Calculation of monolithic bridges taking into account seismic conditions of Republic of Uzbekistan

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Abstract. To improve the transport infrastructure of the Republic of Uzbekistan, the monolithic structure of bridges and overpasses began to be used. The article presents the calculation of a monolithic overpass on the 1083rd km of the M-39 highway passing through Samarkand. The results of the calculation of a monolithic overpass from dynamic load are presented based on the records of two real seismograms for two dangerous earthquakes for the system with spectral composition: Gazli (Uzbekistan) and Manjil (Iran). The calculations show that to ensure guaranteed seismic safety of transport structures, it is necessary to carry out design calculations based on sets of records of earthquakes that occurred, close in dominant frequencies to the characteristics of the construction site. Such a provision should be introduced into the relevant regulatory documents.

1 Introduction

The importance of the transport logistics system in today's globalized world economy is even greater. Developing a logistics system that meets modern requirements is one of the signs of a country's prosperity. Railways, roads, bridges, tunnels, and other artificial structures built on these roads can be indicated as the main part of the logistics system. Providing citizens of our country with convenient and high-quality transport services and ensuring the stable operation of transport and communication systems are important for the development of our state. Today, construction is considered a promising plan for the development of the economy of the Republic of Uzbekistan. The modern construction industry is one of the most prominent national sectors of the economy of the Republic of Uzbekistan, showing stable annual growth.

In a speech at a joint meeting of the chambers of the Oliy Majlis, the President of the Republic of Uzbekistan Sh.M. Mirziyoyev "From the Action Strategy to the Development Strategy: Priority Tasks Implemented as part of the Development Strategy", a special place was given to the construction industry as a locomotive of the economy for the further accelerated development of the construction of buildings and artificial structures on railways and roads.

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As part of the implementation of the Decree of the President of the Republic of Uzbekistan dated October 4, 2019 No. DP-3309 "On improving the system for organizing the construction and operation of road bridges, overpasses, and other artificial structures, " dated November 27, 2018 No. DP-4035 "On measures to introduction of advanced foreign methods of organizing work in the construction and operation of roads", work is underway to build roads and bridges to ensure safe traffic.

In this regard, in recent years, there has been an increased interest in the world in the modernization and expansion of the road network, including bridge structures, using modern technologies and designs of bridges and overpasses made of monolithic reinforced concrete. Although monolithic construction began its development relatively recently, this construction method is considered the most promising at present. Monolithic bridges are used in all developed countries of the world. Monolithic construction is a method of erecting buildings and structures, in which the main material of the structures is monolithic reinforced concrete. The reinforced concrete structure is strong and durable and also has high performance. The main feature of monolithic construction is that the place for producing material for monolithic bridges and other engineering structures is a construction site. The use of monolithic reinforced concrete makes it possible to realize a variety of architectural forms and reduce steel consumption by 7-20% and concrete by up to 12%. In addition, there are several advantages of this method:

– **construction speed.** This method allows you to install supports very quickly and move on to the next stage of construction;
– **reliability.** A monolithic reinforced concrete structure, made in strict accordance with the technology, has increased strength and resistance to design loads;
– **price.** Because the technological process of monolithic construction is quite fast and economical in terms of resources, the cost of work on this technology is much lower than that of possible analogs;
– it is possible to create complex geometric shapes, i.e., many construction companies are convinced that superstructures made of prestressed monolithic reinforced concrete, along with undeniable technical and economic advantages, also have aesthetic appeal. And this is especially important for a city world-famous for its beauty.

To date, to improve the transport infrastructure of the Republic of Uzbekistan, they began to use the monolithic structure of bridges and overpasses. One of the clearest examples of this is the new overpass, which is being built on the 1083rd km of the M-39 highway passing through the city of Samarkand, which is being built by the Kuprikkurilik Trust UE, which is a structural subdivision of Uzbekistan Temir Yollari JSC. The total length of the overpass is 110 meters, and the width is 28.9 meters. The overpass will be divided into 3 lanes on each side with a width of 3.5 meters.

Another example is the construction in Tashkent of a six-lane highway and three overpasses that connect the Sergeli district with the central part of the city [1]. The overpass construction, which shortly will become another excellent example of the creativity of architecture, is carried out based on the latest technologies following international standards.

It is known that the territory of Central Asia, especially Uzbekistan, is a seismically active zone. As a result, the design and construction of bridges, overpasses, and overpasses must be subject to high requirements. In this regard, it is of interest to develop methods and software for calculating bridges and overpasses for the effect of earthquakes based on the available seismic records [2, 3]. Seismic isolating devices are used to dampen vibrations under seismic impacts [3].

Currently, in Uzbekistan, for the design of earthquake-resistant structures, there are current standards KMK 2.01.03-19, and for transport facilities - ShNK 2.01.20-16 "Construction of transport structures in seismic areas". However, in the section of the new
ShNK 2.01.20-16 concerning bridges and overpasses, there are practically no issues of special seismic protection in the calculations of bridges for seismic effects.

Carrying out calculations based on the available real records of seismograms [4], recorded during strong earthquakes and stored in well-known databases in Europe and the USA, makes it possible to study the behavior of the structure in real-time, as well as to evaluate the strength of the elements of calculated bridges and overpasses. This approach will ensure the reliability of bridges and overpasses under seismic effects that have a certain intensity at the construction site.

2 Methods

More than twenty monographs have been published on the issues of seismic isolation of buildings and bridge structures. The classification of seismic isolation devices is given by scientists and specialists V.A. Verkholin [5], A.M. Uzdin and T.A. Sandovich [6], G.S. Shestoperov [7], R. Skinner, W. Robinson, and G. Mtsverri [8] and other authors. In [9], the issues of seismic isolation and seismic damping of bridges, considering the features of seismic vibrations of bridges, assessing seismic loads, and setting the design impact and coefficients of seismic and moving loads combinations are considered.

The three-span reinforced concrete monolithic overpass, 110 m long and 10.5 m wide, has a variable thickness along the overpass. The overpass design is divided into finite elements, taking into account the change in height along the span length. The finite element models axial tension-compression, bending about axes perpendicular to the longitudinal axis of the overpass, and torsion about the longitudinal axis [10, 11]. The span structure of the overpass is made by a continuous monolithic reinforced concrete design scheme of 33m + 42m + 33m of individual design. On the facade, the superstructure is made with a slab of variable height - 1.3 m in the span and 2.3 m above the support.

Bridge structures consist of many elements, the most important of which are supports and supporting parts [12]. The support and supporting parts are the bridge structure's most vulnerable elements; therefore, seismic isolating devices, particularly rubber-metal ones, are used for the supporting part. The supporting part is a seismic insulating rubber-metal device. Due to low shear rigidity, it allows the span to move in the longitudinal direction in the range from 0.1 m to 0.35 m, depending on the models used. The vertical stiffness of the supporting part is 5.908x10^9 H/m; the horizontal stiffness is 4.72x10^6 H/m. The bearing part is modeled as a finite element operating in tension/compression, shear in two directions, and torsion. Intermediate supports have dimensions: height of 5.85 m, width along the facade - 2 m, and in the lateral direction, it has a variable height from 5 m to 8.4 m. In this calculation, we assume their movement is equal to the movement of the base during an earthquake. The material of all structures is concrete of class B35 in strength, with specific gravity \( \gamma = 25000 \text{ N/m}^3 \), elastic modulus \( E = 35200 \text{ MPa} \), and Poisson's ratio \( \nu = 0.2 \).

The seismicity of the territory of Samarkand, according to the map of seismic microzoning made by the Institute of Seismology in 1980, is estimated at 9 and 8 points. The site of the projected construction is located in the 8-point zone.

Following Table 1.1 of KMK 2.01.03-96 within site in the upper 10-meter thickness, counting from the base of the foundations, soils of the II category in terms of seismic properties occur - loams with a porosity coefficient \( e<0.8 \), pebble soil). With this in mind, the seismicity of the projected construction site is recommended to be taken as 8 points. The scheme of a monolithic overpass is shown in fig. 1.
In [13-15], studies were conducted in detail on the method of calculating damped systems; the effectiveness of using the mass damper setting to reduce damage after strong earthquakes was obtained.

Recently, seismograms of earthquake records have been taken as seismic impacts [16, 17]. It is interesting to develop methods and software for calculating bridges and overpasses for earthquake impacts based on the available seismic records.

### 3 Results and Discussions

The impact is set in the form of a series of seismogram records in three directions with amplitude adjustment for different intensities. The equation of motion of the structure after applying the discretization by the finite element method is reduced to the form

\[
[M][\dddot{u}] + \eta[C][\dot{u}] + [K][u] = [P],
\]

with initial conditions from the static solution of the problem.
where \( \{u(t)\}_t=0 = [u(0)] \), \( \{\dot{u}(t)\}_t=0 = [\dot{u}(0)] \),

\begin{equation}
\{u(t)\}_t=0 = [u(0)], \quad \{\dot{u}(t)\}_t=0 = [\dot{u}(0)],
\end{equation}

The seismic action is transmitted to the structure at four points through the supports in the form of equal displacements of the supports and the base surface. At the beginning of the overpass - the left end of the span is rigidly connected to the abutment, and at the end of the overpass - the right end is connected to the abutment with movable bearing parts.

The article presents the results of calculations of a monolithic overpass from the dynamic load based on the records of two real seismograms of dangerous earthquakes: Gazli (Uzbekistan) and Manjil (Iran).

Gazli (Uzbekistan) earthquake dated May 17, 1976, more than 9 points on the MSK-64 scale, maximum acceleration, velocity, and displacement in the direction of seismic wave propagation: 7.22 m/s²; 0.62 m/s; 0.18 m. Vertical acceleration 14 m/s².

Manjil (Iran) earthquake of 06/20/1990, 8 points on the MSK-64 scale, maximum acceleration, speed, and displacement in the direction of seismic wave propagation: 1.93 m/s²; 0.21 m/s; 0.064 m.

The calculation was carried out by the finite element method according to the beam theory; the Newmark method was used for the time variable. The need to carry out calculations for the seismic resistance of unique structures, as well as structures with seismic isolating devices using records of accelerograms and seismograms (displacements) of the soil surface, required the modification of the SHARK software (prof. I. Mirzaev created the software package), which meets the modern needs of researchers and designers in the field of construction in seismic regions [2].

For discretization, the overpass was divided into 220 finite elements, taking into account the operation of each type of finite element. The calculations were carried out using an implicit scheme with a time step of 0.005 s. The energy loss is taken into account in the Rayleigh form.

Earthquake records are taken from the European Strong Earthquake Database [21, 22]. On fig. 3 shows the longitudinal movement of the right end of the overpass (black line), which is free from longitudinal stress, and the movement of the corresponding abutment from active soil pressure (red line) during the Gazli earthquake.

It can be seen from the graph that the maximum displacement in a seismic wave propagating along the longitudinal axis of the overpass is 0.18 m. The seismic wave propagation velocity is 500 m/s. In this case, the maximum difference between displacements is 0.07 m, and at a seismic wave propagation velocity of 250 m/s, this displacement difference will be 0.14 m. This is due to the difference in wave propagation velocities in the monolithic structure of the overpass and in the ground, which leads to a delay in the arrival of the wave along the ground. It follows that the bearing part of the right end of the overpass does not allow the span to fall from the abutment because the maximum displacement of the rubber-metal bearing part is 0.2 m.
Fig. 3. Change in time of the longitudinal movement of the right end of the overpass span and base (Gazli earthquake)

For comparison, the behavior of the overpass structure was also calculated during the Manzhil earthquake. In this case, the maximum difference between displacements is 0.03 m, and at a seismic wave propagation velocity of 250 m/s, this displacement difference will be 0.06 m.

On fig. 4 shows a graph of the change in time of the vertical movement of the overpass span in the middle of the first and second spans during the Gazli earthquake.

Fig. 4. Change in time of the vertical movement of the overpass span in the middle of the first (black line) and second (red line) spans (Gazli earthquake)

Here, the vertical displacements of the monolithic overpass are indicated at a distance of 16.5 m from the left end with a black line and at a distance of 54 m from the left end with a red line. The maximum displacement is 0.21 m, which is associated with a large vertical
acceleration value in the earthquake record, equal to 14 m/s². In the middle of a large span, high-frequency oscillations are observed. A separate comparison of the graphs of vertical displacements of the upper part of the support and the corresponding point of the monolithic overpass showed that the vertical component of the seismic wave tosses the monolithic part of the overpass over the support by fractions of millimeters [23]. In this case, the bearing parts work in tension, which may cause high-frequency oscillations.

Figure 5 and figure 6 show the changes in time of the vertical shear force and bending moment relative to the horizontal axis of the overpass span above the first intermediate support during the Gazli earthquake.

On figure 5 shows the change in time of the vertical shear force of a monolithic overpass at a distance of 33 m from the left end, i.e., above the support. The maximum absolute value is 13.3 MN; the static value is -6.7 MN.

Change in time of the bending moment relative to the horizontal axis of the cross-section of a monolithic overpass at a distance of 33 m from the left end, i.e., above the support, shown in figure 6. Maximum value 79.76 MNm, static value 46.89 MNm.

![Fig. 5. Change in time of the vertical shearing force of the overpass span above the first intermediate support (Gazli earthquake)](image)

Change in time of the bending moment relative to the horizontal axis of the cross-section of a monolithic overpass at a distance of 33 m from the left end, i.e., above the support, shown in fig. 6. Maximum value 79.76 MNm, static value 46.89 MNm.
Fig. 6. Change in time of the bending moment relative to the horizontal axis of the overpass span above the first intermediate support (Gazli earthquake)

Figure 7 shows the change in time of the longitudinal stress at a distance of 54 m from the left end of the overpass span at the midpoint along the width under the upper surface (black line) and above the lower surface (red line) during the Gazli earthquake. This seismic wave causes the stress to increase more than twice the static stress value. After the passage of a seismic wave, the voltage quickly returns to a static state.

Fig. 7. Change in time of the longitudinal stress at a distance of 54 m from the left end of the overpass span (Gazli earthquake)

On figure 8 shows the change in the vertical shear force along the overpass at different times (t=14.26 s; t=15.77 s; t=18.25 s; t=20.45 s) during the Gazli earthquake. In this figure, you can see the oscillatory change in the shear force during an earthquake.
Fig. 8. Change in the vertical shear force along the overpass at different points in time (Gazli earthquake)

On figure 9 shows the change in the bending moment relative to the horizontal axis along the overpass at different times (t=14.26 s; t=15.77 s; t=18.25 s; t=20.45 s) during the Gazli earthquake. In this figure, you can also see the oscillatory change in the bending moment.

Fig. 9. Change of the bending moment relative to the horizontal axis along the overpass at different times (Gazli earthquake)

4 Conclusion

The current regulatory documents on the earthquake-resistant construction of transport facilities do not reflect the seismic resistance of structures, taking into account multi-level design. Unfortunately, in transport construction, domestic design institutes do not use records of real earthquakes in the calculations of bridges for seismic resistance and are
limited to linear-spectral calculations due to the lack of information about the situational seismicity of the territory of Uzbekistan. In this regard, to ensure the guaranteed seismic safety of transport facilities, it is required to carry out design calculations on sets of records of occurred earthquakes that are close in dominant frequencies to the characteristics of the construction site. This provision must be included in the relevant regulatory documents.

References


