Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

The problem of transportation system reliable operation in seismic regions

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ABSTRACT: Reliable and life saving functions of transportation systems may be achieved providing their protection against probable consequences of seismogravitational, seismotectonic and seismodynamic effects. New developments and procedures related to design, constructional and instrumentation aspects, which have been tested, contributed to the problem solution.

Transportation systems such as railways and roadways possess all the attributes of a cybernetic system, but they feature high reliability level. In practice those extended systems can't fail completely along the whole route, in other words, they can't have total failure. Distinctive feature of a road as a whole large system is multiple nature of its failures, classified as single, long-term and permanent ones.

As for the railways, single failure may be caused by wreck or structure breakdown at a road particular section; long-term failure may take place because of bridge's or tunnel's lengthy section breakdown or some small structures failure, resulting in interruption of trains traffic for a long time (some days, for example); permanent failure leads to reduction of road capacity because of wear or partial breakdown of some subsystems or structures. Combined failures may take place as well.

There exist a great deal of causes for failures, one of them being connected with human activity, while others being of purely natural type. Earthquake's effects, such as seismotectonic, seismodynamic and seismogravitational ones, refer to the latter. To provide reliable performance of a road, preventive measures, aimed at track and structures protection and failures prevention, should be taken at their designing stage.

To this end, accumulation of data on the nature and results of earthquake effect and relevant failures is considered to be rather important problem. Besides, information is necessary on the cases, when seismic effects haven't resulted in detectable failure, but prepared the conditions for its occurence to such an extent that any other effect, such as flood, rain, next low-intensity earthquake and heavy freight trains traffic may inevitably provoke the failure. At the same time, data should be accumulated on those specific seismic effects, which cause more frequently one or another deformation, resulting in a system or subsystem failure. All those data are necessary for the development of efficient preventive and protective measures.

As a rule, transportation systems may be considered as life saving systems in earthquake-prone regions. The said was often confirmed during conduction of rescue works and liquidation of high-intensity and catastrophic earthquakes' after-effects such as Spitak 1988 earthquake occured in Armenia. Here, life-saving of buriedalive people depended, to a considerable extent, on urgent delivery of heavy-duty construction equipment from other regions of the country , not speaking about fast arrival of rescue units and evacuation of earthquake victims.

All the above stated predetermines the necessity in detailed study of all the exogenous and endogenous (seismogenous) processes along a route not only in seismic zones, but

in the regions, close to earthquake-prone ones, in order to provide reliable and no-failure operation of a transportation system, at least with regard to long-time failures.

Endogenous (seismogenous) phenomena are characterized by intensification of different-directed block motions in combination with plastic and breaking deformations, which are especially obvious along "alive" (unsteady) deep faults. Seismogenous mountain slopes fissures, cracks and upthrusts, occuring within such faults under destructive earthquake effect, result in relief deformation with significant amplitudes. Thus, Muisk 1957 earthquake in BAM resulted in subsidence of some areas in the epicentral zone up to 5-6 m, followed by formation of a number of lakes. Earth movement within fault fissure zone near Nalband station was 1,5-2,5 m during Spitak 1988 earthquake. Such earth surface movements and even less ones are certainly considered to be rather dangerous for such large structures as bridges and tunnels and lead to long-time failures. As for subgrades (roadbeds), there may be observed single failures.

All the above said requires availability of precise data on location and characteristics of tectonic faults, including forecasting data on their probable displacements.

Exogenous processes, first of all seismogravitational ones, appear to be more dangerous for roadbed projects, as they have ability to be activated not only under severe earthquake, but as a result of frequent and low-intensity ones (especially in the presence of permafrost and intensive atmospheric precipitations). Seismogravitational effects are pronounced in intensification and provocation of taluses, slides and subsidence of slope loose deposits as well as soliflucation and wet landslides and avalanches formation. This is much more dangerous as compared to seismodynamic effect because of zones large extention. The road route, being within such zones and crossing them, can't be changed because of its functional purpose. And besides, seismogravitational processes may be considered as a result of some accumulation of seismic energy and its subsequent concentrated dissipation in modified quality.

All those factors require precise data on the boundaries of dangerous zones along the whole route and prediction of probable conditions for slope processes activization, including those, provoked by active manifestation of the processes, induced by seismogravitation according to chain reaction principle.

Seismodynamic effect depends directly on relative seismic hazard of construction site soils and structure inherent characteristics.

Interference and resonances of seismic waves in soil mass depend on natural vibrational frequencies of loose soil and inward signal frequencies, which depend, in its turn, on soil mass state, its seismic stiffness, seismic wave attenuation by the area and change of loose soil mass up to the bedrock.

The experience gained shows that change of parameters of soil mass state influences significantly on seismic hazard. Thus, temporary rise of ground waters table during Gazli 1984 earthquake had serious effect on the duration of intensive vibration phase. As for Uoyansk 1975 earthquake, the sides of Anamakit river's valley, which are similar by geomorphology, but variably frozen, responded differently to the earthquake of magnitude 6-7: in one case without evident surface deformation, while in the other one with significant activization of slope processes, such as occurence of taluses, slide rocks, rockfalls, ect..

That's why it is necessary to have maps of microseismic zoning with the prediction of engineering and seismological conditions dynamics. In a number of cases there may be required maps in two or more variants with predictional estimation of seismic hazard in the form of contouring the zones of equal intensity and curves of equal values for seismic waves spreading velocity. Acquisition of all the initial data cited for design purposes appears to be a complicated task, which solution requires use of various methods, rather diverse nomenclature and different spheres of science.

Thus, air space methods are becoming more and more popular when studying the nature of exogenous and endogenous processes. Complex system of methods for air space and on-surface investigations of the territories along railways routes, developed at the All-Union Research Institute of Transport Construction in Russia, makes it possible to obtain comprehensive data on faults location and

features as well as contours of the area, having potentially hazardous seismogravitational processes. The above data may be prepared both for single use, when designing a structure, and for multiple use by operating services in the course of subsequent monitoring. The system of the methods given has been widely used in the Central Asia and Siberia for constructional projects.

Methods for probing of loose soil mass, being represented as a dynamic system and being tested by a set of implementation of seismic signals, being represented as random functions, have been used to obtain data (design parameters) when taking into consideration seismodynamics. The said allows to estimate probabilistic characteristics of intensity increment, longitudinal and lateral waves velocities and dynamic elasticity moduli as well as frequency characteristics of the soil loose layer. Those data, being combined with theoretical ones, the system state with regard to the problem under solution may be predicted by a design method. Thus, to design constructions for BAM was used quantitative regional method for prediction of elastic parameters of the base grounds in the systems " construction - soil mass". The method was developed at the Institute of Earth Crust in Siberian branch of the Academy of Sciences of the USSR. The method makes it possible to obtain experimental equations for the relationships between lateral waves velocities for grounds of various composition and state and those for lateral waves. Using Medvedev's formula it is possible to calculate intensity increment at a definite area. It is necessary to take into consideration that the ranges of waves propagation velocities, the acceleration values and amplitude and frequency characteristics may vary considerably, depending on soil mass depth and azmuth of the wave front. Thus, the velocities of longitudinal and lateral waves at Severo-Muisky tunnel's portals in BAM varied from 320 m/sec. (lateral wave at the west portal) to 4000 m/sec. (at the east portal). In the case under consideration soil response was rather different - from its liquefaction (sandy soils under Gazli earthquake; loamy-fragmental soils under 1986 earthquake in Tadjikistan) to cracking and occurence of talus (Spitak and Borzhom earthquakes) and landslides. All the mentioned requires application of universal analising and measuring techniques, such as strong-motion accelerograph (-3), produced by the Association "Seismics" in the USSR and exhibited at the IXth European conference on aseismic construction in Moscow in 1990. The devices of such a type are considered as elements, ensuring reliability of transportation systems. Those devices, mounted in engineering and seismometric stations on constructions and adjacing areas, make it possible not only to collect data for further development of empirical relationships between structure's dynamic parameters and seismic effects level, for plotting histograms for force-displacement relationships and other data for structure aseismic design, but may also serve as a basis for the development of emergency-warning system of "alarm" type. The latter is capable of stopping equipment and trains operating conditions and switching in emergency braking at a definite signal, which is considered to be dangerous for transportation system operation.

Depending on a structure type and seismic effects characteristics, antiseismic measures, envisaged in a design, may be divided into three groups: active structural seismic protection, passive protection or structure ordinary strengthening and preventive aseismic constructions and measures.

Active seismic protection in the form of bracings, dampers and shock absorders may be considered as rather reliable means for protection of buildings, bridges, equipment foundations and tunnel linings against dynamic effects. Active seismic protection is widely used for transportation systems under construction in earthquake-prone zones. Thus, technical decisions, realized in the development of bracings for buildings and dampers for bridges and tunnels were the product of the Institute of Transport Construction activity. Those elements were effectively used for the BAM constructions. As for the damping devices, developed at the same Institute and used for Izhdevan-Razdan railway in Armenia, they proved to act excellently during Spitac earthquake of magnitude 7.0. Not a single bridge or viaduct superstructure of 27 m or higher clearance was damaged, all of them were in service without any limitations in the trains traffic.

Passive seismic protection is being widely used in the structures under construction. Thus, additional reinforcement is used for buildings and tunnels. Ground reinforced with geotextile is used for roadbed. Double-pass linings are used for tunnels.

Various structural constructions, where the above mentioned the Institute-developed technical decisions have been realized, were built in the BAM area and on the roadways, crossing Main Caucasus ridge.

Preventive aseismic constructions such as avalanche protection works, galleries, mudflow discharging works, protecting fillings and trapping walls, being built at rockfall areas, are considered to be effective means against various seismogravitational phenomena along with afforestation of slopes, production of emergency stock of structural elements and organization of emergency service.

All those constructions and measures have been widely used for earthquake-prone sections of railways and proved to be rather effective. Thus, for example, protection works, designed and built according to the recommendations of the Institute of Transport Construction, which were used for the mentioned Idzhevan-Razdan railway, fulfilled their function quite satisfactorily under Spitak earthquake. It was in spite of the fact, that actual earthquake magnitude exceeded the design one. The reserve of protection trapping walls appeared to be sufficient to accumulate the whole rockfall mass. The length of the rockfalling section being more than 70 km, the falling mass overfilled the protection construction only in 5 places with less than 100 m^3 volume and reached the track.

Active and passive seismic protection in combination with preventive constructions and measures are involved into integrated complex, which aim is provision of reliable operation of transportation system in earthquake-prone regions. The construction types and designs being selected properly and their location and service being rational, there may be excluded the possibility of the system failure or, at least, may be minimized failure negative effects.

As the territory protection from possible earthquake effect is not beneficial alone by itself and the date of danger is quite indefinite, the selection of scheme for the territory and its structures protection appears to be extremely difficult technical and economical problem with certain degree of risk.

Differential approach to preventive measures selection makes it possible to reduce the volume of structural elements service reserve and supplies resources at the expense of more rational use of protection functions of the whole complex as compared to individual protection measures. In the light of considered above, programming of works on transportation system construction should be conducted with consideration of the fact, that aseismic measures are a component part of this system, which should be carried out simultaneously.

CONCLUSION

1. Roads, being life-saving projects, should have guarantees in the form of preventive measures and protection constructions against possible long-time and single failures as a result of seismic effects.
2. Differential estimation of seismic effects proves to be necessary for proper selection of technical decisions at the designing stage of a project. It should be taken into consideration that seismotectonic processes are, for example, more dangerous for large structures, such as bridges and tunnels, while seismogravitational effects are dangerous for linearly lengthy structures, such as railways, roadways, culverts and cable lines. Seismodynamic effects appear to be hazardous for the projects related to constructions and mechanisms (blocking and communicating services buildings, railway substations, depot).
3. Formation of a rather powerful system for analysis and generalization of data on a region with the application of various investigations methods, being used in other fields of science - geology, geophysics, etc. - is necessary in order to obtain initial data for selection of technical decisions on the basis of design and prediction of seismic effects on the road under design.
4. Combination of observation data and experimental probing with the theoretical representation of soil mass as a dynamic system, allowing prediction of its state by a design method, is considered to be possible due to creation of a network of seis-

mometric observations with proper instrumentation on the basis of universal digital strong-motion accelerographs of - 3 type, produced in the USSR.

5. The problem, connected with the consideration of the time of design seismic effect for one or another soil state on the route, is still being solved appriori, which determines the need in designing protection constructions and planning organizational measures with a certain share of "cold" reserve to ensure long-time failures prevention. This factor should be taken into consideration in structural decisions for basic constructions as well.

6. Investigations of Spitak earthquake post-effects in Armenia have demonstrated high reliability of the design methods and structural decisions for constructions, designed for railways protection against rockfalls. Those decisions have been adopted on the basis of the results of investigations, conducted at the Research Institute of Transport Construction.