Vol. 5, No. 2, 2023

https://doi.org/10.23939/jtbp2023.02.01

Xin Yao, Viktor Kvasha

TEST RESULTS OF REINFORCED CONCRETE CROSS-RIBBED MODEL OF SPAN STRUCTURE OF THE BRIDGE AND THEIR ANALYSIS

Department of Highways and Bridges
Lviv Polytechnic National University
sin.yao@lpnu.ua

Presentation of samples of basic experimental data from research of spatial work of large-scale (scale 1: 4) reinforced concrete model of cross-ribbed span structure of the bridge and separate beams similar in structure to model beams, as well as methodological features and results of their analysis. During the tests, the model and separate (reference) beams were loaded with concentrated force, alternately at the intersections of the longitudinal and transverse ribs of the model. Deflections in the same nodes and support reactions of longitudinal beams were measured. A new methodological feature of this research was the determination of experimental bending moments in the model beams by direct comparison of the deflections of the model beams with similar deflections of separate (reference) beams. Depending on the location of the external load and the stiffness ratio, the load on the beams of the model is different. Taking into account an elastic-plastic stage of their work, the method of calculation of the maximum bending moments in the most loaded beams is offered in this paper.

Keywords: Span Structure, Large-scale Reinforced Concrete Model, Tests, Elastic-Plastic Work, Load Distribution, Deformations.

Introduction

Reinforced concrete cross-ribbed systems have been widely used in the construction industry due to the rational concentration of material (concrete and rebar) in the most stressful areas. In addition to span structures of bridges, where these systems are used traditionally and most often (Gorbachevskaya et al., 2017; Kvasha et al., 2002; 2008; 2015; Yao et al., 2021), there is a large group of various structurally different floors and coatings in buildings and structures for various purposes, ribbed foundation slabs, and others. From the point of view of structural mechanics, they are complex, repeatedly statically indeterminate systems, the stress state of sections of which determines three components of forces and three components of bending moments, and their deformations – three components of linear and three components of angular displacements (Artemov et al., 2012; Gorbachevskaya et al., 2017; Ivanyk et al., 2019; State Building Norms of Ukraine B.2.3-6: 2009). This solution, taking into account all components of efforts and movements, is considered exact; however, it is rather difficult, and depending on constructive schemes and quantity of the factors considered in calculations, it is not even always possible. In particular, for reinforced concrete elements in the presence of cracks, nonlinear elastic-plastic deformation of concrete, partial loss of adhesion of reinforcement, the problem of theoretical calculation is physically and geometrically nonlinear. (Artemov et al., 2012; Wiśniewski et al., 2013; Castaldo et al., 2019)

Therefore, to solve one of the main problems of calculation-patterns of distribution of external loads between the rods of the system and the resulting forces, as well as other related problems resort to their experimental researches, which, in particular in the study of span structures, are carried out on large reinforced concrete models, which is made of materials that physico-mechanical and functional characteristics correspond to the "original" (real constructions) (Artemov et al., 2012; Gorbachevskaya et al., 2017; State Building Norms of Ukraine B.2.3-22: 2009; Kvasha et al., 2002; 2008; 2015; Radomski et al., 2017; Tarozzi et al., 2022).

Subject to certain rules of modeling, in particular its foundations – the theory of similarity and dimensions (Melnyk et al., 2018; Jin et al., 2020) (geometric similarity of shape and physical similarity of materials) theoretical calculation of the studied model is described by the same mathematical relations as the modelled structure without any adjustment.

Experimental researches of large-scale reinforced concrete models of cross-ribbed span structures are described in the publication (Ivanyk, 2000), so the purpose of this work is to present a sample of the main experimental data of these researches, as well as to present the methodological features and results of their analysis.

Materials and Methods

The experimental structure DK-1 reinforced concrete cross-ribbed model was designed on the principle of complete geometric physical similarity as a model in a scale 1:4 of the thin-walled hall concrete beams diaphragm span structure with welded frame fittings for Typical Project Issue 56 with an estimated span of 16.2 m and a width between the axes of the boundary beams 1.4 * 5 = 7.0 m. (Kvasha et al., 2015)

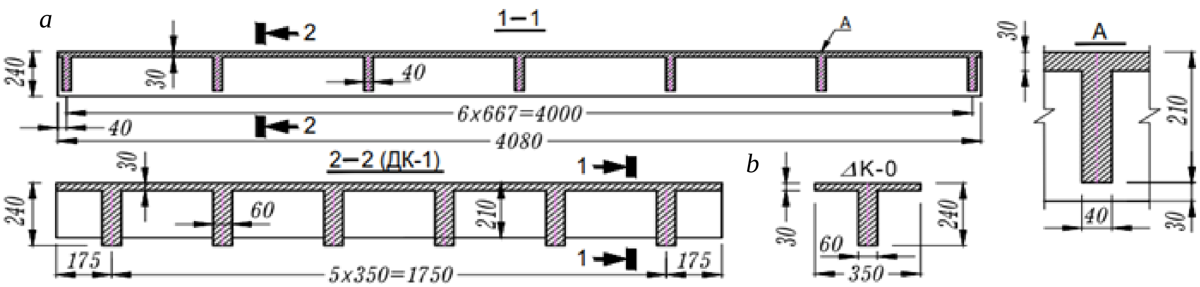

Fig. 1. Geometric dimensions of the model DK-1 (a) and a separate beam DK-0 (b)

A new methodological feature of this research was the additional testing of separate beams, similar in structure and materials to the beams of the model (DK-0). According to the results of these tests, by comparing the deflections of a separate beam and its analogue in the model, the experiments revealed static uncertainty of cross-ribbed span structure. The tests studied the distribution between beams of external load, bending moments and transverse forces, determined the actual stiffness characteristics with different load intensities, and the presence of cracks. (Kvasha et al., 2008; Sukhorukov et al., 2012)

For the manufacture of models and beams, we used fine-grained concrete mixture of factory preparation composition of C: S: CS-1: 1,32: 3,65. For W / C = 0.41… 0.5; crushed stone fraction 5… 15 mm, medium quartz sand, Portland cement (consumption 382 kg per 1 m3 of concrete) design class of concrete – B25 (Ivanyk, 2000).

Separate beams DK-0 in the quantity of 3 pieces were tested on a test setup, equipped with a hydraulic jack and load control devices. The load on the beams in the form of concentrated force was applied in steps alternately in 1/2, 1/3, 1/6 span; that is, in cross sections of longitudinal and transverse edges of the model.

The experimental model DK-1 was tested on a test bench, which provided a load of concentrated force at any point of the model, and also had support parts equipped with exemplary dynamometers to measure the support response of longitudinal beams during loading of the model (Gorbachevskaya et al., 2017; State Building Norms of Ukraine B.2.3-6: 2009; State Building Norms of Ukraine B.2.3-22: 2009; Ivanyk, 2000). The models were loaded with concentrated force alternately in each node of the intersection of longitudinal and transverse ribs in steps, bringing its value to the conditional normative 0.65…0.7 times of the ultimate load, which corresponded to the maximum crack opening of 0.25…0.3 mm.

The vertical displacements of the nodal sections of the model and individual beams were measured, which allowed to estimate the spatial work of the model and the degree of load on the beams in different schemes of application of nodal concentrated force.

Results and discussion

In general, tests of these beams did not reveal any features in their operation at different load levels. The first normal cracks in the zone of maximum bending moments occurred at a load within 0.2… 0.3 times of the destructive load. Their occurrence was accompanied by an increase in deflections and, consequently, a decrease in stiffness. The failure of the beams came from the yield of the longitudinal working reinforcement at the maximum achieved load (bending moment) P_u (M_u) = 28.45 kN (kNm) (average of the three tested beams).

Table 1

Deflections of a separate beam in the studied sections

P, kN	1-1		2-2		3-3	
	M_1, kNm	f_1, mm	M_2, kNm	f_2, mm	M_3, kNm	f_3, mm
3,36	1,12	0,58	2,24	1,00	3,36	1,41
6,72	2,24	1,19	4,48	2,07	6,42	2,77
13,34	4,45	2,83	8,90	5,13	13,34	6,50
20,16	6,72	4,69	13,45	8,60	20,16	10,61
26,88	8,90	6,60	17,80	12,38	26,88	15,04

The sample of deflections for one of the most unfavorable load schemes, with concentrated force in the middle of the span by load levels, is presented in Table 1. The graphical representation in the graphs of Fig. 2 is typical for reinforced concrete bent elements with cracks and do not require special explanations and comments.

Convention description: P – Nodal Load Test, M_1 …M_3, kN*m – bending moments in the studied sections 1-1, 2-2, 3-3 (Fig. 2, a), f1…f3, mm – accordingly, deflections in the same sections

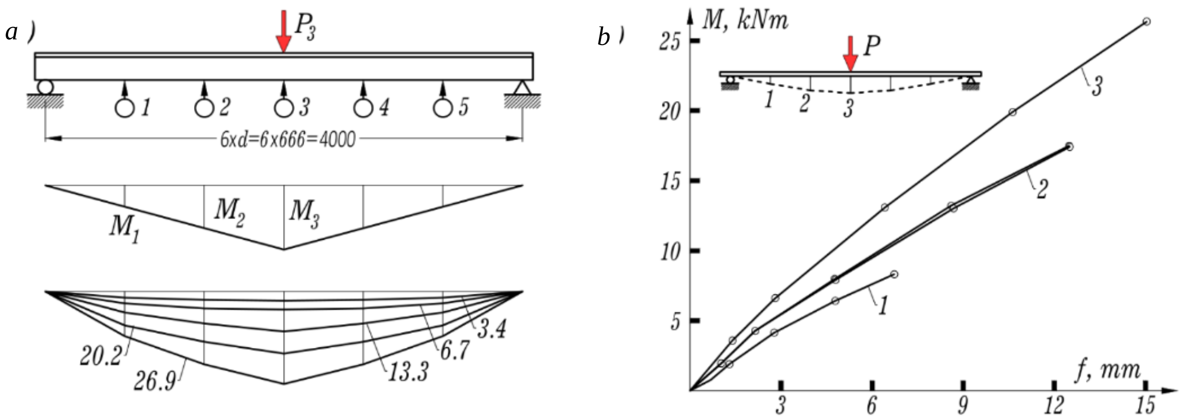

Fig. 2. Graphs of deflections of a separate beam DK-0

These deflections will be used to implement one of the new methods of analyzing the spatial work of the studied model DK-1, the principle of which is to directly compare the deflections of a single (reference) beam with deflections of the same beam working in the model under the same load schemes. Additionally, the same deflections of the reference beam and the beams of the model correspond to the same force (M, Q) or forces that fall on these beams (Ivanyk, 2000).

The advantage and reliability of this method is that to determine the forces in the beams of the model from the action of external forces on the span of the structure adopted real (for reinforced concrete beams) experimental relationship between force and deflection (M_f), considering cracks. Therefore, the influence of these factors is automatically taken into account in the experimental determination of the spatial distribution of forces and analysis of the spatial work of the studied model.

The main result of the tests of the model DK-1, as well as a separate beam DK-0, are the deflections of the beams in these nodes of intersection of longitudinal beams and diaphragms by levels of load of concentrated force alternately in all nodes. For the most unfavorable load schemes to be analyzed, the sample of their distribution across and along the span is presented in Tables 2 and 3, a, visual graphical interpretation in the form of plots of distribution by load levels – in Fig. 3.

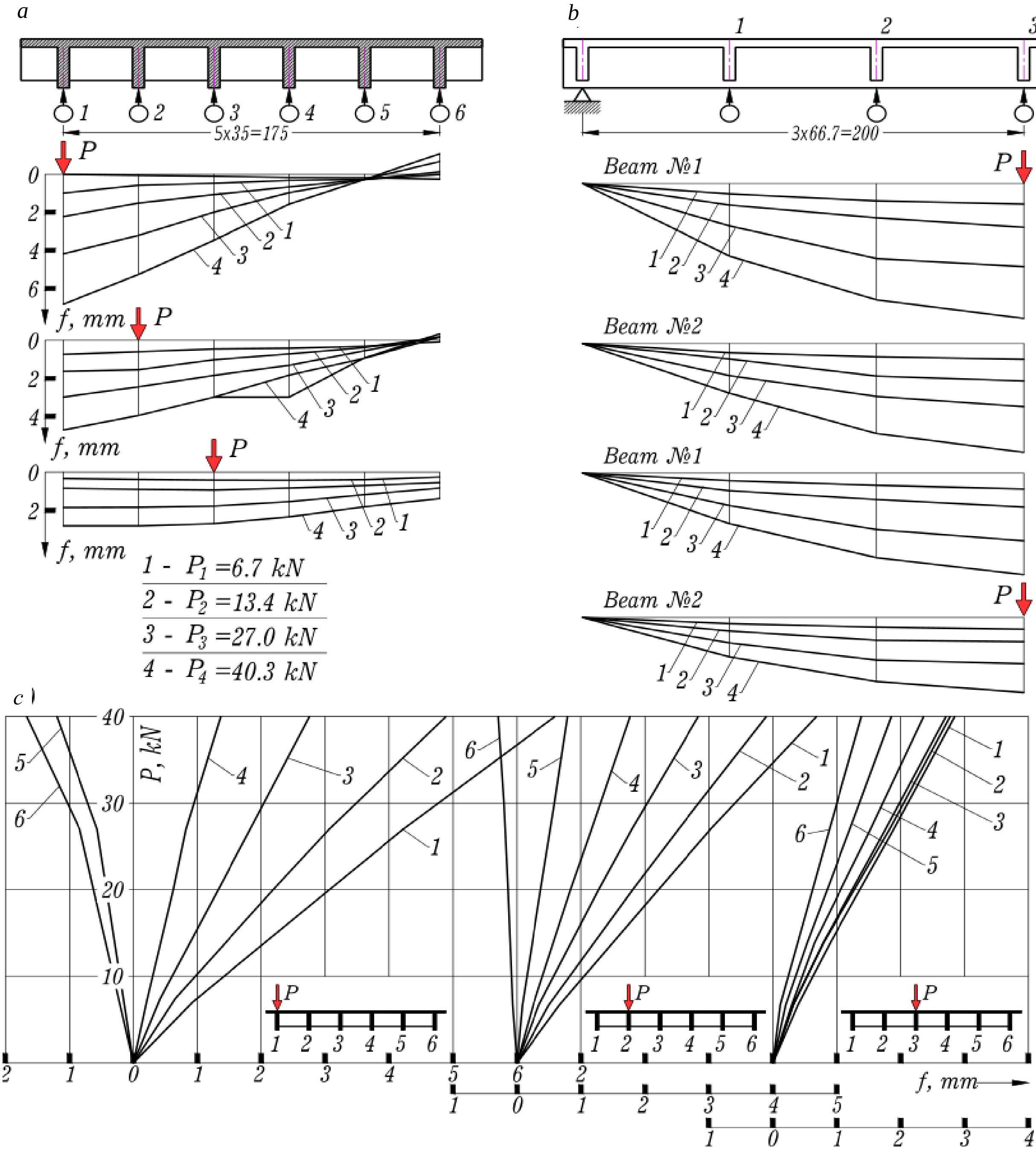

Fig. 3. Diagrams of deflections of beams across (a) and along (b) the span of the model DK-1 under different schemes of nodal load P

The most important and relevant from a practical point of view of the analysis of test results is the experimental identification of the actual patterns of distribution of external load between the cross beams and the resulting forces (bending moments and transverse forces). (Kvasha 2002; Sukhorukov et al., 2012; Yao et al., 2021)

Table 3 also presents the support reactions of the beams measured during the tests also by load levels.

Table 2

Deflections of beams of model across span in section 3-3 depending on level of loading at an alternating arrangement of force P over beams 1, 2, 3

	↓P	Deflections, f, mm				
P, kN	1	2	3	4	5	6
6,7	0,88	0,61	0,38	0,17	-0,2	-0,33
13,4	2,00	1,42	0,90	0,48	-0,01	-0,78
27,0	4,16	3,00	1,85	0,79	-0,12	-1,18
40,3	6,76	5,24	3,44	1,42	0,04	-1,32
		↓P	Deflections, f, mm			
P, kN	1	2	3	4	5	6
6,7	0,62	0,5	0,38	0,21	0,1	-0,01
13,4	1,38	1,14	0,85	0,53	0,22	-0,05
27,0	2,94	2,48	1,78	1,18	0,54	-0,08
40,3	4,32	3,9	2,94	1,83	0,93	-0,29
			↓P	Deflections, f, mm		
P, kN	1	2	3	4	5	6
6,7		0,38	0,36	0,32	0,23	0,14
13,4	0,85	0,84	0,82	0,7	0,53	0,38
27,0	1,86	1,85	1,76	1,52	1,18	0,88
40,3	2,83	2,84	2,72	2,32	1,82	1,36

Due to the rigid connection of cross beams and high stiffness of the diaphragms, the distribution of beams across the span is almost linear at all levels and load patterns to its maximum value (Fig. 3, a), i.e., both before and after the formation of cracks in the longitudinal and transverse beams. This test result clearly confirms that the spatial calculation of reinforced concrete cross-ribbed span structures with the ratio of general dimensions-span length L to the width between the end beams B L / B≥2 can be performed without significant error by simple engineering methods without EOM (for example, the method of off-center compression, well known to many generations of engineers). This is important and relevant for the conversion of existing bridges of old construction to new, standardized temporary loads during their inspection or design of overhaul and reconstruction. (Kvasha et al., 2002; 2008; 2015; Pastushkov et al., 2011; Yao et al., 2021)

The nature of the change in deflections shows that the curved axis of reinforced concrete beams with cracks in the cross-ribbed structure, loaded with concentrated force, is smoothly concave. This in turn indicates the possibility of calculating the deflections of such beams according to the known methods of State Building Standards, based on the use of the classical differential equation of the curved axis of the beam. (State Building Norms of Ukraine B.2.3-22: 2009)

Comparison of beams deflections revealed an important feature of the spatial work of reinforced concrete cross-ribbed span structure: depending on the location of external load, the ratio of stiffness of longitudinal and transverse beams load intensity of separate beams is different, so less loaded – in the elastic. That is, the span structure has two qualitatively different zones in the work of both elastic-plastic and elastic deformation. This feature of the deformation of reinforced concrete systems must be taken into account in each case during the spatial calculation for the correct determination and introduction into the calculation of beam stiffness, without which the calculation of a statically indeterminate system is impossible (Kvasha 2002; Radomski et al., 2017; Wiśniewski et al., 2013).

Comparison of beam deflection graphs revealed an important feature of the spatial work of reinforced concrete cross-ribbed span structure: depending on the location of external load, the ratio of stiffness of longitudinal and transverse beams, the load intensity of individual beams is different, therefore, some of the more loaded work in the elastic-plastic stage, and the other part of the less loaded – in the elastic stage. That is, the span structure has two qualitatively different zones in the work of both elastic-plastic and elastic deformation. This feature of the deformation of reinforced concrete systems must be taken into account in each case during the spatial calculation for the correct determination and introduction into the calculation of beam stiffness, without which the calculation of statically indeterminate system is impossible.

Table 3

Deflections along the span in the most loaded beams, above which the test load is located (№1 and №2), and adjacent №2, when the load over the beam №1 and №1 and №3, in the case of beam load №2

		Beam №1		↓P
P, kN	R, kN	1-1 (f1)	2-2 (f2)	3-3 (f3)
6,7	1,5	0,46	0,77	0,88
13,4	3,42	1,07	1,76	2,00
27,0	7,02	2,20	3,58	4,16
40,3	10,8	4,16	5,84	6,76
		Beam №2		
6,7	1,30		0,55	0,61
13,4	3,70	0,84	1,25	1,42
27,0	5,75	1,50	2,54	3,00
40,3	8,15	2,25	4,45	5,24
		Beam №1		
6,7	1,18	0,34	0,54	0,67
13,4	2,52	0,76	1,24	1,50
27,0	4,95	1,62	2,68	3,20
40,3	7,80	2,50	4,45	5,00
		Beam №2		↓P
6,7	0,96	0,24	0,46	0,50
13,4	2,95	0,56	1,01	1,14
27,0	3,70	1,25	2,17	2,48
40,3	6,30	1,90	3,48	3,40
		Beam №3		
6,7	0,63	0,22	0,32	0,30
13,4	1,60	0,48	0,78	0,68
27,0	3,00	1,00	1,58	1,47
40,3	5,38	1,54	2,57	2,72

According to experimental deflections, this can be done in several ways (Ivanyk, 2000). The first of them, as recommended in State Building Standards – the distribution of force between the beams in proportion to the deflections of these beams in the model was unsuccessful, because it didn't meet the main condition of statics – the equilibrium condition: the fraction of force transmitted to the beam is equal to the sum of the reactions of this beam, measured during the tests. We illustrate this with a numerical example for the beam №1 model for the most unfavorable case of the location of the test load P = 40.3 kg above this beam in the middle of the span (Section 3-3) (Fig. 3, and Table 2). The sum of the deflections of the beams ∑fi= 15,5; the part of the force P = 40.3 kN transmitted to the beam №1 P1=f1/∑fi P=6,76/15,5•40,3=17,58kN. The sum of experimental support reactions of this beam at P = 40.3 kN – – ∑R1=10,8•2=2,6кН>P1=17,58 kN. The difference between them is 18.6%, which is unacceptably large. In the presence of cracks and elastic-plastic deformations of concrete beams, this method is not accurate, although it is quite simple and recommended by State Building Standards. (State Building Norms of Ukraine B.2.3-6: 2009)

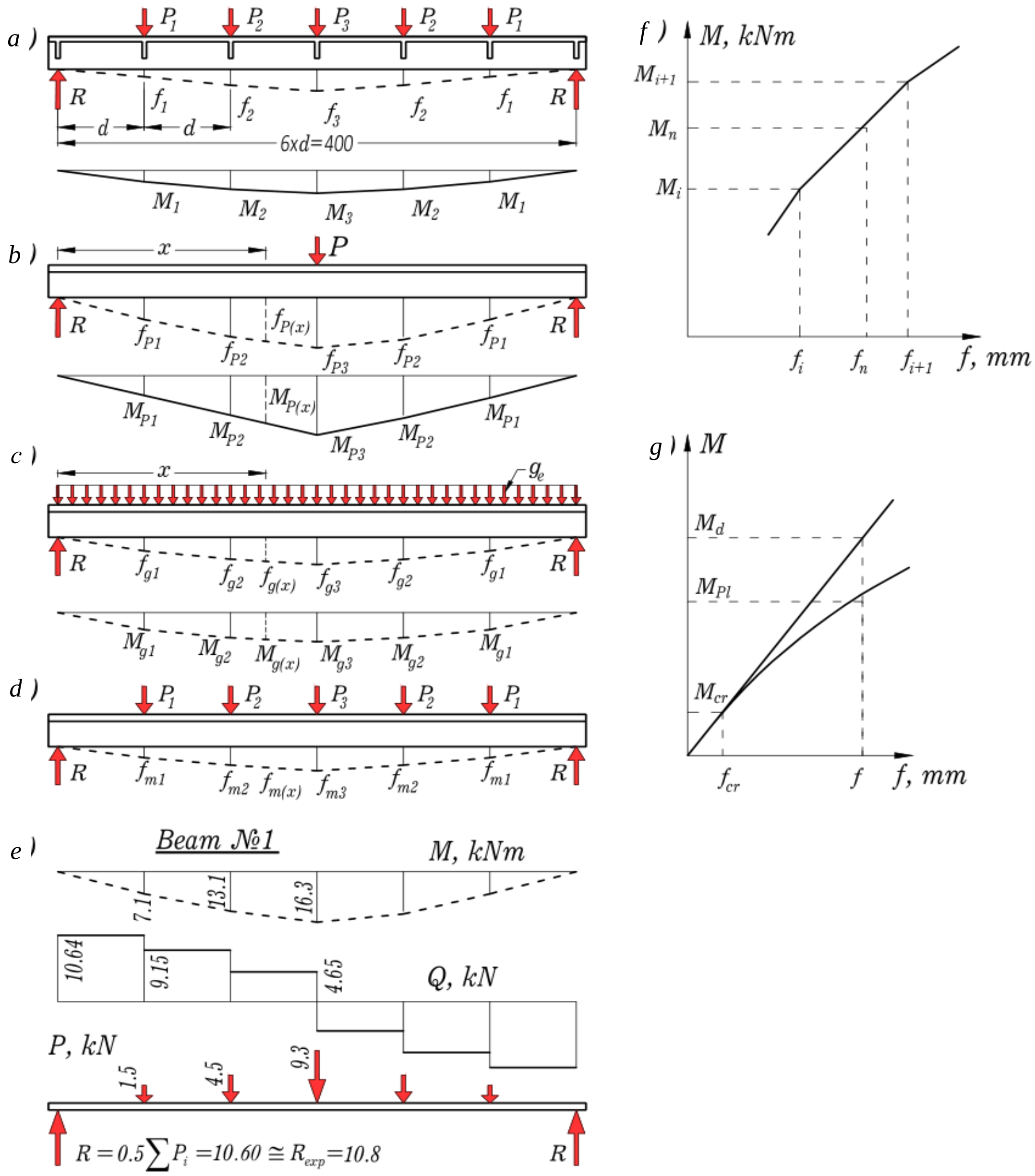

Fig.4 The experimental determination of bending moments of nodal and transverse forces in the beams of the model DK-1 according to the adjusted graphs of deflections of the reference beam: a – a diagram of the actual distribution of the concentrated force P in the nodes of the beams of the cross-ribbed span structure; b – load diagram of the reference beam during the tests; c – conditional scheme of loading of a reference beam by equivalent distributed loading ge; d – the actual load diagram of the reference beam to adjust its deflections; e – plots of bending moments, nodal and transverse forces for the extreme beam of the model DK-1 under its load with a concentrated force P = 40.3 kN in the middle of the span; f – the principle of determining the experimental bending moments by linear interpolation according to the adjusted graphs of deflections of the reference beam; g – a comparison of beam deflections for elastic (1) and elastic-plastic (2) deformation.

The second method is essentially the inverse interpretation of the first: if the support reactions are measured during the test, it is obvious that the sum of the forces transmitted to the beam should be equal to the sum of the support reactions of this beam. If this force is only one, as in the previous case, this method also has insufficient accuracy.

Inaccurate results of load distribution by the above methods clearly confirm the hypothesis of spatial distribution of load on more loaded beams in the presence of cracks and elastic-plastic (nonlinear) deformation of concrete. Therefore, the third way in which the model is loaded (Fig. 4, a), not only between the beams in the cross section of the model, where it is attached (for example 3-3), but also along the span of the beam in its nodes with ribs. 4, a). Therefore, for the experimental finding of the actual load distribution P and it was proposed to use the results of additional tests of a separate beam, similar in constraction to the beams of the model and similarly loaded with concentrated force (Kvasha 2002; Ivanyk, 2000) (Fig. 4, b), assuming the same deflections and the beams in the model correspond to the same bending moments and fractions of forces transmitted to the beams.

Control of the correctness of the distribution – based on the condition of equilibrium: the sum of forces transmitted to the beam is equal to the sum of the support reactions of this beam. ($\sum P_i = \sum R_i$)

But here, in a more detailed analysis, tests revealed another significant discrepancy, which does not allow to directly use a direct comparison of the deflections of a single beam and its analogue in the model. Its essence is that the load scheme during the tests of a single beam (Fig. 4, b) does not correspond to the load scheme of a similar beam model with several nodal forces along the span (Fig. 4, a).

Therefore, analyzing the situation, we conclude that the measured deflections of a separate beam under its load by one concentrated force (Fig. 4, b) should be adjusted by calculation, bringing the operating conditions of a separate beam to its counterpart in the model (Fig. 4, a), for which you need to find the experimental bending moments, transverse and nodal external forces of P_i.

The proposed method of calculated adjustment is based on two extreme schemes of beam loading: concentrated force P (Fig. 4, b), when the deflections f_p will be maximum; and equivalent distributed load g_e= P/l (Fig. 4, b), when these deflections f_g will be minimum for the same for both considered schemes support reactions R (Fig. 4, b, c). It is probable that under the load scheme of the beam with several concentrated forces along the span (Fig. 4, d) its deflections fm will be in the interval between these extreme values ($f_g < f_m \le f_p$) and will be a certain part of the nth sum: fm=n(f_p+f_g). According to the results of numerical analysis, the real range of change of the indicator n: 0.4≤ n ≤0.6, and for the first attempt to adjust you can set the value n = 0.5.

To calculate the deflections, use the known formula:

$$f = S\frac{Ml^2}{B} \tag{1}$$

Here: S – coefficient that takes into account the static scheme of the beam and the scheme of its loading (makes a significant role); M – bending moment; l – span length, B – stiffness of the cross section of the beam. Deflections in an arbitrary section x (Fig. 5, b, c) for both load schemes P and there:

$$f_p\ x\ = S_p\ x\ \frac{M_p\ x\ l^2}{B_p}, f_g\ x\ = S_g\ x\ \frac{M_g\ x\ l^2}{B} \tag{2}$$

In these formulas (according to reference data):

$$M_p\ x\ = 0{,}5\,px;\ S_p\ x\ = \frac{1}{24}\ 3 - \frac{4x^2}{l^2} \tag{3}$$

$$M_g\ x\ = 0{,}5 g_e x\ l - x\ ;\ S_g\ x\ = \frac{1}{12}\ \frac{l - \frac{2x^2}{l} + \frac{x^3}{l^2}}{l - x} \tag{4}$$

Numerical analysis shows that the stiffness B_p and B_g differ by 5-7%, so the actual accuracy of the calculation of deflections in order to simplify it, this difference can be neglected and take Bp = Bg. (Artemov et al., 2012)

Further course of calculation.

Deflections of the beam loaded with concentrated forces (Fig. 4, d) at n = 0.5:

$$f_m = 0{,}5\ \ f_p\ x\ + f_g\ x \tag{5}$$

Adjustment factor for arbitrary section X:

$$K(x) = f_m/f_p \tag{6}$$

This coefficient is multiplied by the experimental deflections measured by the load of the beam by one concentrated force (Table 1; Fig. 4, b), and thus we can obtain corrected graphs of deflections (M- f_k), which by linear interpolation determine the bending moments in the nodes of the applied concentric forces (Fig. 4, e).

The bending moment in a given section corresponding to the deflection of the beam in the same section f_m is determined according to the scheme of Figs. 4, d):

$$M_н = M_k + \frac{(f_m - f_k)(M_k - M_{k+1})}{f_{k+1} - f_k} \quad (7)$$

The positive effect of elastic-plastic nonlinear deformation of some of the most loaded beams in the cross-ribbed span structure revealed during the research of the model made it possible to offer a rather simple engineering, computer-free two-step “express method” for calculating maximum bending moments at maximum time. Loaded cross-sections of maximally loaded beams due to physically nonlinear deformation of reinforced concrete, the presence of cracks and the consequent reduction in the stiffness of their cross-sections, ie in the elastic-plastic stage of beams (State Building Norms of Ukraine B.2.3-6: 2009; Kvasha et al., 2015).

The first step is to calculate the maximum bending moments M_{el}, one of the known methods (engineering or “accurate”) in the assumption of elastic operation of the span structure. The second step is the transition to the elastic-plastic bending moment M_{pl}, using as the main dependence of the deformation of the deflection diagram (Fig. 4, e), which summarizes the impact on the stress-strain state and stiffness of nonlinear deformations of concrete and reinforcement, cracks, duration or repetition of loads, static circuit, etc. The relationship between the elastic and elastic-plastic bending moments Mel and M_{pl} is obtained by comparing the deflections of the system beams in the elastic and elastic-plastic stages of $f_{el}=f_{pl}$ (Fig. 4, e).

According to known formulas:

$$f_{el} = SM_{el}l^2/EI_{red};\ f_{pl} = S_1 M_{pl} l^2/B \quad (8)$$

Here: B – the actual stiffness of the beam in nonlinear deformation after the formation of cracks; Ej_{red} – initial stiffness of the beam; S, S_1- coefficients that take into account the static scheme and the load scheme of the beam, respectively, in the elastic and elastic-plastic stages of operation.

According to experimental data S_1 / S = 0.9, then:

$$M_{pl} = 0{,}9\ M_{el}\ B/(Ej_{red}) \quad (9)$$

During the recalculation of the existing span structures, the stiffness B is determined according to the recommendations of the relevant State Building Standards for bending moments, taken as a fraction of the destructive M_u for a particular beam. For calculations on the first group of limit states, it is recommended to take $M_I \leq (0.75 ... 0.8)$ Mu; for the second, take $M_{II} \leq (0.5 ... 0.6)\ M_u$. When designing new systems, the stiffness can be determined by the method of successive approximations, calculating it first by the bending moment M_{el} and sequentially forming, during each successive determination of the bending moment M_{pl}.

A comparison of deflection graphs (Fig. 4, e) for elastic (1) and elastic-plastic (2) cross-sectional work and the formula (9) obtained from this comparison shows that, due to the decrease in stiffness, the elastic-plastic bending moment M_{pe} will be less than elastic M_{el} due to the redistribution of part of the load on adjacent to the calculated more rigid elements. This reduction compared to the elastic calculation, which designed the beams, and will be a hidden reserve of their load capacity, which in real conditions (depending on the ratio of stiffness) for some of the most loaded beams can reach 35-40%. This is enough to allow further operation of reinforced concrete span structures of the old building on the current increased temporary loads without their reinforcement.

Conclusions

1. Experimental research concerning large-scale reinforced concrete model of cross-ribbed span structure revealed new patterns of its spatial work, the purpose of which is that depending on the location of external load and the ratio of stiffness of separate beams, their intensity is different, so some -plastic stage, and the second less loaded – in the elastic stage. That is, in real conditions, the span structure has two qualitatively different in the nature of the distribution of forces of the zone: elastic-plastic and elastic work. Their limits for the most unfavourable schemes of external load must be established by spatial calculation of span structures.

2. A new methodological feature of the analysis of the results of experimental studies of the model, was the disclosure of internal static uncertainty and determination of experimental bending moments in separate beams using corrected reference graphs of deflections in the studied sections obtained from tests

of separate beams identical in structure beams. Despite the similarity of this method, its overall accuracy is higher than the recognition of the distribution in the traditional way, in proportion to the deflections and the initial stiffness of the beams in allowing their elastic work after the formation of cracks.

3. Compared with the calculations for the conditionally elastic stage of work, the proposed method of experimental calculation of bending moments in the most loaded and working in the elastic-plastic stage beams allows in real conditions due to redistribution to reduce them to 35-40%, which is sufficient for further operation reinforced concrete bridges of old construction on modern increased temporary loads without their strengthening.

References

Artemov, V. E., & Raspopov, A. S. (2012). To the question of the accuracy of calculations in the calculations of building structures. Bridges and tunnels: theory, research, practice, (3), 6-8. https://cyberleninka.ru/article/n/k-voprosu-o-tochnosti-vychisleniy-v-raschetah-stroitelnyh-konstruktsiy

Bień J., Gładysz-Bień M. (2014) Classification of diagnostic tests of bridge structures. Engineering and construction. N7. -p. 364-367. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-3e53c81b-9bf2-4ecb-8572-699a633c7e38?q=bwmeta1.element.baztech-0205ba42-346b-483b-98cb-c43756f737b9;0&qt=CHILDREN-STATELESS

Castaldo, P., Gino, D., & Mancini, G. (2019). Safety formats for non-linear finite element analysis of reinforced concrete structures: discussion, comparison and proposals. Engineering Structures, 193, 136-153. https://doi.org/10.1016/j.engstruct.2019.05.029

Gorbachevska, A. A., & Kvasha, V. G. (2018). Operational condition, reconstruction and test results of the reconstructed road overpass. Bulletin of the Lviv Polytechnic National University. Series: Theory and practice of construction, (877), 66-77. https://science.lpnu.ua/sites/default/files/journal-paper/2018/may/12224/13360.pdf

Ivanyk, I. G. (2000). Spatial calculation of cross-ribbed reinforced concrete systems taking into account physical nonlinearity. Dissertation for obtaining a candidate of technical sciences. Lviv, 202. http://www.irbis-nbuv.gov.ua/cgibin/irbis_nbuv/cgiirbis_64.exe?C21COM=2&I21DBN=ARD&P21DBN=ARD&Z21ID=&IMAGE_FILE_DOWNLOAD=1&Image_file_name=DOC/2000/00iigvfn.zip

Ivanyk, I., Vikhot, S., Vybranets, Y., & Ivanyk, Y. (2019). Research of monolithic cross-ribbed concrete slabs with of the office-commercial-entertainment complex building in Kyiv. Journal of the Kharkiv National Automobile and Road University, 1(86), 174-174. https://doi.org/10.30977/BUL.2219-5548.2019.86.1.174

Jin, L., Chen, H., Wang, Z., & Du, X. (2020). Size effect on axial compressive failure of CFRP-wrapped square concrete columns: Tests and simulations. Composite Structures, 254, 112843. https://doi.org/10.1016/j.compstruct.2020.112843

Kvasha, V. G. (2002). Effective systems of expansion and strengthening of reinforced concrete beam span structures of highway bridges. Abstract of the dissertation of the Doctor of Technical Sciences.–K.: KNUBA. http://www.irbisnbuv.gov.ua/cgibin/irbis_nbuv/cgiirbis_64.exe?C21COM=2&I21DBN=ARD&P21DBN=ARD&IMAGE_FILE_DOWNLOAD=1&Z21ID=&Image_file_name=DOC/2002/02kvgbam.zip

Kvasha V.G., Kovalchyk T.P., Muryn A.Ya., Polets V.M., Saliychuk L.V. (2008). Reconstruction of the city overpass with the expansion of the span structure of reinforced concrete with a precast monolithic overlay slab. Bulletin of the Lviv Polytechnic National University. Series: Theory and practice of construction. 627, 122-128. https://ena.lpnu.ua/bitstream/ntb/8047/1/40.pdf

Kvasha, V. G., & Rachkevich, V. S. (2008). Analysis of the distribution of the temporary load between the beams of the span structure based on the results of natural tests. Journal of Lviv Polytechnic National University. Series: Theory and practice of construction. 627, 122-128 https://vlp.com.ua/files/24_33.pdf

Kvasha, V. G., Saliychuk, L. V., & Kotenko, V. T. (2015). Technical solutions for the reconstruction of a bridge with prefabricated reinforced concrete prestressed span structures. Bulletin of the Lviv Polytechnic National University. Theory and practice of construction, (823), 135-140. http://nbuv.gov.ua/UJRN/VNULPTPB_2015_823_24

Melnyk, O., & Orlova, O. (2018). Theoretical and experimental studies of spatial work and torsional stiffness of reinforced concrete elements of floors and bridges. Young scientist, (11 (63)), 372-377. http://molodyvcheny.in.ua/files/journal/2018/11/88.pdf

Pastushkov, V. G., & Pastushkov, G. P. (2011). Experimental studies of the spatial performance of reinforced concrete diaphragm-less spans using large-scale models. Vestnik Perm. national research Polytechnic un-ta. Environmental protection, transport, life safety, (2), 141-151. http://vestnik.pstu.ru/get/_res/fs/file.pdf

Radomski W., Kasprzak A. (2017). Widening of Bridges. 341 https://www.biblos.pk.edu.pl/ST/2017/12/100000307104/100000307104_Radomski_PoszerzanieMostow.pdf

State Building Norms of Ukraine B.2.3-6: 2009. Transport facilities. Bridges and pipes. Examinations and tests. 31.

State Building Norms of Ukraine B.2.3-22: 2009. Bridges and pipes. Basic requirements. 72.

Sukhorukov, B. D. (2012). Distribution of live load between beams in a reinforced concrete road overpass of a continuous frame system. Bridges and tunnels: theory, research, practice, (3), 199-206. https://cyberleninka.ru/ article/n/raspredelenie-vremennoy-nagruzki-mezhdu-balkami-v-avtodorozhnom-zhelezobetonnom-puteprovode-ramno-nerazreznoy-sistemy

Tarozzi, M., Pignagnoli, G., & Benedetti, A. (2022). Evaluation of the residual carrying capacity of a large-scale model bridge through frequency shifts. Journal of Civil Structural Health Monitoring, 12(4), 931-941. https://doi.org/10.1007/s13349-022-00586-0

Wiśniewski D., Majka M. (2013). Assessment of the load capacity of bridges during their operation – domestic and foreign experience. Engineering and construction. 7-8st edn. 364-367. https://yadda.icm.edu.pl/ yadda/element/bwmeta1.element.baztech-a4015f96-4de3-42f2-9a7c-afe553ae6650

Xin, Y., Saliychuk, L. V., & Kvasha, V. G. (2021). Experimental studies of the spatial work of a cross-ribbed span building on a large-dimension reinforced concrete model. Resource-saving materials, constructions, buildings and structures, (40), 224-233. http://irbis-nbuv.gov.ua/publ/REF-0000803303

Xin, Y., Yupin, M., Saliychuk, L., & Kvasha, V. (2021). Optimal Structural And Technological Solution For The Reconstruction Of The Urban Road And The Results Of Its Tests. Bridges and tunnels: theory, research, practice, (20), 92-107. https://doi.org/10.15802/bttrp2021/245601

С. Яо, В. Г. Кваша
Національний університет "Львівська політехніка"
Кафедра автомобільних доріг та мостів

РЕЗУЛЬТАТИ ВИПРОБУВАНЬ ЗАЛІЗОБЕТОННОЇ ПЕРЕХРЕСНО-РЕБРИСТОЇ МОДЕЛІ ПРОЛЬОТНОЇ БУДОВИ МОСТА ТА ЇХ АНАЛІЗ

Представлення вибірки основних експериментальних даних з досліджень просторової роботи великомасштабної (масштаб 1:4) залізобетонної моделі перехресно-ребристої прольотної будови моста і окремих балок, аналогічних за конструкцією до балок моделі, а також методичних особливостей та результатів їх аналізу. Під час випробувань модель навантажували зосередженою силою, почергово у вузлах перетину поздовжніх і поперечних ребер моделі. Вимірювали прогини у цих же вузлах та опорні реакції поздовжніх балок. Окремі балки випробовували за аналогічною схемою. Новою методичною особливістю цих досліджень було визначення експериментальних згинальних моментів у балках моделі прямим порівнянням прогинів балок моделі з аналогічними прогинами окремих (еталонних) балок. За результатами цих випробувань шляхом порівняння прогинів окремої балки та її аналога у складі моделі експериментально розкривали статичну невизначеність перехресно-ребристої прольотної будови, досліджували розподіл між балками зовнішнього навантаження, згинальних моментів і поперечних сил, а також визначали фактичні характеристики жорсткості за різної інтенсивності навантаження з урахуванням наявності тріщин. В залежності від місцеположення зовнішнього навантаження і співвідношення жорсткостей навантаженість балок моделі є різною, тому частина найбільше навантажених має тріщини і працює у пружно-пластичній стадії за нелінійного деформування, а друга – менш навантажених у пружній. Наявність у складі прольотної будови двох якісно відмінних зон просторової роботи необхідно враховувати у розрахунках. Запропонований метод розрахунку максимальних згинальних моментів у найбільш навантажених балках з врахуванням пружно-пластичної стадії їх роботи. Згинальні моменти у пружно-пластичній стадії роботи балок у реальних умовах є на 35-40% меншими, порівняно з пружними. Це і становить прихований резерв вантажопідйомності, який дозволяє подальшу експлуатацію залізобетонних мостів старої побудови на сучасні збільшені тимчасові навантаження без підсилення балок.

Ключові слова: прольотна будова, залізобетонна великорозмірна модель, випробування, пружно-пластична робота, розподіл навантажень, деформації.