stress concentration would be significantly aggravated. Therefore, the cross-section at the second support would be the dangerous cross-section, or the weakest link of the whole cable tray, which needs to pay special attention in the design.

For the convenience without loss of generality in what follows, the value of the strength-stiffness ratio of the simply supported beam is set as $\beta = 1$ in Table 1, while all other parameters for each beam are kept unchanged.

3. Application of Strength-Stiffness Ratio

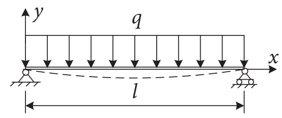
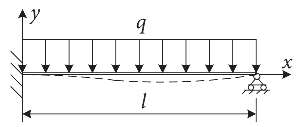
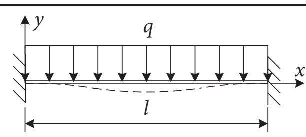
Under the premise of ensuring safety, if both the inequalities (7) and (8) are able to take the equal sign in the design, i.e., the strength-stiffness ratio $\beta = 1$, both the strength and the stiffness conditions of the cable tray can be satisfied at the same time. In this case, the utilization of material is the most reasonable, which would be thought as an ideal working condition. Considering the wide range of demand and the substantial product yield and output value for the cable tray [1], making the cable tray service in the ideal working condition will help to bring about economic and social benefits to the maximum. It needs to be pointed out that, unless otherwise specified, the discussion in what follows in the paper will focus on the simply supported beam under uniformly distributed load as the basic mechanical model of the cable tray.

3.1. Strength-Stiffness Ratio in Design. According to equation (11), the strength-stiffness ratio of the cable tray is related to the allowable strain $[\varepsilon]$ of the material, the allowable dimensionless deflection $[y]$ of the beam, the height-span ratio (h/l), and the characteristic coefficient C_β. The ratio reflects the relation between the local deformation and the overall deformation of the cable tray to some extent. As stated above, since there are many factors affecting the strength-stiffness ratio of the cable tray, the value of which varies in a large range, it would not be easy to make the cable tray work just in the ideal condition. On the other hand, however, many factors will leave room for the subjective initiative of designers to make the value of strength-stiffness ratio β close to 1 for the cable tray in the design process.

From the design point of view, if the strength-stiffness ratio is greater than 1, the safety in stiffness will be higher than that in strength for the cable tray. Specifically speaking, the strength condition of the beam will just be satisfied when inequality (7) takes equal sign, while the left hand side of the stiffness condition (8) will certainly be less than 1. Then, the bearing load on the beam can be taken as the allowable load or the safe working load when the strength condition (7) is set to be equal. It shows that the stiffness condition of the cable tray will always be satisfied as long as the strength condition is satisfied in the case if the strength-stiffness ratio β is greater than 1. For example, if the cable tray is working under the safe working load at the full load, then the maximum stress of the dangerous section is equal to the allowable stress, while the maximum dimensionless deflection of the cable tray does not reach the allowable value, which is only $(1/\beta)$ of the allowable deflection.

The situation is exactly the opposite when the strength-stiffness ratio is less than 1. The stiffness condition (8) of the beam will just be satisfied when inequality (7) is set as equal, while the left hand side of the strength condition (7) will

Table 1: Comparison of mechanical models for three kinds of beams with uniformly distributed loads.

Support form	Diagram of the beam	C_β	B	Maximum bending moment	Midpoint deflection
Simply supported		9.6	1	$(ql^2/8)\,(x = (l/2))$	$(5ql^3/384EI_z)$
Single-clamped		24	2.5	$(ql^2/8)\,(x = 0)$	$(ql^3/192EI_z)$
Clamped-clamped		32	3.33	$(ql^2/12)\,(x = 0, l)$	$(ql^3/384EI_z)$

certainly be less than 1, which means that as long as the stiffness condition of the cable tray is satisfied, the strength condition can always be satisfied. For example, assuming that the strength-stiffness ratio $\beta = 0.9$, at the moment when the maximum dimensionless deflection of the cable tray reaches the allowable deflection, the maximum stress on its dangerous section is only 90% of the allowable stress. In this case, the strength potential of material has not yet been fully utilized.

3.2. Strength-Stiffness Ratio in Test. The tests of the cable tray can be classified into the design and the verification tests according to the purpose of test. The design test can improve the design process to obtain a reasonable safe working load. It is noticed from the industrial standard [32, 33] that the load at the time of generating 1/200 residual deflection is taken as the ultimate load. The fact that the residual deflection of the cable tray occurs indicates that the maximum stress on the dangerous section meets or even slightly exceeds the conditional yield stress of the material when the load reaches the limit, i.e., the ultimate strength condition (9) takes the equal sign, if the effects are not taken into consideration of the local plastic deformation at the place of local stress concentration of components, and the creep at room temperature of the material, etc., if there would be no cracks and the local instabilities including the side flanging, the lateral bending, the buckling, and the wrinkle in the process of loading. Validation tests are used for the quality control and sampling inspection in the production process or for the acceptance of user products.

In the case that the strength-stiffness ratio β is greater than 1, the test should be carried out by load control with stepwise loading in combination with the deflection measurement of the test sample in both the design and the validation tests. Since at the moment when the limit strength condition (9) reaches equal sign, the left hand side of the limit stiffness condition (10) is always less than 1. Before the deflection of the cable tray reaches the prespecified limit, its dangerous section will enter the plastic state first and begin to form plastic hinge. As a result, a certain amount of residual deflection will remain after unloading. The maximum load before unloading can be taken as the ultimate load if the value of residual deflection is within the specified range. By taking advantage of this phenomenon, the value of the safe working load can be determined. If the value does not meet the demand in engineering, however, the structural design needs to be further modified and improved. For the validation test, as long as the cable tray is in the elastic range during the loading process, the maximum deflection will not exceed the specified limit value of deflection.

On the contrary, in the case that the strength-stiffness ratio β is less than 1, the test should be carried out by deflection control. If the residual deflection is used to obtain the safe working load, however, since at the moment the limit strength condition (9) reaches the equal sign, the left hand side of the limit stiffness condition (10) must be greater than 1, indicating that the deflection of the cable tray is out of the limit or the stiffness is not up to standard. Another way of test is to load the cable tray step by step until the ultimate deflection. At the moment of ultimate deflection, the limit stiffness condition (10) takes the equal sign, and in what follows, unloading. In this case, the safe working load can be obtained correspondingly, in conjunction with the safety factor by the limit load defined at the moment of the limit deflection, see [30]. It needs to be pointed out that the left hand side of (9) is always less than 1 under the limit load defined in this way, since (10) takes the equal sign. At this moment, the maximum stress on the dangerous section of the cable tray does not reach the yield stress of the material, indicating that a relatively safer allowable working load is obtained.

In fact, the safety concerns of strength always take precedence over those of stiffness either in theory or in practice for any load bearing component. Therefore, considering both the sufficient development of the strength potential of material and the feasibility of the deflection test, it would be reasonable to make the strength-stiffness ratio less than and close to 1 in the design, which is beneficial to the load deflection controlled test of the cable tray. It can be seen from Table 1 that the strength-stiffness ratios of the single-clamped and the clamped-clamped beams are comparatively much greater than that of the simply supported beam. They are respectively 2.5 and 3.33 times of that of the simply supported beam. Even if the strength-stiffness ratio of the simply supported beam is less than 1, the strength-stiffness ratio of the cable tray as a continuous beam with uniformly distributed load may eventually be greater than 1, showing further the rationality of making the strength-stiffness ratio less than 1 for the simply supported beam.

3.3. Numerical and Experimental Determinations of Strength-Stiffness Ratio. With the development of numerical analysis and the popularization of the finite element software, the finite element method has become increasingly an important means for design and optimization of the cable tray. The strength-stiffness ratio of the cable tray can be obtained readily with equation (12) by making use of the finite element results. In equation (12), the allowable stress $[\sigma]$ and the allowable dimensionless deflection $[y]$ are both the known parameters. y_0 and $\sigma_{\max}$ are respectively the maximum dimensionless deflection and the maximum stress obtained from the finite element results. It is important to note that the computed objects overall should be in the elastic state under loading. $\sigma_{\max}$ can be the maximum equivalent stress, taking from the cross-section with the maximum bending moment located on a surface with a distance of h from the neutral axis, as shown in Figure 1, rather than from a position of stress concentration on the component.

With the aid of the stress testing technique, it is also convenient to obtain the strength-stiffness ratio of the cable tray with (12) according to the results of the load test. In this case, y_0 and $\sigma_{\max}$ are respectively the maximum dimensionless deflection and the maximum stress obtained from the test. Once the strength-stiffness ratio is available, whether from calculation or experiment, it can be used as a reference for the optimal design of components in order to maximize the potential of materials. It needs to be pointed out that, no matter how powerful the computing software develops, the numerical calculation cannot replace theoretical analysis and thinking. The experiment under the guidance of theory is the final test of the results from theoretical analysis and numerical computation. In theory, computation and experiment are mutually reinforcing and complementary with each other.

3.4. Effect of Strength-Stiffness Ratio on Load Tests in a Series of Span. The standard spans are specifically recommended for the manufacturer in the standard [32, 34] of the cable tray. It is often the case, however, that the distances of supports and hangers at the installation site are not always equal to the recommended spans in design. In view of this issue, the load tests in a series of span are recommended in some standards to obtain the load-span curves, or the load characteristic curve of the cable tray [32, 34]. In practical terms, the maximum load of the test is specified in the standards according to the strength conditions. For ease in measuring, on the contrary, the stiffness-based criterion is also specified to determine if the cable tray is qualified by the value of dimensionless deflection measured from the test. If qualified, the values of the corresponding load will be converted into the safe working load. Then, the load characteristic curves of the products can be obtained by summarizing the test results.

For the simply supported beam with uniformly distributed load, the maximum bending moment of the cable tray is proportional to the square of the span, while the maximum dimensionless deflection is proportional to the cubic of the span [35]. For the sake of discussion, suppose that the cable tray with standard span works just in the ideal condition with the strength-stiffness ratio $\beta = 1$. Denote the standard span as l_0; the curves of dimensionless load (q/q_0) based on both the strength condition and the stiffness condition are shown in Figure 3, respectively, where q_0 represents the safe working load (N/m), corresponding to the standard span l_0.

It can be seen from Figure 3 that the two load characteristic curves of the cable tray are not the same, which are divided into two parts according to the size of span. In the part that the dimensionless span (l/l_0) is less than 1, the strength-stiffness ratio of the cable tray β is greater than 1 with a great difference between the two load characteristic curves. As discussed previously, if the strength-stiffness ratio β is greater than 1, the test should be carried out by load control with stepwise loading in conjunction with the deflection measurement of the test sample, whereas in the part that the dimensionless span (l/l_0) is greater than 1, the strength-stiffness ratio β is less than 1 and the curve based on the strength condition is located above the curve based on the stiffness condition so that the relatively safer working load can be obtained through the load test with deflection control. It can be seen also from Figure 3 that in the part that (l/l_0) is greater than 1 or β is less than 1, there is no much difference between the two curves, which is considered within the acceptable limits in engineering, showing further the rationality of making the strength-stiffness ratio less than 1. As a matter of fact, it would be more reasonable to redesign the cable tray in case of big difference between the distances of designed spans and the supports and hangers at the installation site.

3.5. Effects of Materials on Strength-Stiffness Ratio. When the safety factor is given, the allowable strain $[\varepsilon]$ is the maximum allowable elastic strain of the material from equation (5). At present, there are many kinds of cable tray products in the market. Common examples include low-carbon steels, stainless steels, aluminum alloys [36], and engineering plastics [37]. It is known from equation (11) that if all parameters are kept unchanged, the influence of the material on the strength-stiffness ratio β of the beam is embodied in the values of the allowable strain $[\varepsilon]$ or the value of the conditional yield strain $\varepsilon_{0.2}$ of the material after considering the safety factor. The reference values of performance parameters of commonly used materials for the cable tray are listed in Table 2, where the conditional yield strengths of engineering plastics are estimated as half of the tensile strength. For ease of comparison, suppose that the cable tray made of low-carbon steel just works under the ideal state with its strength-stiffness ratio $\beta = 1$. It can be seen from

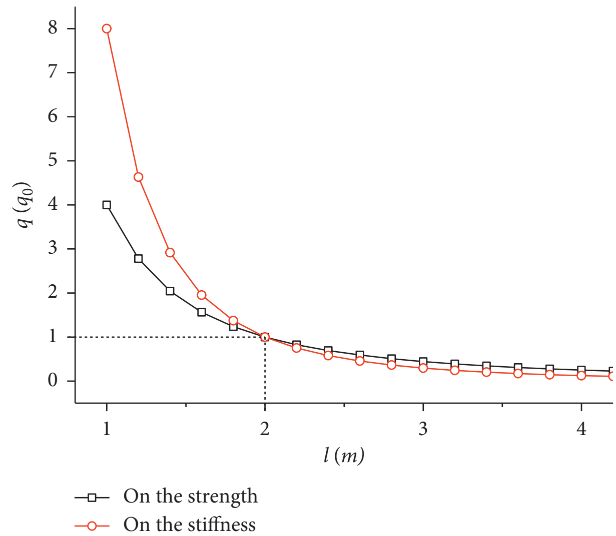


Figure 3: Comparison of load characteristic curves of cable tray.

Table 2: Effect of materials on the strength-stiffness ratio β

Material	Brand	Young's modulus, E (GPa)	Conditional yield strength, $\sigma_{0.2}$ (MPa)	Conditional yield strain, $\varepsilon_{0.2}$ ($\times 10^{-3}$)	Strength-stiffness ratio, β
Low-carbon steel	Q235	210	235	1.12	1
Stainless steel	304	194	205	1.06	1.056
Aluminum alloy	LF21	69	50 ~ 130	0.725 ~ 1.88	0.40 ~ 1.03
Engineering plastics	Nylon 6	0.8 ~ 2.6	~ 30	~ 17.6	~ 0.064
Engineering plastics	PVC	2.9 ~ 3.4	~ 30	~ 9.5	~ 0.118

Table 2 that there is little difference between the values of the conditional yield strain of stainless steel and low-carbon steel so that the values of the strength-stiffness ratio are very close for the cable tray made of these two materials. The allowable dimensionless deflection of aluminum alloy cable tray is specified as $[y] = 1/300$ [34], which is (2/3) of that of steel cable tray. The Young's modulus of aluminum alloy is only about one third of that of steel, the strength of which depends largely on the material process state. The strength-stiffness ratio of the cable tray made of aluminum alloy will approach that of steel only in the state of cold-working hardening. The properties of engineering plastics depend also on the state to a large extent [37]. In general, since the strength of engineering plastics is lower than that of steel by about one order of magnitude, the Young's modulus of engineering plastics is lower than that of steel by about two orders of magnitude; the value of the conditional yield strain of engineering plastics is relatively higher. Therefore, in the design process, it needs to pay attention that the strength-stiffness ratio of the cable tray made of engineering plastics is much smaller than that of the metal-made cable tray with the same sizes [38].

4. Conclusion

(1) In the paper, the definition of the strength-stiffness ratio of the cable tray is proposed, with which the relation between the strength and stiffness of the cable tray under static load is expressed quantitatively in a dimensionless form. There is no direct link between the strength-stiffness ratio and the load.

(2) The strength-stiffness ratio depends on many factors such as the allowable strain, the allowable dimensionless deflection, the height-span ratio, and the characteristic coefficient of beam, which reflects the relation between the local and the overall deformations of the cable tray to some extent. A reasonable strength-stiffness ratio is beneficial to give full play to the strength potential of the material.

(3) It would be reasonable to make the strength-stiffness ratio less than and close to 1 in the design, which is beneficial to the utilization of materials and the load deflection controlled test of the cable tray, to obtain a relatively safer allowable working load. The value of the strength-stiffness ratio is obtainable using either the finite element method or the load test of the cable tray.

(4) The two curves of load characteristics of the cable tray are not the same obtained from the strength and the stiffness conditions. The difference between the two curves of load characteristics is considered acceptable within the limits in engineering in the range that the value of the strength-stiffness ratio is less than 1.

(5) As a continuous beam with equal span of the horizontally mounted cable tray, the maximum moment and the maximum bending stress are located at the

cross-section of the second support on the side span. Considering the stress concentration in the contact position between the tray and the support, as well as the aggravation of the stress concentration in the joint connection of the cable tray, the section at the second support of the side span is the weakest link of bearing capacity of the cable tray. These issues require special attention in the design and manufacture of the cable tray.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The work was supported by the Natural Science Foundation of China (no. 11672173).

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