CALCULATION OF THE DYNAMIC EFFECTS OF A MONOLITHIC OVERPASS TAKING INTO ACCOUNT THE POST-TENSIONING OF THE SPAN ROPE ON THE BASIS OF REAL EARTHQUAKE RECORDS

[1]Ibrakhim Mirzaev, [2]Shermukhamedov U.Z., [3]Abdullaev A.R.
[1, 2,3]Tashkent State Transport University, Tashkent, Uzbekistan
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***Abstract**. In order to improve the transport infrastructure of the Republic of Uzbekistan started to use monolithic structure of bridges and overpasses. The paper presents the calculation of a monolithic overpass 120 metres long, located in the area of 8 point seismicity according to MSK-64 in Jizzak over the high-speed railway line Tashkent-Samarkand (Republic of Uzbekistan). Numerical solution of the problem of earthquake resistance of the overpass determines the change of its stress-strain state in time. The results of calculation of monolithic bridge from dynamic loading on records of real accelerograms of Gazli (Uzbekistan) earthquake with intensity more than 9 points on MSK-64 scale are presented. The results of calculations of normal stress variation in the upper and lower parts of the span along the length of the bridge have been analysed. The calculations show that the bridge span and supports have a safety margin for a 9-point earthquake. In order to ensure guaranteed seismic safety of bridge structures, it is necessary to carry out design calculations using sets of records of earthquakes that are close in dominant frequencies to the characteristics of the construction site.*

***Keywords**: non-split scheme, monolithic, motorway overpass, reinforced concrete, span structure, steel rope, real earthquake records, post-tensioning.*

Introduction

In recent years, new pages in the Uzbek bridge construction industry have been opening up at a rapid pace. The design and construction of monolithic bridges and overpasses is considered to be an important aspect. Today, the technology of construction itself is developing, as a result of which new approaches to the construction of transport structures are being implemented. In this regard, designers and builders are thinking of moving to the creation of extraordinary engineering solutions. It should be noted that due to high architectural qualities, economy, strength and durability, monolithic overpasses with non-split span structures are recommended for use in urban areas.

It is known that in Uzbekistan a significant part of construction falls on seismically dangerous areas. Seismic resistance of structures, including non-sectional monolithic bridges and overpasses is an important task of modern construction. The study of world experience in the field of design and construction of monolithic overpasses shows that the use of the principle of post-tensioning of the working reinforcement taking into account seismic effects is widely used. In this method, the reinforcement bundles (ropes) of non-sectional monolithic overpass spans are tensioned by special jacks under pressure up to 32MPa, which in turn will serve to increase the seismic resistance of non-sectional monolithic overpasses in case of strong earthquakes.

It should be noted that about twenty scientific papers on post-tensioning of the working reinforcement of bridge structures have been published. Experimental and numerical studies of post-tensioned concrete beams have been carried out by scientists and specialists such as A. Stolarski and A. Jancy [1], M. Khatib [2], Jeung-Hwan Doh and Sam Fragomeni [3], Terje Kanstad and Daniel Cantero [4] and other authors. In [5], a systematic review of the behaviour of post-tensioned concrete structures with different reinforcement rope bonding conditions was reviewed, and the relationships between flexural strength and different rope bonding conditions of prestressed reinforced concrete structures were investigated.

Modelling of bonded and unbonded post-tensioned concrete flat slabs under bending and thermal loading is presented in [6]. In this work, the structural behaviour of post-tensioned reinforced concrete slab spans is also investigated, a nonlinear finite element model is developed for the analysis of unstressed and unbonded concrete slabs at elevated temperatures, and the interface between the reinforcing rope and the surrounding concrete is modelled, allowing the rope to retain its profile shape during slab deformation. The load deflection behaviour, load force behaviour in the rope and failure modes are presented. Numerical analyses were carried out using ANSYS finite element software and performed on two different one-sided concrete slabs.

In [7], quasi-static cyclic tests of a hybrid post-tensioned bridge support resting on a monolithic foundation were investigated. The dynamic response of the dissipative controlled rocking (DCR- dissipative controlled rocking) support built on a flexible foundation was considered to be different from that of a structure with a fixed foundation, which is primarily due to the energy dissipation capability of the flexibly supported structure. The flexibility of the soil foundation increased the service life of the structure and reduced the seismic response of the DCR column.

The seismic analysis of post-tensioned and hybrid bridge piers with buckling restraining braces, as well as the stability of a post-tensioned bridge have been studied in [8, 9]. In this paper, a new method of earthquake-resistant bridge construction using ABC- Accelerated Bridge Construction (ABC- Accelerated Bridge Construction technology) is proposed. A hybrid double-anchored bridge with post-tensioned precast concrete piers and a diagonal buckling restrained brace (BRB- buckling restrained brace) as an external energy dissipation device was tested under cyclic loads. The design of the initial post-tensioning force and the selection of the tensile yield strength of the BRB are presented. It can be replaced after an earthquake, and the proposed system is promising for the construction of stable bridges using ABC technologies in seismic regions.

In [10], the sliding behaviour of unbonded reinforcement ropes in post-tensioned concrete structures is modelled. The post-tensioned reinforcement ropes are modelled by a nonlinear tether element and embedded in a nonlinear reinforced concrete beam element. The embedding element is an elastic Euler beam element with very large stiffness. The validation of the proposed formulations and implementation have been carried out in several numerical studies. The proposed formulations reproduce the global bending behaviour with a reasonably high accuracy and also predict local losses and redistribution of prestress.

The vertical seismic response of a box section bridge reinforced with post-tensioned prestressed CFRP sheets was investigated in [11]. A finite element model has been developed to analyse the response of a box section bridge to various seismic waves before and after reinforcement with post-tensioned prestressed CFRP sheets. The dynamic response of the box section bridge to three different earthquakes showed that the vertical displacement and acceleration of the sections under the Tianjin wave slowly decayed after its peak; however, the vertical displacements and accelerations for the El Centro and Lanzhou waves slowly stabilised.

Consequently, the Tianjin wave caused more damage to the bridge structure than the other two waves. The seismic response of the bridge to earthquakes can be effectively reduced after reinforcement with post-tensioned prestressed carbon fibre reinforced plastic sheets.

At present, in the world practice of earthquake-resistant construction, a particularly important issue is dynamic calculations of structures based on earthquake accelerograms. It should be noted that such calculations are especially important in the design and calculation of large multi-span bridges, unique buildings and other critical facilities, in the assessment of damageability of structures, etc. At present, there are two opposite approaches to modelling design accelerograms: modelling the impact for the construction site and modelling the impact for the structure [12]. In [13], kinematic, spectral and energy properties of the impact are identified. The values of the energy characteristics IA, CAV, SED, as well as the values of the harmonicity coefficient κ and base accelerations PGA should be set in such a way that they correspond to the values of the same characteristics at the construction site with a given security. The assessment of the impact hazard for the structure is performed using the spectra of kinematic values and spectra of plastic deformation force work.

The length of structures under seismic vibrations is one of the important factors affecting their seismic resistance. Studies [14] in this area have led to the development of a methodology for the calculation of multi-supported structures, which in turn has led to the need to modify the existing methodology for the calculation of seismic resistance taking into account the non-synchronous excitation of the structure supports. The obtained calculation results show that taking into account the non-synchronous excitation of the support points of an extended system significantly reduces the inertial seismic loads on its elements.

Recently, accelerograms of earthquake records with recalculation of velocimeters and seismograms have been chosen as seismic effects [15, 16]. In this regard, it is of interest to develop methods and software tools for earthquake calculations of bridges and overpasses based on available accelerogram records.

Materials and methods of research

In static and seismic calculations of bridge structures, they are usually modelled in the form of girder-split, girder-non-split and girder-cantilever schemes. Unsplit monolithic reinforced concrete bridges and overpasses consist of many structural elements, the most important of which are the span, abutments, supports, footings and post-tensioning reinforcement ropes. The most critical elements of unsplit bridge spans are their post-tensioning reinforcement ropes, which are considered to be the main elements in the design and construction of monolithic bridges in severe earthquake zones. The most convenient method for carrying out calculations is the finite element method. The finite element models axial tension-compression, bending with respect to perpendicular axes to the longitudinal axis of the bridge and torsion with respect to the longitudinal axis. In this regard, the calculations are carried out using the finite element method for bridge structures, the Newmark method [17] was used for the time variable. The impact is given as a series of records of a three-component accelerogram with amplitude correction for different grades. The equation of motion of the structure after discretisation using the finite element method is reduced to the following form

$$[M]\{\ddot{u}\} + \eta[C]\{\dot{u}\} + [K]\{u\} = \{P\}, \quad (1)$$

with initial conditions from the static solution of the problem

$$\{u(t)\}_{t=0} = [u(0)], \quad \{\dot{u}(\mathrm{t})\}_{t=0} = \{\dot{u}(0)\}, \quad (2)$$

where *{u(t)}* is the vector of absolute displacements of nodal points of the finite element model of the structure, [*M*], [*C]*, [*K*] are matrices of masses, damping and stiffnesses, {P*(t)*} includes the given ground motion and acting forces. The ground motion is specified in the form of accelerogram records [18].

Consider a three-span reinforced concrete monolithic overpass, located in Jizzak, 120 m long and 21 m wide, the span structure has a variable thickness along the overpass, is made non-sectional monolithic reinforced concrete design scheme 35+50+35m individual design. On the facade the span structure is made by a slab of variable height - 1.35m in the span and 2.0m above the intermediate support. The structural elements of the overpass (span structure and post-tensioning reinforcement ropes) are modelled in the form of a finite element working in tension-compression, bending with consideration of shear deformation in two directions (Timoshenko beam) and torsion. The finite element matrices of the Timoshenko beam are given in [19]. The intermediate supports are two-pillar, have dimensions: height 12m, width on the facade - 2m, and on the lateral direction has a variable size in height from 3m to 5m. The scheme of the monolithic overpass is shown in Fig. 1, the general view of the intermediate support is shown in Fig. 2.

Fig. 1. Schematic diagram of the monolithic overpass

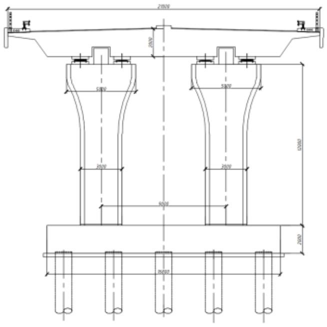

Fig. 2. General view of the intermediate support

In this calculation, the movement of the overpass foundations is assumed to be equal to the movement of the base during the earthquake. Material and main characteristics of the whole structure are given in Table 1.

The high-strength reinforcement is tensioned by applying a bundle tensioning force of up to 4000 kN. The number of bundles is 19 pieces.

When determining the stress losses and elongations (extensions) of the high-strength reinforcement, the reverse displacement of the ropes relative to the anchor plate during the transfer of tension from the jack to the anchor is taken into account.

The value of this displacement is 6 mm. The high-strength reinforcement is made of seven-wire twisted reinforcement ropes d=7.8 mm made of steel.

The bundles are made of 31 ropes, arranged polygonally. The locations of the ropes are shown in Figs. 3 и 4.

Table 1

Main characteristics of structural elements of the bridge

№	Name of construction element	Material and class	Specific weight γ, N/m³	Modulus of elasticity E, MPa	Poisson's coefficient ν	Shear modulus G, MPa
1	Foundation	Concrete B40	25000	36000	0.2	15000
2	Abutment	Concrete B40	25000	36000	0.2	15000
3	Intermediate support	Concrete B50	25000	38000	0.2	15833,33
4	Spanstructure	Concrete B50	25000	38000	0.2	15833,33
5	Post-tensioning reinforcement ropes	K-7 steel	78000	195000	0,3	750000

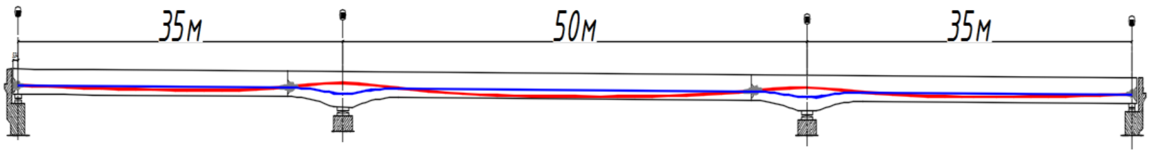

Fig. 3. Location of post-tensioning ropes in the span. Blue line - neutral axis of the span; red line - post-tensioning rope in the span

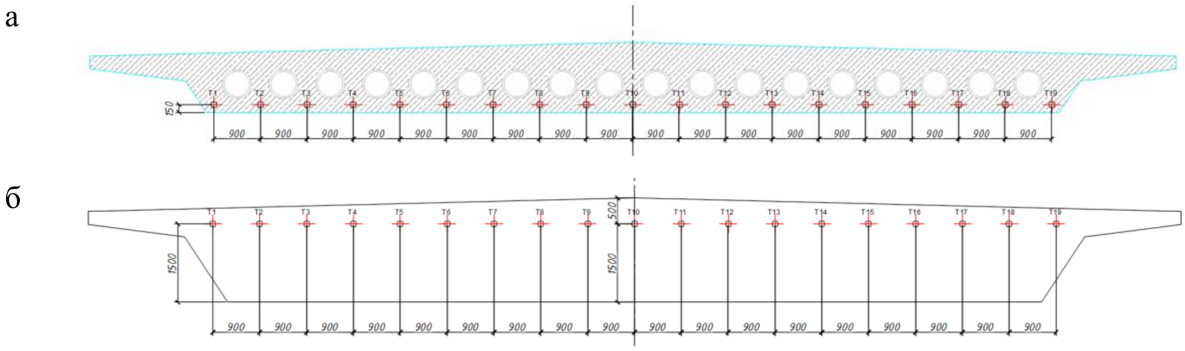

Fig. 4. Positioning of post-tensioning ropes in the span: a-in the middle of the span; b-above the intermediate support.

Results of the study

Seismicity of the territory of Jizzak, according to the map of seismic microzonation, performed by the Institute of Seismology in 1980, is estimated at 7, 8 points. The site of the projected construction is located in the 8-point zone.

In accordance with Table 1.1 of KMK 2.01.03-19 [20] the category of soils by seismic properties is III (third) - loess-like loams with interlayers of loam with porosity coefficient **e<0**.8). Taking this into account, the seismicity of the projected construction site is recommended to be 8 points.

The seismic impact is transmitted to the structure at four points through the supports in the form of equal displacements of the support foundations and the base surface. The span is connected to the supports using LRB-SN series rubber-metal supports.

Numerical calculations were carried out by the SHARK (Step Algorithms for Structural Calculation) software package developed by the authors, based on real earthquake records. The results of calculations of monolithic bridge from dynamic load are presented, on records of real seismograms of Gazliyskiy (Uzbekistan) earthquake from 17.05.1976, more than 9 points on MSK-64 scale, maximum acceleration, velocity and displacement in the direction of longitudinal axis of the bridge, seismic wave propagation: 7.22 m/s^2 ; 0.62 m/s; 0.18 m . Vertical acceleration 14 m/s^2 . Earthquake records are taken from the European database of strong earthquakes [18].

For discretisation, the overpass was divided into 278 finite elements, taking into account the operation of each type of finite element. The calculations were performed using an implicit scheme with a time step of 0.001 s. The energy loss is accounted for in Rayleigh form.

The influence of tensioning of reinforcement ropes of the monolithic overpass spanning structure on static and dynamic stressed state in three variants has been investigated:

Reinforcement rope in post-tensioned condition;

Reinforcement rope in post-tensioned state with a coefficient of expansion 2 times less;

Reinforcement rope in unstressed condition;

Figs. 5-7 shows the plots of time variation of normal stress in the upper (a) and lower (b) parts in the middle of the overpass (Ghazli earthquake).

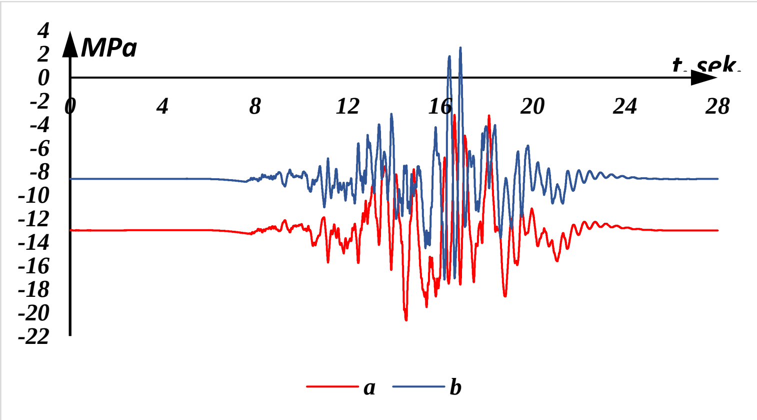

Figure 5. Time variation of normal stress in the upper (a) and lower (b) parts in the middle of the overpass (Ghazli earthquake) in the first variant of tensioning

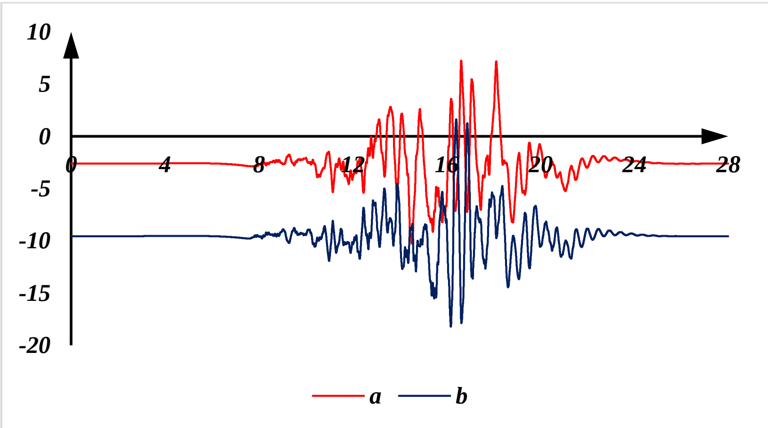

Figure 6. Time variation of normal stress in the upper (a) and lower (b) parts in the middle of the overpass (Ghazli earthquake) in the second variant of tensioning

Table 2 presents the results of calculations of normal stress variation in the upper and lower parts of the elements of the spanning structure of a non-split monolithic overpass under the Gaslian earthquake for three cases of reinforcement tensioning.

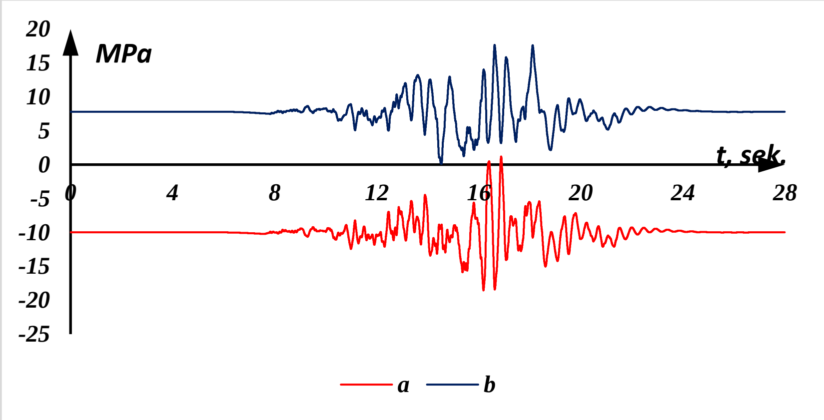

Figure 7. Time variation of the normal stress in the upper (a) and lower (b) parts in the middle of the overpass (Ghazli earthquake) in the third variant without tensioning

Table 2

Maximum stress values in the upper (a) and lower (b) parts in the middle of the overpass

№	Combination	Expansion coefficient of the rope	Maximum stress in the upper part, MPa	Maximum stress in the bottom part, MPa	Maximum allowable stress according to SNK 2.05.03-2022, MPa
1	Reinforcement rope in post-tensioned condition	-0,00504	-3,3036	2,2516	3,22
2	Reinforcement wire rope in post-tensioned state with expansion coefficient 2 times lower	-0,00252	1,2498	6,8166	3,22
3	Reinforcement wire rope in unstressed condition	0	0,6797	17,372	3,22

The results of calculations for seismic effects of an uncut monolithic overpass based on the existing records of the Gazli earthquake of more than 9 points in accordance with SNC 2.05.03-22 [21] were compared with the permissible stress values for concrete classes. For the span made of B50 grade concrete, the allowable tensile stresses are 3.22 MPa.

The results of calculations of the overpass in accordance with without prestressed rope (reinforcement rope in unstressed state) and with reinforcement rope in post-tensioned state with expansion coefficient 2 times less, the calculated values were higher than the values of tensile stresses permissible according to the normative documents, respectively, 5.4 times and 2.11 times. This shows that in these cases the span structure may collapse under the action of an earthquake with an intensity of more than 9 MSK-64. When comparing the values taking into account the rope tension (reinforcement rope in post-tensioned state), the calculated values of stresses correspond to the normative ones. According to the results of calculations during the earthquake, the maximum compressive stress in the upper part of the span is -3.3036 MPa, and the maximum tensile stress in the lower part is 2.2516 MPa. The post-tensioning of the rope prevents the formation of cracks in the span. As a result of numerical calculation of the earthquake resistance of an unsplit monolithic overpass taking into account the rope post-tensioning, it was revealed that the overpass retains its operational characteristics during earthquakes with an intensity of more than 9 points.

Conclusions

Based on the results of the study, the following conclusions can be drawn:

A three-dimensional finite element model of a non-split monolithic reinforced concrete road overpass is constructed using the Timoshenko beam model taking into account the post-tensioning of the reinforcement rope. The Newmark method is used to solve the dynamic problem with given earthquake accelerograms.

The rope tensioning plays an important role in non-split span overpasses. For the overpass considered, the degree of tension used for the steel wire rope can withstand an earthquake of more than 9 magnitude.

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