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Force Determination in Short Steel Rods Based on an Experiment

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Abstract. There are many structures in building and civil engineering where the important structural elements are loaded by a significant tensile force (e.g. tension bars of building structures). In many cases it is important to know the real value of tensile forces in tensile structural elements for assessment of their reliability. The four experimental approaches are applied for evaluation of tensile forces in practice most often. One of them is the vibration frequency method which is very suitable for experiments done only one time or occasionally, especially in cases when the investigated structural elements are already activated and the application of an experimental method is inevitable in this situation. The experiment, which is described in this paper, was focused on the tensile force determination in steel rods which were very short and relatively stiff. The evaluated tension forces of the investigated short steel rods were affected by a significant error when only the simple models (the simply supported beam and the fixed beam) and measured natural frequencies were used. In order to precise the evaluated tension forces, the theoretical beam model supported by simple supports with torsion springs ("the elastically fixed beam") and the measured natural modes of the rods had to be necessarily taken into account.

Introduction

There are many structures in building and civil engineering where the important structural elements are loaded by a significant tensile force (e.g. tension bars of building structures, external prestressing cables of prestressed concrete bridges, cables of cable-stayed bridges, suspender rods of suspender bridges, support cables and edge cables of tension fabric structures). In many practical cases it is important to know the real value of tensile forces in tensile structural elements for assessment of reliability both during construction and during operation of a building or civil engineering structure.

The four experimental approaches are applied for evaluation of tensile forces in practice. One is the method that directly measures the element tensile forces by a pre-installed load cell. The second one is the approach that evaluates the tensile force in a cable on the base of the measured transverse force and the measured transverse cable displacement caused by the force [1,2]. The third one is the magnetoelastic method [3] and the fourth one is the vibration frequency method that indirectly evaluates the tensile force using the measured natural frequencies [4,5,6].

The vibration frequency method is often used in practice because it provides an efficient, cheap and relatively easy way to determine the element tensile forces and a standard measuring line for dynamic experiments can be used. If the setup of an experiment and the evaluation procedure are chosen suitably, the method provides results precise enough for majority of tension structural elements.

The experiment, which is described in this paper, was focused on the determination of the tensile forces in steel rods which were very short and relatively stiff. The evaluated tension forces of the investigated short steel rods were affected by a significant error when only the simple models (the simply supported beam and the fixed beam) and measured natural frequencies were used. In order to precise the evaluated tension forces, the theoretical beam model supported by simple supports with torsion springs ("the elastically fixed beam") and the measured natural modes of the rods had to be necessarily taken into account.

Description of the Experiment

After finishing of a building structure the investor of the building wanted to verify forces in thirty six short steel rods, tension bars in four anchors of one part of the building (see Fig. 1), experimentally. The vibration frequency method was chosen for the experiment, because all anchors were already activated and deactivations or removals of the investigated rods were impossible. Not only the natural frequencies (see Table 1) but also the basic natural modes were measured for all investigated rods (see Fig. 2, Fig. 3 and Fig. 4).

The vibration of observed rods was excited by a force impulse and the rod response in nine measured points (see Fig. 1) was recorded by the nine piezoelectric acceleration transducers Brüel&Kjaer type 4507 B005. Two coupled vibration control stations Brüel&Kjaer Front-end 3109, 3560B120, and control software Pulse were used for measurement control.

Fig. 1. The view on the four investigated steel rods (the rods No. 1a, 1b, 1c and 1d) and on the placed accelerometers on the rod No. 1b.

Evaluation of the Tensile Forces

The length of the investigated steel rods was very short (the length of the shortest rod was 2.07 m and of the longest one 2.42 m) and the bending stiffness was relatively high (the diameter of all rods was 45 mm). It was completely obvious based on previous autors' experiences, that the simplest theoretical models (the string model [4,5,6], the simply supported beam [4,5,6] and the fixed beam [5,6]) were not appropriate for modelling of the investigated steel elements.

Therefore the elastically fixed beam, which is described in detail in [5,6], was used for modelling of the individual steel rods by identification of the rod tensile forces N_T because the results for the simplest rod models would have been affected by significant errors, as it is shown in the Table 1. The tensile forces evaluated by using of the string model and the simply supported beam would have been much greater than the real rod forces and the forces determined on the fixed beam would have been smaller than reality (see Table 1). The zero forces in the column "FB" of the Table 1 mean that the pressure force was evaluated for the steel rod and it is physically impossible thing.

Table 1. The four selected rods - the rod parameters and the evaluated tensile forces determined based on four different theoretical models (SM – the string model, SSB the simply supported beam, FB – the fixed beam, EFB – the elastically fixed beam).

The rod No.	The rod length [m]	The measured natural frequencies		The evaluated tensile forces N_T			
				The used theoretical model			
		$f_{(1)}$ [Hz]	$f_{(2)}$ [Hz]	SM [kN]	SSB [kN]	FB [kN]	EFB [kN]
1a	2.10	43.6	118.1	593	373	0	33
1c	2.29	38.9	102.0	539	356	0	79
2d	2.37	39.5	100.3	571	401	45	154
3b	2.20	39.2	107.0	531	333	0	28

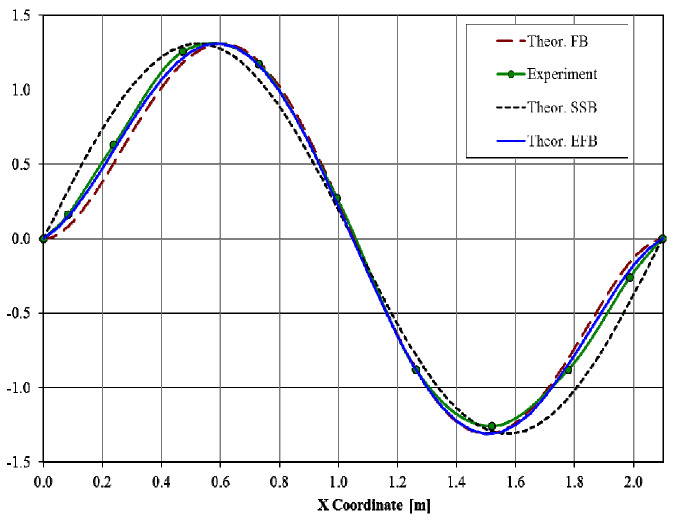


Fig. 2. The steel rod No. 1a – the comparison of the theoretical and measured 2nd natural mode shapes.

The used elastically fixed beam was described by its length L, bending stiffness EI and stiffness of torsion spring k_ζ . The mass of the beam was considered as the continuously distributed mass μ. The length L and the continuously distributed mass μ were assumed constant by identification. The other parameters of the model (the cable tensile force N_T , the bending stiffness EI and the torsional stiffness of the supports k_ζ) were variables. The great number of combinations of the values N_T, EI a k_ζ was generated using random number generator. For each generated combination of values, the natural frequencies and mode shapes were calculated. Subsequently, the degree of conformity between the theoretical and experimental characteristics of the natural vibration of the rod was evaluated. Not only the natural frequencies and also the natural modes were taken into account by conformity assessment.

There are the tension forces N_T in column "*EFB*" of the Table 1 which were evaluated by help of the procedure mentioned above. The identified stiffness of the torsion spring was different for individual steel rods (e.g. 685 kNm for the rod No. 1a, 452 kNm for the rod No. 1c, 284 kNm for the rod No. 2d, 530 kNm for the rod No. 3b).

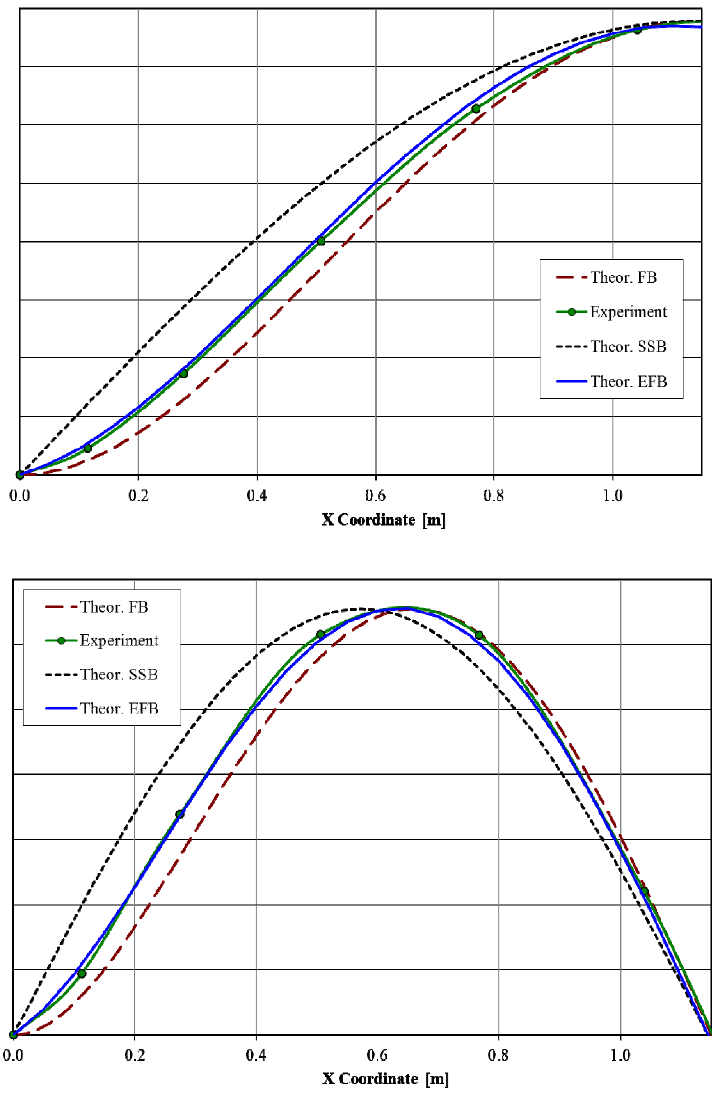
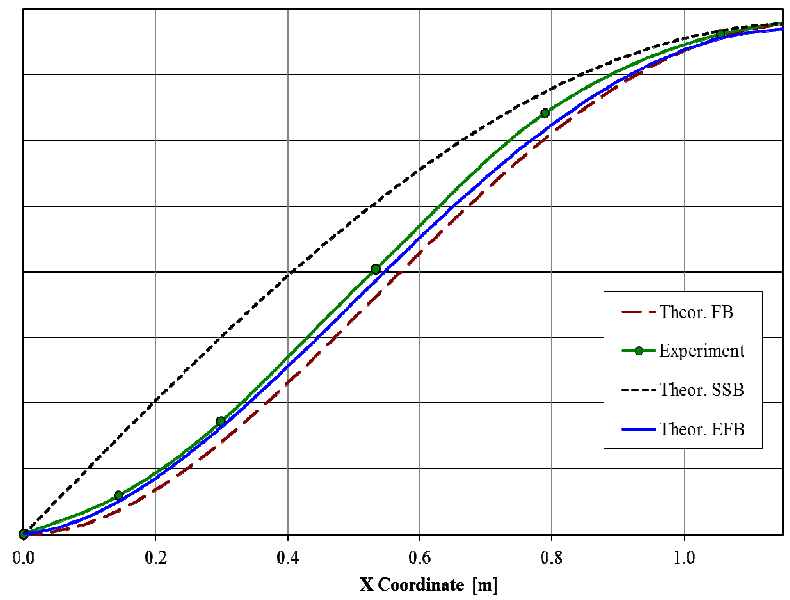


Fig. 3. The steel rod No. 1c – the comparison of the theoretical and measured natural mode shapes on the half of the rod length (above – the 1st mode shapes, below – the 2nd mode shapes).



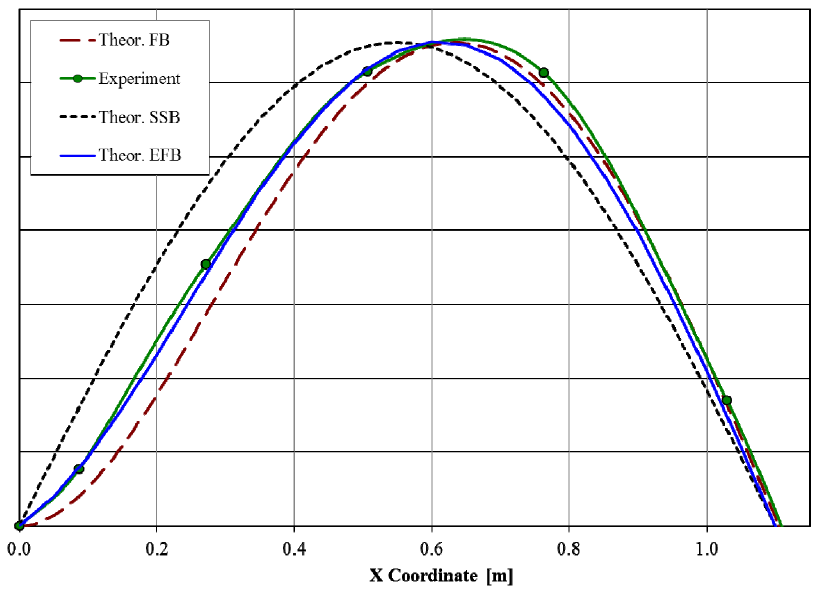


Fig. 4. The comparison of the theoretical and measured natural mode shapes (above – the 1st mode shapes of the steel rod No. 2d, below – the 2nd mode shapes of the steel rod No. 3b).

As it is evident from the Table 1, Fig. 1, Fig. 2 and Fig. 3, the real properties of the investigated steel rods lay between two boundaries which were described with two models. On one hand, it was the simply supported beam, and on the other hand, it was the fixed beam. The interval between these two boundaries was too large for the investigated steel rods and the identification result specification based on the elastically fixed beam had to be taken into account.

There is visible in the Fig. 2, Fig. 3 and Fig. 4 that the real measured natural mode shapes lay between the limits – mode shapes of the simply supported beam (SSB) and mode shapes of the fixed beam (FB). The theoretical natural mode shapes calculated on the identified elastically fixed beam (EFB) model are close to the measured natural modes as it is shown in the Fig. 2, Fig. 3 and Fig. 4.

Conclusions

The vibration frequency method is very suitable for experiments done only one time or occasionally, especially in cases when the structural elements are already activated and the application of a method is inevitable in this situation. If the setup of an experiment and the evaluation method are chosen suitably, the method provides results precise enough for majority of tension structural elements.

The theoretical model with the elastically fixed supports ("e.g. the elastically fixed beam") have to be necessarily taken into account when short and relatively stiff structural elements are tested. The results can be made more precisely using the detailed analysis of the measured natural mode shapes. The evaluated tensile forces of the investigated short steel rods were affected by a significant error when only the simple models (the simply supported beam and the fixed beam) were used (see Table 1).

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