Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 •

Inspection and reconstruction of bridges after earthquakes in the Caucasus

G.S. Shestoperov & V.I. Shesterikov
All-Union Research Institute of Transport Construction, Moscow, Russia

ABSTRACT: The paper deals with bridges damages due to 1988 and 1991 earthquakes in the Caucasus. Estimation of bridges vulnerability is presented for seismic effect intensity from 7 to 10 according to MSK-64 scale. Basic requirements for engineering structures design and maintainance, preventing them from destruction under seismic effects, are formulated. Design charateristics of soil vibration and structural decisions, being used for bridges reconstruction in seismic regions, are discussed.

In the 1988 and 1991 Caucasus earthquakes many bridges suffered significant damages. The inspections conducted have made it possible to estimate vulnerability of the bridges, built in those regions with regard to seismic effects and to determine the purpose and basic principles of aseismic measures in bridge building engineering.

The magnitude of the basic shock in the 7th December, 1988 earthquake was equal to 7.0. The focal depth was 14 km. The intensity of earthquake effects in the epicentre reached the value of 9-10 according to MSK-64 scale. The earthquake under consideration is regarded as the most devastating natural calamity of the XXth centuary. More than 25 thousand people perished as a result of buildings collapse in the North Armenia.

More than 30 railway and highway bridges, viaducts and overpasses have been inspected in the earthquake zone. Third of all the bridges inspected had seismic damages, among them several bridges which damages resulted in traffic interruption.

There were observed numerous defects in reinforced concrete girder superstructures of bridges, located in the epicentral zone. They were as cracks and concrete spalling and crushing in girder edges, which is indicative of superstructures tossing up under influence of seismic shocks. The same is evidenced by damages in bearing blocks and cross beams in the places of girders support.

Piers damages were also observed in the epicentral zone. Overpasses abutments shifted forward under the influence of embankments soil pressure. Abutments wings and inverted walls moved apart from the roadway centre. Cracks and concrete spalling occured in concrete abutments bodies and reinforced concrete legs and cross beams of bents.

The earthquake of the 29th April, 1991 in the South Osetia had approximately the same seismic characteristics as those of the Spitak one. It was accompanied by landslides and rockfalls along rivers banks and from steep mountain slopes. Some bridges were also damaged as a result of the earthquake.

The bridge across Dzhava river was built in 1970. The bridge superstructure consisted of prestressed concrete girders (4 x 21.1 m). Bearings are made from steel. Piers are two reinforced concrete columns integrated by a cross beam. The substructure is on pile foundations.

The earthquake induced displacement of the right-bank abutment by not less than 12 cm towards the river's bed. The latter resulted in the girders shift from the design position and destruction of abutment's parapet wall.

The inspections results showed that the bridge suffered damages because of insufficient shear stability of the left-bank abutment. So, when liquidating the earthquake post-effects, the following measures are supposed to be taken: to eliminate the earthquake-induced damages in the structure; to install aseismic devices, preventing the girders from falling from the piers; and to take the necessary measures, ensuring stability of the left-bank slope and its abutment.

The available data, including information on the earthquakes in Moldavia (1986), in Armenia (1988) and in the South Osetia (1991), have made it possible to determine the typical damages of the most spread types of old bridges.(Table 1).

Table 1. Bridges vulnerability under in earthquakes

Earthquake intensity acc. to MSK scale, categories	Bridges typical damages
7	Local deformations Cracks in bridges masonry constructions. Cracks and spalling of concrete protective layer in reinforced concrete legs for overpasses piers.
8	General deformations Settlements, inclinations and horizontal displacements of piers, based on soft sandy-clayey soils. Displacement of rollers and inclination of expansion rollers.
9	Strength disturbance Blockwork breaking and crushing in masonry and concrete bridge constructions. Concrete fracture and reinforcement deformation in reinforced concrete piers and superstructures in the places of stresses highest concentration.
10	Stability disturbance Displacement and overturning of masonry and concrete piers. Collapse of single girder superstructures. Overturning of viaducts reinforced concrete piers in some cases.

The inspection materials, relating to the bridges, having aseismic design, show that there also occur damages in their bearing elements under seismic effects. However the bridges damages were not so severe as compared to those, which were designed without consideration of seismic effects.

Thus, basing on the experience, gained through bridges service in earthquake-prone zones, one can make a conclusion that it is very difficult to design such structures, which would not have any damages under earthquakes of intensity 7 and higher. But obligatory preservance of bridges main servicing function, i.e. its traffic capacity for vehicles and pedestrians, after designed earthquake, along with provision of trouble-free operation of bridges service lines, may be considered as really practicable and economically expedient. Here, local and general deformations may appear in bridge structures, but they don't require its service interruption according to the requirements for vehicles safe traffic.

To achieve the above considered level of bridges aseismicity, when there excluded any possibility for their failure under earthquakes, the following basic requirements should be met:

1. To select the most favourable site from engineering and seismological points of view.
2. To use such bridge designs, which would be less vulnerable seismically and more maintainable.
3. To check bridges bearing capacity by aseismic design.
4. To use strong and steady base for piers foundations.
5. To use superstructures and piers constructions with less dead load.
6. To use purpose-designed aseismic devices for the constructions, when necessary.
7. To provide seismic stability of precast elements on storage and erection areas.
8. To repair and strengthen the constructions suffered from earthquake.
9. To envisage instrumental control of large projects state.
10. To envisage the required improvement of old bridges aseismicity during their reconstruction.

When reconstructing bridges in seismic regions, the engineers are faced with the following situations. There exist bridges, which insufficient seismic stability is being revealed in the course of construction or during the first years of their service, when deterioration of constructions is not very significant or it is lacking. In this case, reconstruction consists in strengthening of intermediate piers, abutments and bearing elements in conformance with seismic stability design. At the same time, bridge damages due to earthquake influence are being removed.

The second situation refers to the structures, having serious physical and moral deterioration. Reconstruction of such structures pursues several objects. For example, the problem relating to provision of seismic stability may be solved with simultaneous increase of bridge traffic capacity and its durability.

Repair and improvement of seismic stability often require considerable capital investments and performance of technically complicated jobs, accompanied by temporary limitations in bridge traffic in its interruption. So, if a bridge suffered comparatively minor damages as a result of earthquake, which don't create any danger for its safe service during coming years, then some alternatives of the bridge reconstruction are advisable to be considered.

Various antiseismic measures may be used for bridge reconstruction depending on its system. Strengthening of existing constructions and installation of special antiseismic devices are considered to be the basic means, providing improvement of seismic stability. In practice there may be used some other measures as well. They should provide reliable operation of a bridge under earthquake's effects.

Aseismic devices are widely used to increase earthquake resistance of railway and highway bridges. In our practice are used such devices as stoppers, anchors, hinged joints, buffers and their combinations. The devices mentioned restrict transverse and longitudinal displacements of superstructures relatively piers, absorb impacts energy and perform some other functions, aimed at superstructure protection against seismic effects.

Use of reinforced concrete jackets is considered to be effective, when strengthening of masonry piers is required. Jacket's thickness is specified depending on concreting conditions. Reinforcement is determined by a design or is selected on the basis of structural concepts. A jacket is usually reinforced with 10-16 mm bars, forming a mesh with 12-20 cm cells sides. The piers, having such reinforcement, are resistant to earthquake intensity of 7-8 according to MSK-64 scale. To increase earthquake resistance of pile foundations, additional piling is carried out. Grillage's reinforced concrete plate is developed in plan. To provide reliable combination of old and new parts of the foundation, thickness of grillage's plate should be increased and appropriate reinforcement of the latter should be performed. Strengthening of foundation, resting on soft soils, requires considerable material consumption - up to 100 % and more, as compared to that of the old foundation for the regions of earthquake intensity 9.

Various solutions advanced have been realized in practice. Let us consider, as an example, strengthening of a highway overpass in Armenia.

The overpass of 478 m length is at highway intersection of Pambak river in Spitak and railway tracks. It was designed for earthquake intensity 8 according to MSK-64 scale. Its superstructures are erected from prestressed concrete 28.0 m long girders. The height of bents varies from 10.0 to 21.0 m. Bents' legs are assembled from 1.6 m diameter casings with their subsequent filling with concrete. Foundations are of two types (pile or massive ones, depending on soil conditions). They are built separately for every leg.

The geological formations in the area consist of gravel, sandy and clayey soils with poor mechanical characteristics. The right bank of Pambak river consists of vulcanic tuff, covered with sand layer of mean density.

Most of foundations and piers legs were erected before the 7th December earthquake. Three girders were mounted on padstone in one span.

Seismic shock of intensity 9 induced some shift of the foundations in the plan. Piers cross beams, not concreted with legs, and separate girders were displaced or overturned. Transverse cracks of up to 1 mm width developed in the lower sections of legs.

Probable accelerations of ground vibrations were analysed on the basis of overpass structure state after the earthquake. The analysis showed that accelerations of ground vibrations along and across the bridge axis reached the values of 0.2-0.3 g. At the same time vertical component of acceleration was approximately twice as much and reached at least the value of 0.5 g (Fig.1).

Thus, when designing overpass strengthening, it is necessary to check additionally the strength and stability of its constructions under seismic effects with horizontal acceleration of 0.25g and with vertical acceleration of 0.5g

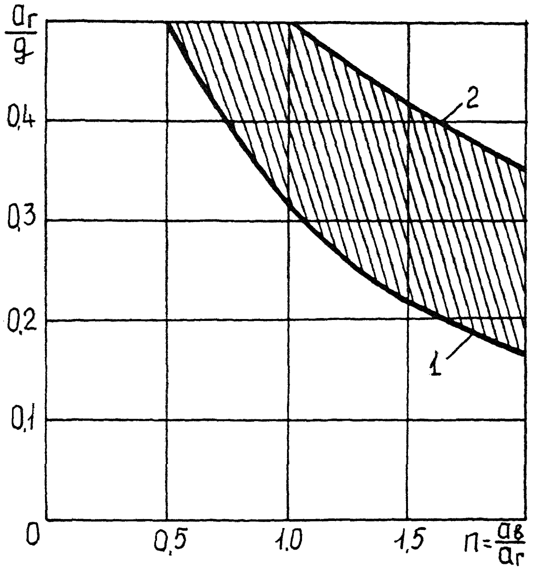

Figure 1. Estimation of accelerations of ground vibrations by the analysis for intermediate pier foundation stability:
1 - by foundation shear analysis;
2 - by foundation overturning analysis; a_r - acceleration of ground horizontal vibrations; a_B - the same for vertical vibrations; g - gravity acceleration.

The analysis conducted showed that the upper section of the river's bank side may lose its stability under condition of ground vibration with higher vertical component.

Taking into account the experience, gained through bridges service in earthquake-prone regions, the shallow foundations have been recommended to be substituted for pile ones. In the middle section of the overpass, where soils conditions allowed shallow foundations, the latter should be strengthened by means of separate constructions integration into common foundation for two legs of every pier. To reduce excessively high amplitudes of cross beams vibrations and to increase the strength of piers over foundations, there were proposed massive reinforced concrete walls, which would be erected to integrate legs by 6 m height (Fig.2).

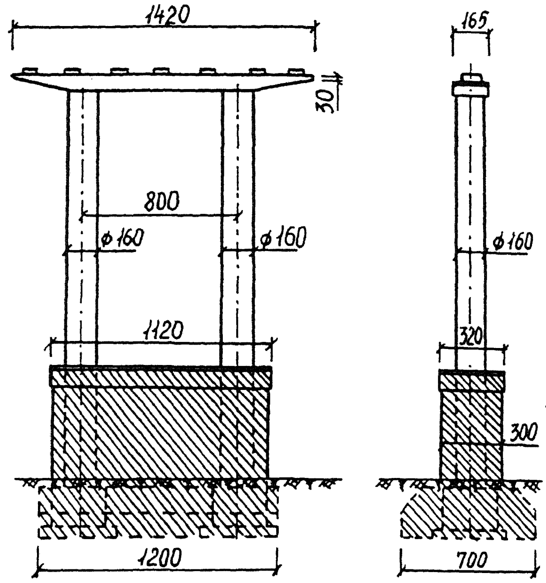

Figure 2. Strengthening of intermediate piers for the overpass

There was also proposed to remove the overpass pier from unstable bank side. In this case, reinforced concrete superstructure of 24.0 m length should be substituted for composite construction of 44.0 m length. Combined antiseismic devices are supposed to be used for superstructures protection against earthquakes effects.