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Original Research Article

Static and dynamic stiffness of reinforced concrete beams

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ABSTRACT

In this paper experimental studies of reinforced concrete beams are reported. The influence of load on deflections and basic eigenfrequency was investigated. Eigenfrequencies were registered using the operational modal analysis. Static stiffness (on the basis of deflections) and dynamic stiffness (on the basis of eigenfrequencies) were obtained indirectly (with calculations). A comparative analysis shows that these figures differ in value. The paper is completed with the theoretical analysis.

1. Introduction

One of the fundamental principles of the theory of reinforced concrete structures states that the effects related to cracks impact the generalized displacements and redistribution of internal forces. This fact combined with some relevant scientific works [1,2], inspired the author to investigate the field of the reinforced concrete beams dynamics. The result of this investigation was to propose our own calculation model. The research involved a meticulous preparation of the experimental setup in order to assure the adequacy of the elements tested and calculation model. In view of the latter, the investigations were performed on precast beams. Thanks to that, the realization of a clear and close to ideal investigative scheme was possible. Moreover, dynamic analyses required suspending the beams on elastic ropes, as described in greater detail in the paper.

2. Experimental studies characterization

Experimental studies were performed on reinforced concrete beams in half-natural scale. Each of the elements had the dimensions of 3300 mm × 250 mm × 150 mm. The cross-sections with a reinforcement are shown in Fig. 1.

Series B-I, B-II, and B-III had the same tensile reinforcement ratio of 0.65%. The B-IV beams series were reinforced stronger (1.38%). The elements were made of the C25/30 class concrete. The longitudinal reinforcement was made using class A-IIIN rebars, while the stirrups were class A-I (classes of reinforcing steel according to [3]). The basic material properties are listed in Table 1.

The goal of the investigations was to estimate bending stiffness of the elements indirectly. The static stiffness was calculated on the basis of the beams' deflections. The deflections were registered with the inductive gauges with accuracy

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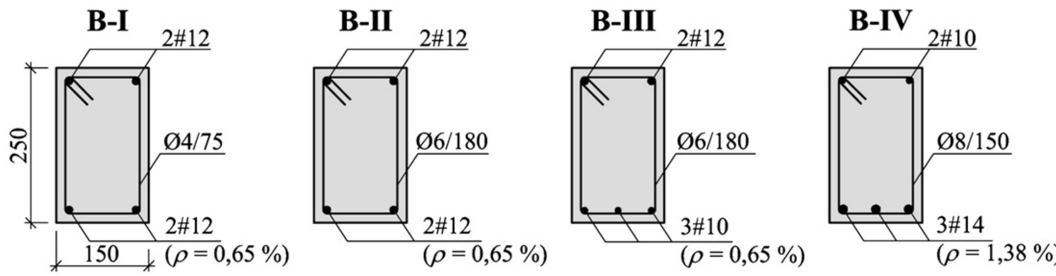

Fig. 1 – Investigative elements (dimensions in mm).

Table 1 – Basic material properties.

Material	Property	Series			
		B-I	B-II	B-III	B-IV
Concrete	Mean compressive strength, f_{cm} (MPa)	51.7	51.2	45.6	41.1
	Mean splitting tensile strength, $f_{ctm,spl}$ (MPa)	3.58	3.21	3.03	2.79
	Mean Young modulus, E_{cm} (GPa)	30.3	29.6	28.5	30.0
Steel (longitudinal rebars)	Mean yield strength, f_{ym} (MPa)	563	563	548	555
	Mean Young modulus, E_{sm} (GPa)	202	202	200	202

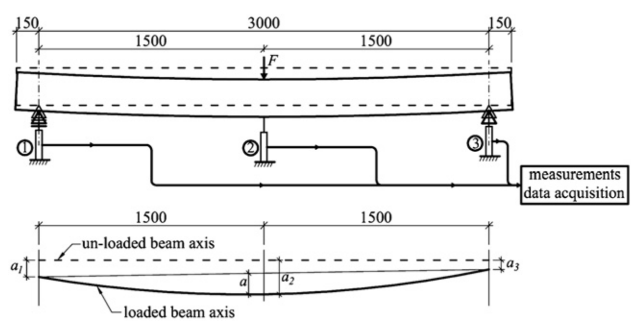

Fig. 2 – Experimental setup for the static analysis—sketch (dimensions in mm).

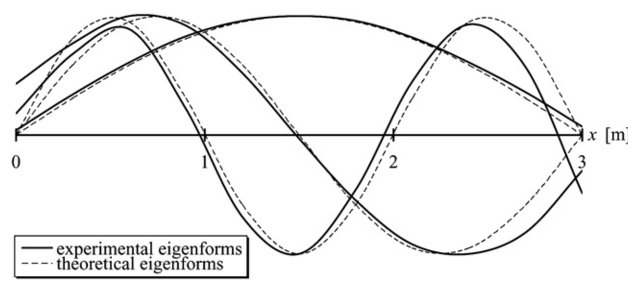

Fig. 3 – Eigenforms of a simply supported beam.

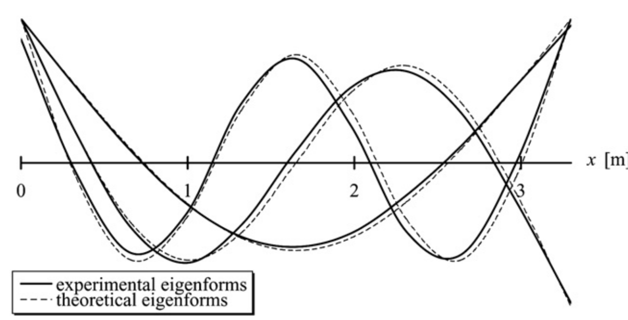

Fig. 4 – Eigenforms of a suspended beam.

of 0.001 mm. The beams were loaded with concentrated force applied at the mid-span (three points bending test). The scheme of the experimental setup is shown in Fig. 2. The deflection measurements at points 1 and 3 were carried out to register any potential settings of the supports.

Dynamic stiffness was calculated on the basis of the eigenfrequency. A Brüel & Kjær data acquisition and processing system was used in the measurements. The system uses the operational version of the modal analysis [4]—presently, a popular tool for nondestructive testing of engineering structures and machines. The system registers the beam's response (acceleration of certain points) on external random forces. The vibrations in the beams are caused randomly by the setup environment, and include acoustic noise, air flow, gentle strokes in investigative element. One of the main advantages of the operational modal analysis is that there is no need to measure the external triggering sources and separate the element under tests from any background influences. These characteristics are particularly desirable in case of large engineering structures (e.g. chimneys and bridges), when there is no practical possibility of eliminating wall external influences. The measurements yield basic dynamic parameters of the object investigated (eigenfrequencies, eigenforms, damping parameters).

In order to select the optimal investigative procedure, several preliminary analyses were carried out [5]. Two schemes were considered: one consisting of a beam suspended on elastic ropes while another involving a simply supported beam with an application of double sided, fastened screwed bearings. The acquired and theoretical three first eigenforms are shown in Figs. 3 and 4.

It may be noticed that better agreement between the measurements and theory is obtained for the case of a beam