# EXPERIMENTAL STUDY ON TORSIONAL STIFFNESS STRENGTH OF REINFORCED CONCRETE ELEMENTS WITH NORMAL CRACKS IN TORSION

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## Introduction

The article presents rectangular beams with normal artificial cracks test data, which are exposed to torque. The mode of failure of the samples, the impact of reinforcement and normal cracks upon stress-strain state of the samples is analyzed.

**Analysis of Publications and Problem Statement.**

A number of studies confirm that the torsional stiffness of the elements of reinforced concrete beams influences the redistribution of forces in reinforced concrete beams which are deformed [7 12, 14,15].

A great number of theoretical and experimental work is done on flexural rigidity research but only limited number of researches are done on torsional rigidity

In particular, it is found that the compressed torsion increases stiffness of a twisted rod: insignificantly with solid closed cross-section and to a greater degree with open section [10,13].

Central Scientific - Research Institute of Office and Residential buildings offered a convenient and practical way of stiffness test for twisted ribbed slabs [8].

The advantage of this test is that it takes into account physical nonlinearity of a concrete under bending as well as under torsion

In general, most of experimental and theoretical works concern the study of strength of reinforced concrete elements with cracks [11,16,19].

It is determined [6] that the presence of holes in the beams under bending with torsion effects the deformation property of experimental samples.

Deformability of straight section beams with through holes increases as height and length of the holes increase**.** This effect is apparent with hole height of 0,25$h_0$.

In these studies except the questions of strength the problem of cracking and crack angles to element edges is considered , different shapes of cross-sections, different relations of bending and torque forces, strength characteristic effect of concrete and reinforcement, spacing clamp, prestressing stress upon the strength of concrete element under bending with twisting are studied. In [18] and in others works experimental investigations on reinforced concrete beams, their deformations in the process of testing are given. However, the question of calculating of deformability and torsional stiffness isn’t considered. In [18] experimental study of bend- twist test of the beams with artificial cross-cut cracks is described.

However, much attention is paid to the research of strength characteristics of samples.

It is quite common when a concrete element has a single reinforcement and there are only normal cracks in it.

These elements include ribs of floor slabs. In spatially deformed flor slabs these elements are affected not only by bending but also by torque strengths.

Therefore, the purpose of the article is to analyze the results of experimental studies of stiffness characteristics of reinforced concrete beams of rectangular cross section with normal artificial cracks.

**Statement of the Basic Material.**

Concrete beams with rectangular cross section with normal artificially created slits simulating cracks were tested in the laboratory of Sumy concrete structures plant.

The purpose of this experiment was the determination of stiffening behavior as well as the strength of samples.

Experimental samples of reinforced concrete beam in sizes 1000x200 x120 mm were produced. (Fig. 1).

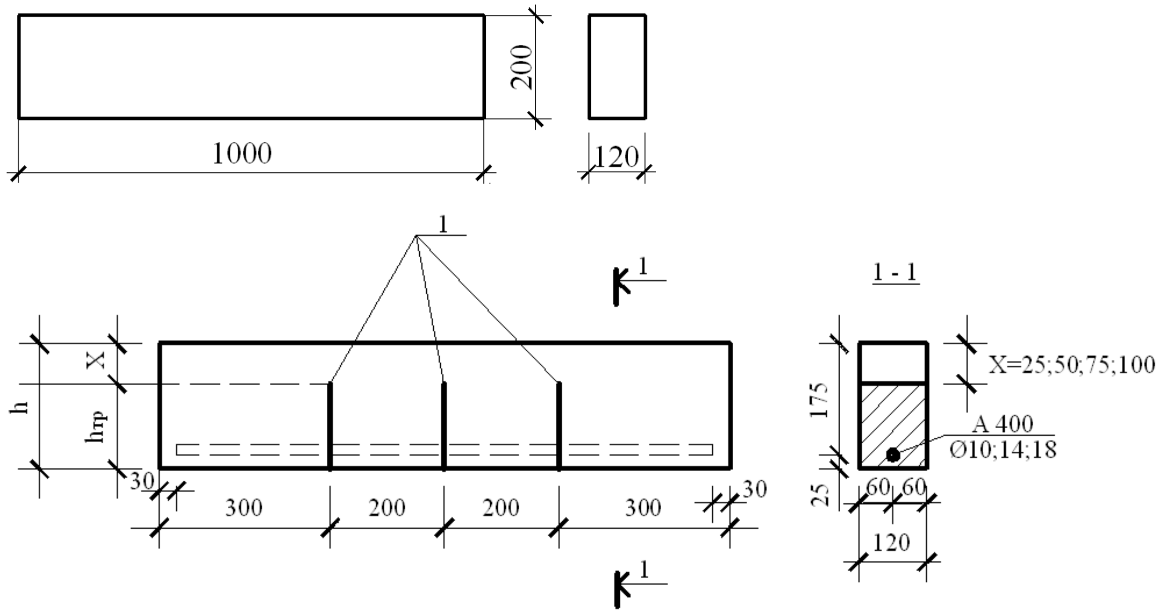



*Figure 1. Experimental beam*
*a) geometric data; b) beam adjustment with normal cracks into single parts; reinforcement scheme of the samples; 1- wood-fiber plate inset*

Fifteen beams of 5 types with ordinary longitudinal bar made of I-steg reinforcement: A-600c grade, diameter 10,14 i 18 mm were produced. There was no crosswise reinforcement.

Type classification of beams was performed depending on the cracks-free zone height, and subrange classification depending on the reinforcement diameter. Beams of the fifth type were produced without artificial cracks (see. Table 1).

Table 1

**Experimental beams marking**

| The height of the zone without cracks **x**, mm | Reinforcement diameter $\mathbf{d_s}$, mm | Beam mark |
|---|---|---|
| 25 | 10 | B 1-1 |
| 25 | 14 | B 1-2 |
| 25 | 18 | B 1-3 |
| 50 | 10 | B 2-1 |
| 50 | 14 | B 2-2 |
| 50 | 18 | B 2-3 |
| 75 | 10 | B 3-1 |
| 75 | 14 | B 3-2 |
| 75 | 18 | B 3-3 |
| 100 | 10 | B 4-1 |

| | | |
|---|---|---|
| 100 | 14 | B 4-2 |
| 100 | 18 | B 4-3 |
| No cracks | 10 | B 5-1 |
| No cracks | 14 | B 5-2 |
| No cracks | 18 | B 5-3 |

According to [3], during the determination of the compressive strength of concrete in six cube samples according to [3] it was determined that the concrete, these cubes were made of, is rated in the B30 class. Modulus of deformation of concrete which was obtained during the testing of eight prism-samples according to [5] was equal to 32097,5 MPa and that fact confirmed trueness in determination of concrete grade. Test data of reinforcement[4] with different diameters showed that the average yield strength equaled 584,98 MPa and is equivalent to reinforcement grade A 600.

General view of the experimental setup with the sample is shown in Fig. 2.

Sample load was carried out in stages, with 10 minutes delay on load.

For the load they used pre-weighed and marked artificial metal weights placed on the metal pallets in such a fashion that at each stage approximately the same load was kept.

During the study of stiffening behavior of samples with normal cracks at the stage of vertical loading displacement of two medium blocks *D* and *C* were measured relatively to two outside blocks *A* and *D* respectively (Figure 2,3)

Routine of experiment was thus the following:

- the sample was coated with four steel frames and it was mounted in base face boxes (Figure 2) the ends of the sample were fixed with bolts;

- the horizontal position of the sample in the setup was calibrated; frames were mounted on the sample as it was shown in Figure 3 and were fixed with the help of clamping bolts. 200 mm distance between frames P-1 and P-2, P-3 and P-4 was held(base measurement), which is equal to the length of the block between the cracks;

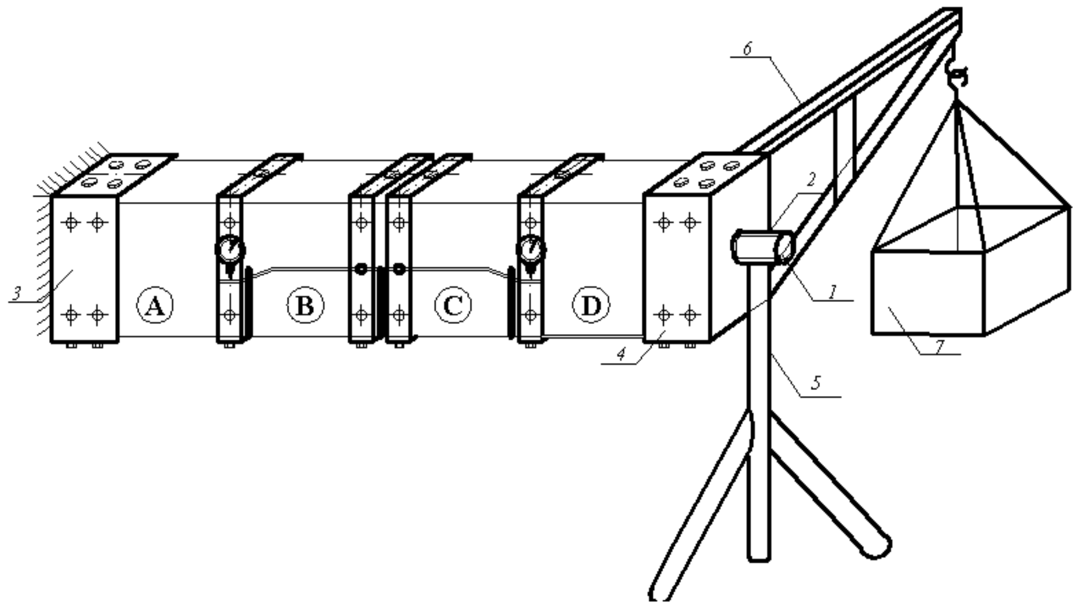



*Fig. 2 Test facility.*

*1-rotary unit welded to base duct ; 2-sleeve; 3- rigidly attached duct; 4- duct with swing support; 5-column; 6- lever; 7 – pallet*

- the distance between *DI -1* and *DI -2* stems and the lateral face of the beam was measured;

- experimental sample-beams were scaled in several stages with the help of metal weights which were put onto the duct and had approximately the same weight. All artificial weights were scaled and marked beforehand. The sample was under the load for 10 minutes. Gradually applied load lasted up to the destruction of the samples.

- at the beginning and at the end of every stage of loading data about displacement of units was filled in the indication log . Dial indicator was used.

**Reseach Findings.**

Beam-samples of the $1^{st}$ series could not be considered to be suitable for research because artificial normal cracks divided the sample into separate blocks before its installation in the test facility namely it happened at the time of erection load (in spite of low height of compression area). During the experiment with the beams of the $4^{th}$ series the defect of the test facility was detected, so the displacement value of the units divided by the cracks was incorrect.

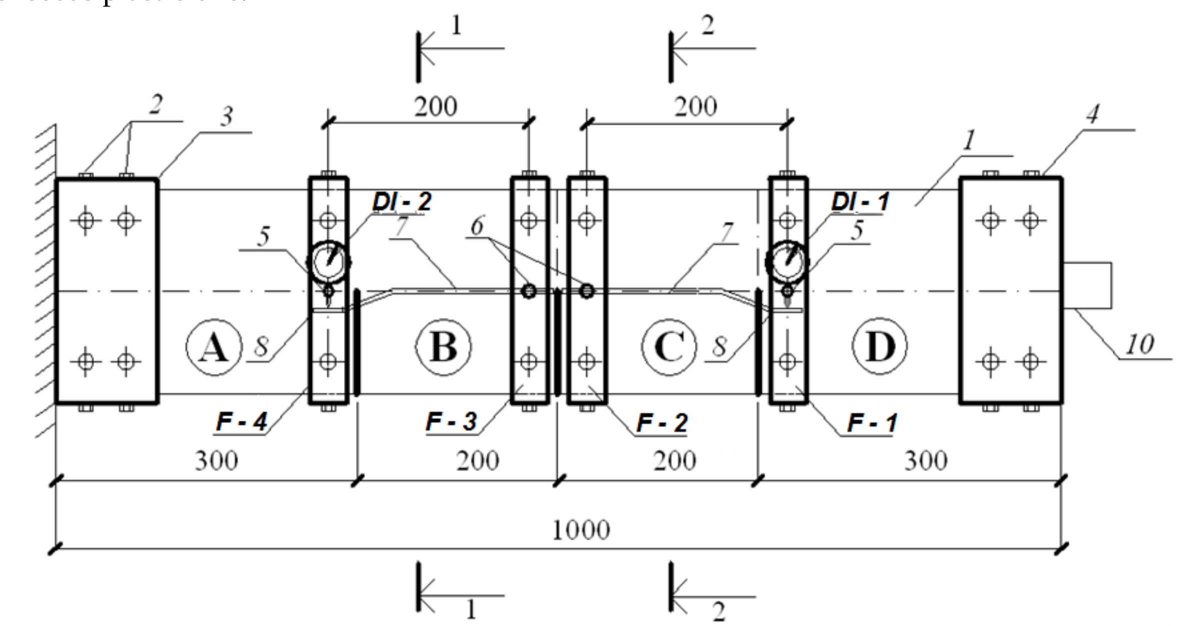
Analyzing dependences (Fig.4,5), we can come to the conclusion that the work of all experimental beams under torsion up to the moment of destruction was almost of elastic nature.

With the increase in the height of the compression area dependency "moment-displacement" became more linear and nature of work - more elastic.

Similarly with an increase of the diameter of longitudinal reinforcement the nature of work also became more elastic.

This “effect” is especially evident in beams with longitudinal reinforcement with the diameter of the rod of Ø 18 mm (Fig. 4, B).

So according to the dependences on the figure 5 it can be stated that “moment-displacement” curves for the beams of the $5^{th}$ series without cracks are almost of directly proportional nature. And in fase of loading in deformation of units the elastic component exceeds plastic one.



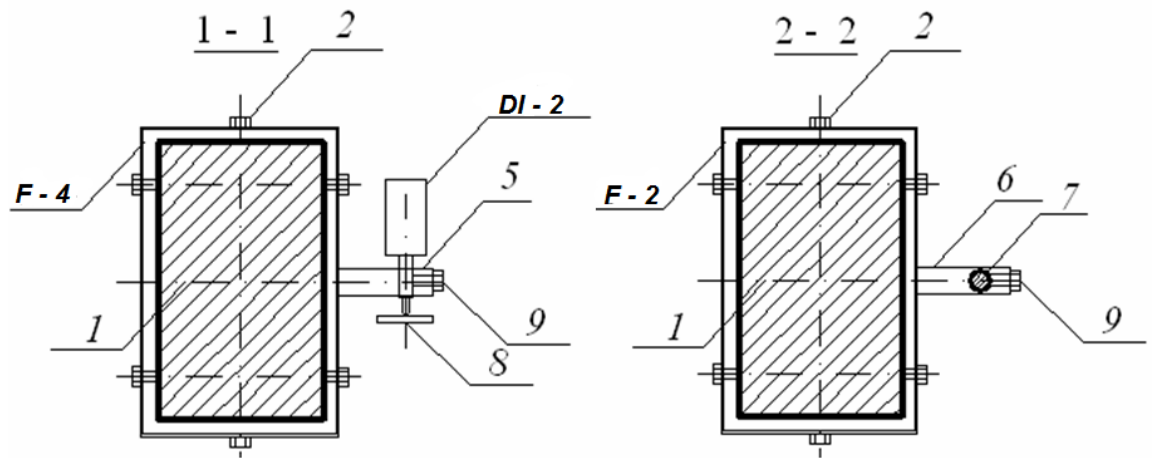
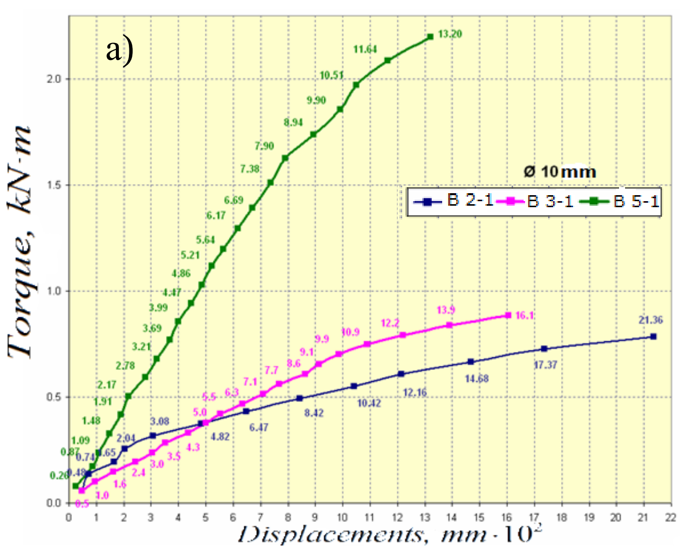
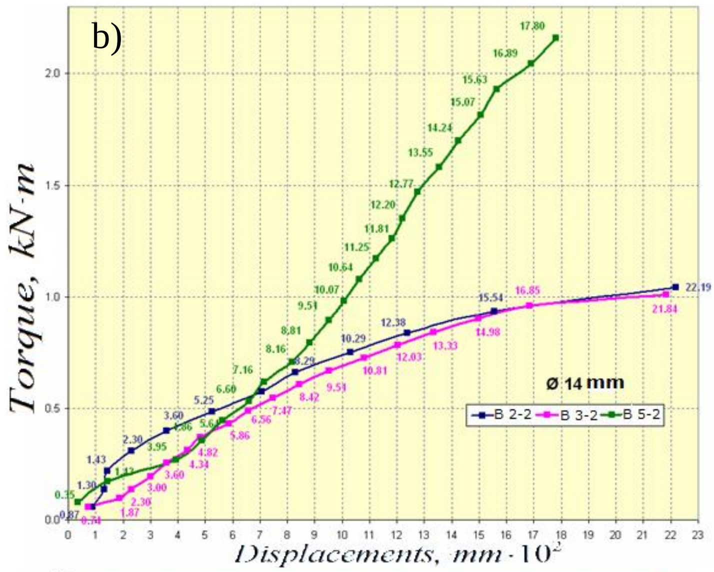



*Figure 3 Position measurement  plant for units divided by normal crack*

*DI -1, DI -2 – dial indicators; F-1, F-2, F-3, F-4 - steel frames of band steel; 1- experimental beam; 2 clamp  bolts; 3 base duct  tightly welded to the stand; 4 base duct  with rotary unit; 5-holder made of round steel for the indicator; 6- holder made of a round steel  for a rod; 7- rod; 8- thin plate; 9-clamping bolt for the indicator  and rod in  holders; 10- rotary unit*

a)





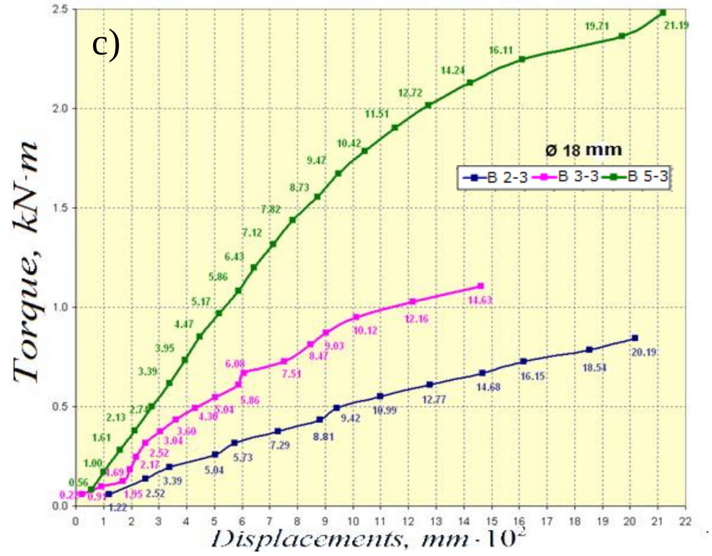
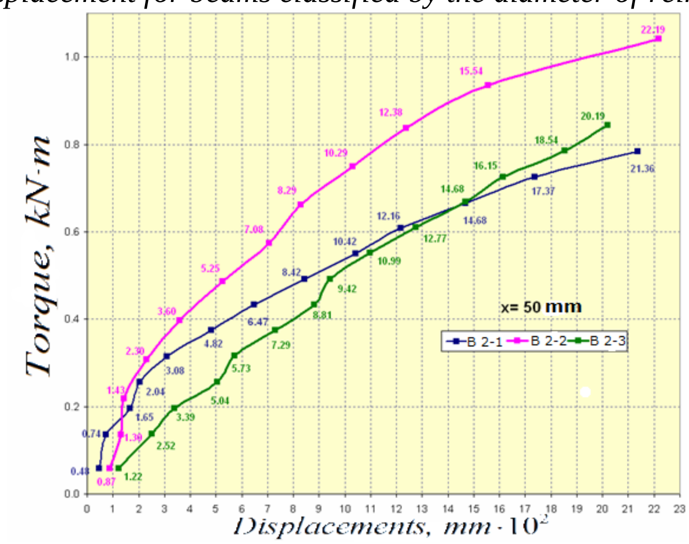




*Fig. 4 Displacement for beams classified by the diameter of reinforcement*



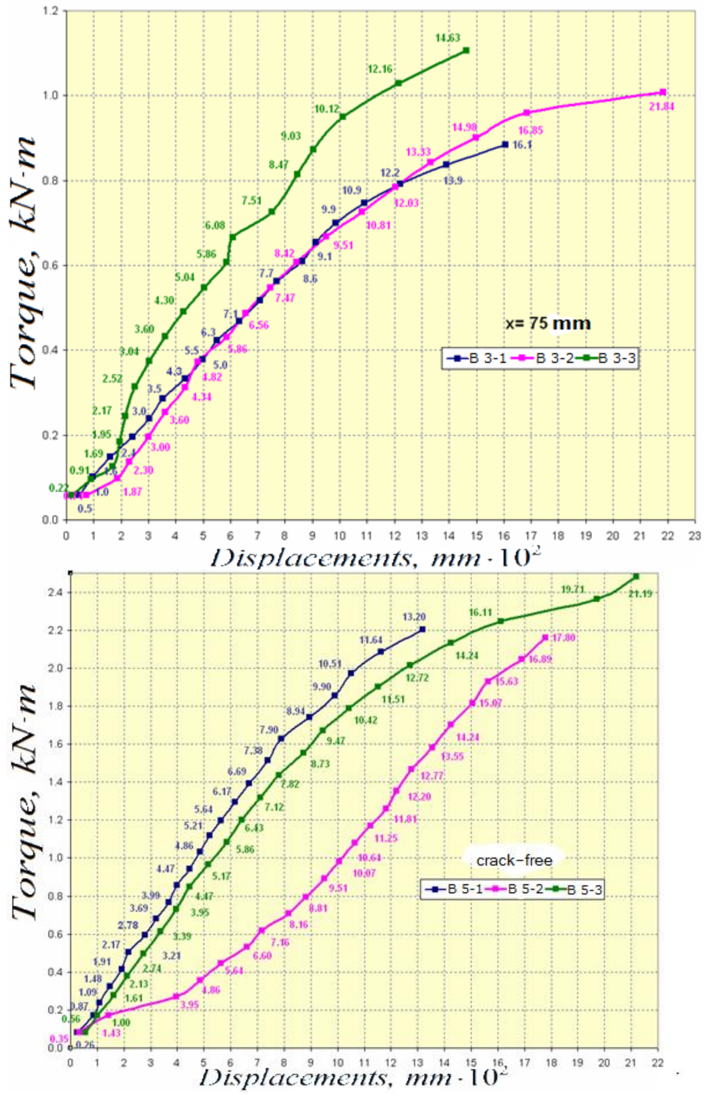



*Fig. 5 Displacement dependence on torque for beams, classified by height compression area*

Table 2 shows displacement value which was obtained experimentally and theoretically by the procedure described in [1]. At the same time this theoretical displacement was obtained as a displacement caused by the torsion of integral part of a block 200 mm long and displacement in the crack that consists of (see [1].) crumple and shift of reinforcement on both sides of the crack.

Table 2

| Beam mark | Reinforcement diameter (mm) | Compression area height (mm) | *Displacement, mm·10²* | | $\frac{a}{a_{test}}$ | Note |
|---|---|---|---|---|---|---|
| | | | Experimental, $a_{test}$ | Theoretical, $a$ | | |
| B-2-1 | 10 | 50 | 1,65 | 1,77 | 1,072 | |
| B -2-2 | 14 | 50 | 1,45 | 1,58 | 1,087 | |
| B -2-3 | 18 | 50 | 3,80 | 1,45 | - | ν |
| B -3-1 | 10 | 75 | 1,77 | 1,61 | 0,91 | |
| B -3-2 | 14 | 75 | 2,50 | 1,46 | - | ν |
| B -3-3 | 18 | 75 | 1,23 | 1,38 | 1,12 | |
| B -5-1 | 10 | - | 0,99 | 1,00 | 1,01 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| B -5-2 | 14 | - | 2,50 | 1,00 | - | ν |
| B -5-3 | 18 | - | 1,04 | 1,00 | 0,96 | |

Experimental and theoretical values in Table 2 were obtained at 0,2 kN·m torque.

The experimental data in Table 2 marked "ν" were not taken into account.

The comparison had showed satisfactory coincidence of data that made possible to use the above mentioned method [1] in the calculations.

The value of critical torque obtained for the beams as a result of this experiment indicated the proportional dependence of the moment from reinforcement diameter and height which was compressed by bending zone of beam intersection (Figure 6).

The mode of failure of all samples was fragile in most cases and it was momentary.

During the phased load up to the last phase no cracks were detected on the faces although dial indicators sensed the large jump of deformations during the last phases of exposure under load. [2].

The fragility and instantaneousness of destruction is explaned by the presence in beams only longitudinal reinforcement and by the absence of cross closed stirrups which would react the shear stress caused by torsion. This explanation is confirmed by the HJ. Cohen [9] and other authors [17].

In all cases, the crack caused by torsion developed on the side face in free-cracks segment at 45º to the upper end of one of the three artificial normal cracks.

It spread quickly along the upper face moving to the side face, which was distant from the transverse force.

The crack developed in the most weakened sections all along the closed line, creating spatial oblique section.

Thus, the destruction was caused by the spatial torsion crack appeared in the compression area at torque value equal to limit value.

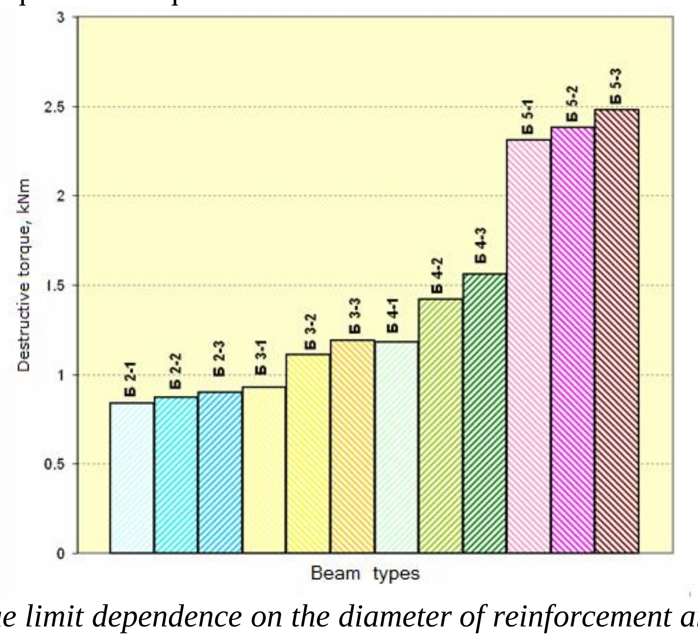



*Figure 6 Torque limit dependence on the diameter of reinforcement and compression area height*

**Conclusions and Prospects of the Research**

1. Reinforced concrete elements with normal cracks under torsion have the diagram "*Torque (moment)- deformation* " of a curved line which confirms elastic-plastic deformation character of samples under torsion.

2. With increasing of height of compressed by bending zone and enlargement of longitudinal reinforcement diameter the character of deformation in samples with normal cracks reinforced only longitudinally approximates to elastic.

3. Reinforcement of experimental beams with normal cracks only by longitudinal reinforcement does not significantly affects the torsion strength caused by fragile samples and instantaneous nature of their destruction. The main type of fracture is a fracture of a compressed zone from the effects of oblique tension that arises as a result of torsion.