SOME FEATURES OF DAMAGE TO UN-CUT REINFORCED CONCRETE BRIDGES UNDER SEVERE EARTHQUAKES

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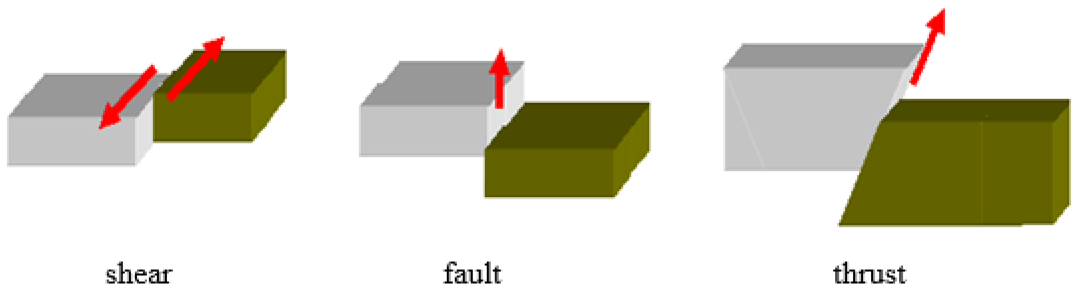
Abstract. *The main types and reasons of the initiation of specific damage to un-cut reinforced concrete bridges under strong and destructive earthquakes are discussed in the article. A brief review of the features of the destruction of un-cut reinforced concrete bridges and railway tracks under severe earthquakes in Europe and Asia is presented.*

Keywords: *un-cut reinforced concrete bridges, earthquake, bearing part, seismic intensity scale, railway track, superstructure, support, expansion joint.*

An earthquake is a tremor and vibrations of the earth's surface. Movements in the upper mantle make layers of the earth's crust collide with each other and cause earthquakes. If the distance between the moving parts of the earth's crust is small then its elasticity is not high, and when the stresses in the rock masses reach a certain level, it exceeds their tensile strength, and fractures are formed, the edges of the rocks move apart, and the ground moves. In most cases, earthquakes occur in sites where the strength of the earth's crust is less strong. According to the type of thrusts, the mechanism of earthquakes in fault areas is divided into three types - shear, fault, and thrust (Fig. 1) [1].

Fig. 1.

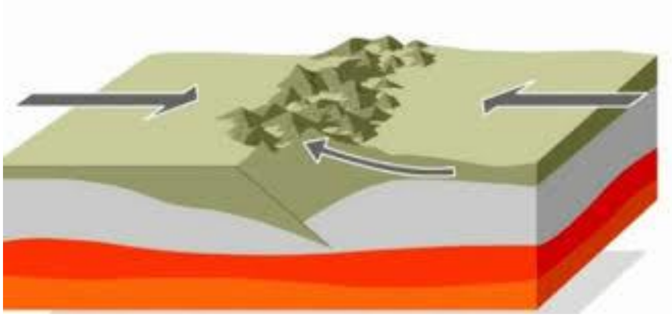
Types of tectonic fractures



Earthquakes are usually caused by tectonic strains in the earth's crust. Under such strains and the impact of certain values of tension, sudden distortions arise - displacements of one form or another are formed. In this case, a large amount of strain energy is released and waves that propagate in all directions are formed. Reaching the earth's surface, the waves cause earthquakes - vibrations of the upper part of the soil layer [1].

Fig. 2.

The process of tectonic earthquakes



The problem of seismic resistance of bridges and bridge structures is extremely important due to the fact that severe earthquakes destroy them, making it difficult for them to function normally. Bridges and bridge structures are made up of many elements, the most important of which are piers and bearing parts [2].

Factors that cause the destruction of bridges during an earthquake are numerous. These include the discontinuous tectonic motion of the crust, seismic ground vibrations, landslides, caving-ins, avalanches, mudflows, tsunamis, liquefaction, and soil settlement.

Among the devastating earthquakes of the second half of the 20th century and the beginning of the 21st century, the following seismic events should be mentioned: The Tokyo earthquake of 1923, in Japan, with the magnitude of 8.2 points, claimed 143 thousand people dead. The damage caused by the earthquake to Tokyo and its environs amounted to 3 billion dollars in 1923 prices. The earthquake and tsunami in Japan caused damage to 582 roads and to 32 bridges. The roads were mostly cracked, but in some cases, there was complete destruction of the roadbed and bridges.

Another strong earthquake occurred on September 17, 2022, on the east coast of the island of Taiwan (destructive at the epicenter according to the Seismic Intensity Scale "SIS-17") with M = 6.7. After 17 hours and 3 minutes, on September 18 at 9:44 (Moscow time), the second shock occurred (catastrophic at the epicenter according to the SIS-17) with M = 7.3. The epicenter of the earthquake, which originated on the northeast coast of Taiwan, at a depth of 10 km, was located 127 km east-northeast of Taiwan, 137 km southeast of Taichung and 210 km south of Taipei. The epicenter of the second shock was located 13 km northeast of the first. During September 17-19, the Geophysical Service registered 14 shocks with magnitudes from 4.5 to 5.7. Bridges, roads, buildings, and infrastructure were damaged. A three-story house collapsed in Yuli Township, Hualien County. In Hualien County, at the Dongli railway station, several wagons of the train derailed (Fig. 3). In a number of mountainous areas, landslides and rockfalls were observed, which led to the evacuation of hundreds of tourists from there. The epicenter of the first earthquake was located 39 km southwest of the epicenter of another severe earthquake on March 22, 2022, with M = 6.7, 105 km south-southwest of the epicenter of the strong earthquake on February 4, 2018, with M = 6.3, 109 km south-southwest of the epicenter of the strong earthquake on February 6, 2018, with M = 6.5 and 95 km southeast of the devastating earthquake on September 20, 1999, with M = 7.7. More than 1,500 people died and 3,800 were injured. In Puli, 98% of the buildings were damaged or destroyed [3].

Fig. 3.

(a) Train derailment at Dongli station in Hualien. (b) - (c) Collapsed train platform roof at Dongli Station in Hualien County.

(a)

(b)

(c)

In 2022, (September 11, at 2:46 Moscow time) on the island of New Guinea, Papua New Guinea, a strong earthquake occurred (significant at the epicenter according to the SIS-17) with M = 6.9. The epicenter of the earthquake (the focus of which was on the island of New Guinea in the province of Morobe, Papua New Guinea, at a depth of 90 km) was located 72 km northwest of Lae, 140 km southeast of Madang, 367 km north of Port Moresby, the capital of Papua New Guinea. The Geophysical Service registered one aftershock with M = 5.2 after 56 min [3].

On October 14, 2022 (at 03:53 Moscow time), a tangible earthquake occurred in the area of Lake Baikal (significant at the epicenter according to the SIS-17) with M = 5.1. The epicenter of the earthquake, the focus of which was in the waters of Lake Baikal at a depth of 10 km, was located 16 km east-northeast of Bolshoi Goloustnyi, 99 km east-southeast of Irkutsk and 108 km northwest of Gusinoozersk. The epicenter of the earthquake was located 10 km west-southwest of the epicenter of the tangible earthquake on June 8, 2022, with M = 5.2 and 41 km northeast of the epicenter of the tangible earthquake on December 15, 2021, with M = 4.9 in the area of Lake Baikal [3].

Fig. 4.

Severe damage and displacement of railway tracks after the 2022 Taiwan earthquake.

Given the complex nature and aftermath of seismic hazard, many outstanding scientists from around the world (A.A. Gelfer, G.N. Kartsivadze, G.S. Shestoperov, A.M. Uzdin, T.R. Rashidov, I.O. Kuznetsova, U.Z. Shermukhamedov, E.N. Kurabatsky, V.K. Musaev, Yu.I. Nemchinov, Wai-Fah Chen, Lian Duan, Charles Scowthorne, Steven L. Kramer, et al.) conducted research on the development of anti-seismic measures in roads and bridge construction. Studying the consequences of earthquakes, scientists and engineers in Japan, the United States and Russia have proposed many methods for the construction of particularly stable buildings and structures that can withstand strong ground motion.

The most typical seismic damages of bridge structures indicate that, in the general case, they are caused by a number of reasons that make up the main factors of seismic impact. Analysis of various data allows us to distinguish two groups of damage to bridge structures [4, 5]:

– *damage to span structures*, their shift on bridge seats or falling from supports under relatively minor damage to the latter;

– *destruction or severe damage to the supports*, resulting in the complete or partial collapse of the bridge.

The most important source of information is the earthquakes that occurred in the CIS countries, Europe and Asia. Based on the study of the earthquake aftermaths, conclusions can be drawn about the vulnerable objects of the national economy and possible risks of destruction of bridges and transport infrastructure in countries with high seismic activity.

As is known, man-made structures such as bridges and overpasses are complex design solutions with many coupling elements. For example, in the longitudinal direction, spans can be continuous (monolithic), free or fixed to the structure. Thus, for the structure to be effectively strong, the connections at the top and bottom of the piers must be strong enough to operate in plastic hinge mode. If the bearings are poorly designed, then most of the damage occurs in those places, which leads to less reliable results. Most often, damage of this type occurs due to insufficient reinforcement at the joints. This occurs between decks and piers, as was observed during the 1995 Kobe earthquake (Figure 5), or between piers and foundations, as occurred during the San Fernando earthquake (Figure 6).

Fig. 5.

Devastating earthquake in Kobe (Japan) January 17, 1995

Another type of joint damage often observed after earthquakes is related to the lack of stiffness at the joints between the pier and the foundation. If a connection should transmit bending moments and shear forces between elements, then a large amount of reinforcement is required to prevent shear damage at the joints [6]. Figure 6 shows weak reinforcement of the piers located in pile clusters that contributed to the overturning of the bridge during the 1971 San Fernando earthquake.

Fig. 6.
Overturning of the bridge during the earthquake in San Fernando, 1971

One of the most recent destructive earthquakes in the history of mankind was the Wenchuan earthquake, on May 12, 2008, which reached a magnitude of M 8.0, the epicenter was in the city of Yingjiu, Wenchuan County, the focus depth was 14 km; it was a shallow earthquake, its aftermaths spread to most regions of China, including Sichuan, Gansu and Shaanxi, and even abroad. The affected areas have mostly mountainous relief, which led to destructive secondary disasters such as landslides and rockfalls. The infrastructure of expressways, national and provincial highways, and rural roads suffered various levels of damage [6].

Of the 2,154 bridges surveyed after the earthquake, erected on national and provincial highways, 401 bridges were damaged, of them, 52 were completely destroyed, 70 were seriously damaged, and 279 were moderately damaged [6].

Seventy-three bridges built on the national highways and expressways from Dujiangyan City to Yingjiu City suffered such damage as collapse, displacement of the road paving (bridge deck), abutment shear failure, and pier failure.

The Shoujiang Bridge (Fig. 7) suffered serious damage, such as the displacement of beams, sliding of the bearing parts, abutment shear failure, and subsidence of the bridge deck. The fifth span of the Baihua Bridge collapsed, and the others were badly damaged, making them unusable (Fig. 8). Fig. 7.

Bridge Damage in Shoujiang

Fig. 8.

Baihua Bridge: (a) destruction of the connection of tier with a tie beam; (b) tie beam fracture, destruction of bearing parts

(a) (b)

In addition, local bridges in various cities in China were damaged to varying degrees. The piers of the Mianzhu Huilan overpass collapsed under shear, one span of the Gaoyuan Bridge in Dujiangyan city collapsed; The Mianyang Airport Terminal Bridge sustained damage such as shear failure of supports (Fig. 9) and displacements of the superstructure.

Fig. 9.

Mianyang Airport Terminal Bridge, bearing shear failure

It should be noted that the practice of seismic design and construction of man-made structures in Italy is still relevant, despite the fact that four major earthquakes have occurred in the country in recent years, which severely damaged the infrastructure and artificial structures in various cities: in Friuli (1976, M6,4), Irpinia (1980, M6.9), Umbria and Marche (1997, M6.1) and L'Aquila (2009, M6.3). Bridges and viaducts are the most common types of man-made structures in Italy and have sufficient capacity to withstand horizontal forces.

Thus, a total of 10 viaducts showed various degrees of earthquake damage, affecting more than 250 spans. The type of damage, as expected, was limited to the destruction of the bearing parts with more or less serious consequences in the form of obstacles to movement at the expansion joints of the superstructure. There was a single case of subsidence of the support backfill. In one case, significant residual bending cracks were recorded in some bearings [6].

Figures 10 and 11 show some typical cases of bearing failure, the displacement of the bearing hinges, up to complete offset, damage to the trusses, and significant permanent displacements. The latter, in turn, often led to relative displacements and destruction of the expansion joints of the superstructure, as shown in Fig. 12.

Fig. 10.

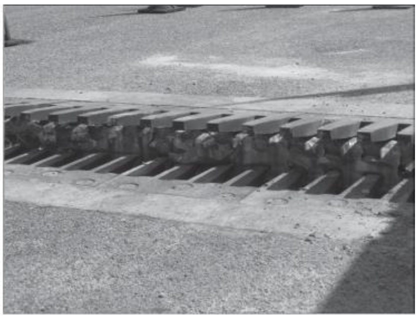
Damage to hinge bearing elements

Fig. 11.

Damage to the abutment: offset of the hinge of the bearing part and damage to the abutment stone

Fig. 12.

Consequences of the destruction of supports at the level of the roadway: rubber expansion joints (left) and steel expansion joints of the abutment (right)

World experience shows that in the field of seismic resistance of bridges, many problematic issues have not yet been resolved. The methods for calculating the anti-seismic strengthening of bridges that exist in regulatory documents do not fully ensure their seismic resistance, durability, and reliability. To ensure their seismic strength, it is necessary to use seismic protection devices in bridge engineering [5].

At present, the world practice of earthquake-resistant construction applies a multi-level approach to the design of seismic-resistant structures. In accordance with this approach, the structure is calculated for several levels of seismic impact at the corresponding limit states. This approach is adopted in Eurocode-8, where it is recommended to consider at least two levels of impact and two limit states - a violation of normal operation (serviceability limit state (SLS)) and a collapse of the structure (ultimate limit state (ULS)) [4].

So, the following conclusions can be drawn:

–- in order to eliminate such damage, it is necessary to ensure a sufficient width of the dimensions of the head of the supports in order to ensure sufficient displacement of the superstructures and to provide special damping and seismic protection devices;

– it is necessary to carefully carry out calculations of the optimization of the supporting parts for the effect of the design and maximum-design earthquake when designing artificial structures;

– a multi-level approach to the design of artificial structures allows the accounting for many characteristic features of their seismic vibrations: the presence of a temporary load, the degree of responsibility, and the features of seismic isolation and seismic attenuation of bridges.

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