Structures of pedestrian underpasses and overpasses under seismic conditions

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Abstract. In this article, on the basis of analyzing damages of pedestrian passes during earthquakes that caused injuries or death of people, structural designs of these structures in order to enhance their stability are elaborated, and actions for reduction of their damageability degree are proposed. The essence of the invention lies in the fact that operation of arched ceilings is in reduction of reinforcement ratio, enhancement of dynamic stiffness, and reduction of seismically active earth thrust due to reduction of thrust force. The proposed structure operates in compression, which allows diminishing the thickness of concrete, due to which inertial seismic forces are reducing. In this structure, foundation is combined with the floor and transmits the thrust force from wall panels to the arched floor. Strategically, arched structures are better than beam structures, as their sections are mainly operating for off-center compression; at that, stretching forces caused by bending moments are insignificant, whereas bending moments occurring in beam structures cause essential stretching.

1. Introduction

Analysis of aftermath of strong earthquakes shows that the problem of stability, security and safety of people in these engineering structures has not received proper attention. It is known that many people died during earthquakes in China and Mexico (on October 18 of 2016). One of the reasons for this was damage of ceilings in underground passages, partial obstruction of entrance and exit, and flooding of the space inside the passage. Outer passages received significantly more damage caused by loss of abutment’s stability and external stress imparted by neighboring structures.

Pedestrian underpasses and underground utility systems are exposed to constant impact of moving transport (cars, trains) and the possible earthquake effect. Therefore, in order to provide safety of people inside the passages or keep intact the underground utility systems consisting of a dense network of sewer lines and water discharge facilities, it is necessary to consider the impact of transport and of seismic forces simultaneously. This provides the possibility of assessing damage of these structures and determining the weakest spots, which in turn will allow developing new and more stable structures [1-5].

As results of researching the condition of pedestrian underpasses and underground utility systems showed, soil layer of 1 meter thickness in traffic roads and 2 meters for railroad transport is not sufficient for providing normal operation of these structures. Constant impact and vibration loads lead to preterm reconstruction of these structures, i.e. they are exposed to ultimate loads and it is not hard to imagine what is going to happen under additional seismic impact. With the increasing tonnage of automobile transport and railway vehicles as well as the moving speed, the loads on underground
structures are increasing, as vertical oscillations occur and become higher the faster is the moving speed and the heavier is the weight of transport [6-10].

Analysis of constructed pedestrian underpasses in the Republics of Uzbekistan, Kazakhstan, Kirgizia and Tajikistan, which are located in zones of high seismicity, shows that possible aftermaths of earthquakes in these structures are not taken into account properly [11,12]. In some projects, taking seismic forces into account expressed in slight enhancement of reinforcement of structures, though structural modifications were not observed [13].

2. Reliability of structure

Model experiments, carried out with replacement of flat ceiling to arched ceiling, allows reducing reinforcement ratio of slabs and side walls for 15-20%. At that, dynamic stiffness of the structure increases up to 30%. Seismic active earth thrust on the side walls reduces due to thrust forces of the arched ceiling. Vibration oscillations caused by the impact of outer transport reduce due to enhanced stiffness of ceiling slabs, which has a favorable effect on the structure as well as on the feeling of people inside the passage, i.e. ecological requirements are fulfilled (figure 1). The structures are working in compression, which allows diminishing the thickness of concrete, i.e. seismic inertial forces are reducing.

![Figure 1. The structure of arched underground passage.](image)

The recommended height of arch is fa = 0.05L, fk =0.005H. Reduction of soil layer of floor filling from the ceiling till the pavement base compensates arched ceiling, which transfers part of vertical loads to vertical arch walls, which in turn get partially subdued by active earth thrust.

In order to ensure safety of people during possible obstructions of entrances or exits, it is necessary that surrounding buildings were located in distances that exceed their height. Conduit gas pipes and electric cables should be placed out of passages. Canopies that get constructed above the steps of entrance and exit should be designed taking into account earthquakes, because if collapsed, they might block the passage or prevent people from saving themselves, which had already happened during destructive earthquakes.

In big cities, well-lit long underground passes have already been constructed, but often during an earthquake, the lighting system gets destructed, and what is going to happen to people in total darkness remains unknown. For such cases, probably, it is necessary to introduce accumulator batteries that could switch on automatically under failure of the main lighting, which would allow avoiding panic among people as well as providing timely aid.

Using the previously designed constructions of underground structures [14-18] and taking into account small loads caused by pedestrians inside the passages, a more efficient cross-section (figure 2) has been obtained based on a series of additional model experiments. In this structure, foundation is
combined with the floor and transmits the thrust force from wall panels to the arched floor. Height of the floor is \( f_n = 0.03L \).

![Figure 2. Efficient cross-section of the arch structure.](image)

3. Calculation of structures

On the basis of previously elaborated theoretical solutions on the impact of outer transport on underground structures, and confirming the results of field studies and model experiments, a formula was obtained for determining maximum stress on the structure’s base in the bottom plate for pedestrian underpass during an earthquake [19,20]:

\[
\sigma = \frac{WT \left( (E_n + \alpha E_r) \gamma_{np} \right)^{1/2}}{2\pi \left( (1 + \alpha) g \right)^{1/2}} k
\]

(1)

where \( \alpha \) is coefficient that takes into account cooperative work of the foundation and the structure, \( \alpha = 2.8 \); \( E_n, E_r \) is modulus of elasticity of the bottom plate and the foundation; \( W \) is the design seismic acceleration during an earthquake; \( T \) is the period of ground vibration during an earthquake; \( \gamma_{np} \) is the average bulk density of the soil and the plate; \( k \) is structural coefficient that depends on the degree of the bottom plate’s concavity, \( k = 0.45 \).

The researched pedestrian overpasses and their design solutions allow for a statement that possible seismic forces haven’t changed the structure. Pedestrian passages above railroads are long. Under longitudinal impact alongside the passage’s axis, dynamic stiffness does not cause concern. Under traversal impact of a seismic wave, dynamic stiffness is low and has significant oscillation amplitude. In order to enhance dynamic stiffness, we recommend designing support pillars with a tilt \( \alpha = 15° \text{ to } 20° \) (figure 2).

4. Conclusion

It is advisable that ceiling plates are designed in the arched form, which enhances dynamic stiffness of the entire structure and reduces oscillation amplitude, which in turn will increase the integrity rate during earthquakes (figure 4). Height of the arch \( f = 0.05L \). Arch thrust gets completely neutralized by tilted columns and the recommended foundation construction. Reinforcement rate in the plates reduces for 10%. A better runoff of atmospheric precipitations gets provided. It is advisable that foundation for the structure (figure 4) was designed with a “tooth” or with a spherical supporting surface, which will prevent horizontal shift of tilted columns.
Further partial destruction of outer pedestrian bridges over the railroad might lead to catastrophic accidents, as it is impossible to stop a railway vehicle quickly, which is going to result in its collision with destructed structures.

![Structural layout of pedestrian overpass.](image1)

**Figure 3.** Structural layout of pedestrian overpass.

![Layout of pedestrian overpass.](image2)

**Figure 4.** Layout of pedestrian overpass. 1-foundation with a “tooth”; 2-foundation with concaved support.

Arched ceiling plate (figure 4) will be 20% lighter that the one on the layout (figure 3), which rapidly decreases seismic inertial forces and therefore favors for integrity of the engineering structure. Reinforcement rate of the plate reduces for 8%, which reduces the plate’s cost.

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Acknowledgments
The work was supported by Act 211 Government of the Russian Federation, contract No. 02.A03.21.0011.