Geodesic support of urban socio-ecological safety given the geodynamic activity of residential territories

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Abstract. The paper considers the need for and viability of a newly proposed geodesic control service in order to increase the construction and operational safety of urban infrastructure. We provide a justification for carrying on continuous survey of geodynamic processes of both natural and anthropogenic origins. Using a unifying Geographic Information System to manage digital passports of every major object of urban infrastructure will allow for better control over the current state and will also enable the planners to evaluate and analyse probable scenarios with technological accidents. All of these will improve the ecological safety and quality of living of urban population in seismic regions of Russian Federation.

1. Introduction
Providing high standards of living in urban areas is one of the most pressing socio-economic development tasks in modern society. Complex terrain, historical land-use constraints limiting the neighbourhoods, limited options of further transportation network development led to modern practices of the infill development. In mountainous areas, multi-storey construction primarily happens on top of artificial terraces reinforced with retaining walls located on the terrain slopes.

Meanwhile, there is an insufficient level of attention paid to the subjects of construction and operational safety of urban infrastructure. Multiple multiyear observations of natural phenomena happening in metropolitan areas track a significant volume of technogenic accidents related to movement of underlying geological horizons. Heterogeneousness of underlying soil, insufficient depth of a foundation and its posts in bedrock may lead to uneven foundation settlement resulting in structure tensions, wall cracks, chips, and in worst cases, collapse of the entire bearing structure. As the result of static tensions in the underlying soil, the surrounding ground is subject to erosion, which can grow up to a significant size. For example, the multi-storey building of the Moscow State University, since its construction, caused a gradual settlement of the soil of 4.7 cm deep in 50-120 m radius from the building perimeter [1].

Due to uneven settlement and erosion of underlying soil, a damage to connected engineering networks may occur, often leading to large technogenic accidents. A new and emerging threat comes from shifts of the crust caused by large-scale anthropogenic activity like construction of water reservoirs, mining, and storing liquid waste in underground caverns.

During construction on soft soils, it is important to consider the emerging static tensions caused by the weight of the newly constructed building.
When construction is taking place on sites with stronger soils, the tension may grow in the bedrock horizon. Critical levels of tension in the bedrock may result in dynamic and sometimes abrupt changes.

When construction is happening on mixed terrain, emerging static tensions can lead to landslides, damage to nearby retention walls and roads, and in some cases, destruction of the building under construction itself.

A significant danger comes from the accumulated tectonic tensions in the bedrock underlying urban areas. At the same time, there is no well-established methodology of assessing the risks of technogenic seismic activity, yet the damages caused by the manifestations of various geodynamic events continue to grow. Establishing such methodology will require standardized surveying of geological and tectonic environments of both construction sites and buildings which are already in operation, defining the corresponding building code, and actions to bring the urban infrastructure in compliance with this code.

2. Methods
In order to increase the ecological and social safety of the population, a set of tasks related to studies of geomechanical state of the bedrock underlying urban territories, as well as ranked analysis of existing buildings from the standpoint of their seismic resilience needs to be executed. The geomechanical state of the underlying bedrock needs to be studied in order to build a diagnostic map of the area of interest containing known and discovered boundaries of stable, weak, and particularly dynamic soils, as well as zones of increased internal tensions and stress release.

Overlaying the map of the geomechanical state with the map of urban infrastructure will help to quickly identify the regions and individual objects at risk and prioritize them. As a result, a standardized set of measures for increasing the seismic resilience of existing buildings can be defined. An implementation of such measures could be done through a prioritized set of practical actions aiming at increase in seismic resilience of each identified building at risk.

It is important to require detailed geodesic surveys including seismic mapping to be performed not only on the new construction sites, but also of nearby territories, neighbouring buildings, and engineering subnetworks.

In case of multi-storey building construction, it is also important to consider the soil erosion which will be developing during the construction itself and after the building is put into operation. The soil erosion size directly depends upon physical and mechanical properties of the underlying soils. The caused nearby erosion can be mitigated by increasing the depth of the foundation poles and application of specialized enforcement technics on the foundation design itself. Consequently, the exploitation parameter values should be maintained within the ranges defined in design documentation during the entire period of operation. This needs to be enforced by periodic service and monitoring of the foundation, the load bearing structures, and connected engineering networks.

All the new buildings under design and construction need to go through a mandatory evaluation and licensing by an independent state agency for meeting the standards of seismic resilience. The evaluation must result in a detailed analysis of both the design and the constructed structure meeting the geological and mechanical properties of the construction site, list of feasible anti-seismic measures, and set of mitigation measures aiming at minimizing the consequences of probable seismic events. During the construction, a periodic oversight needs to be performed by the licensing agency.

The existing options and future development of multi-storey construction along with connected underground infrastructure require a large-scale system of geocontrol with the goals of continuous monitoring of the earth surface and the geological horizons containing associated engineering networks. A comprehensive system of monitoring and control should encompass virtually all urban assets including not only buildings, but also transportation networks and underground infrastructure. Creation of such system needs to be based on a long-term strategy of urban areas development.
The system needs to keep track of all the existing urban assets in operation: buildings and other engineering structures, transportation, and utility networks. It also needs to grow as new assets are constructed and be expandable for an easy integration of new types of modern geocontrol tools and sensors. A large-scale system of geocontrol is going to represent a hierarchy of local (modular) subsystems controlling particular regions, neighbourhoods, individual objects, and important construction sites.

The modules at the bottom of the hierarchy controlling individual objects will oversee the current state of the foundations, underground floors, engineering network connectors, and soil in direct proximity.

The top-level analysis module will be responsible both for the current operational picture and for building what-if scenarios producing recommendations for preventive measures.

The backbone of the system is going to be a network of georeferenced geophysical wells with installed geophones, shift sensors, etc. allowing for monitoring of dynamic and static processes in the geological horizons.

The large-scale system of geocontrol needs to include:
- sensor module for monitoring of:
  o tension and deformation;
  o geospatial properties of the structure and soil in immediate proximity;
  o hydrogeological environment;
- other modules / subsystems:
  o data collection and ingestion into a Geographic Information System;
  o analysis and forecast of hazardous geodynamic and hydrogeological events.

3. Results

The research results which have come and are still coming from already implemented and still in-progress regional and federal goal-oriented initiatives aiming at improvement of urban infrastructure seismic resilience [2-4], allow creating the detailed cartography of seismic zoning for particular regions of Russian Federation, seismic microzoning for the territories defined as of advanced development type, and others, e.g. for coastal regions – maps of zones of tsunami-hazard, as well as a set of recommendations for mitigating the adversarial events of the aforementioned type using the consolidated cartographic information.

The large-scale system of geological control of seismic regions will improve safety of construction and operation of urban infrastructure given the static and dynamic events caused by both natural and anthropogenic reasons.

Statistical analysis of collected observations will allow for a higher quality and better justified decision making of design and development of both underground and above-ground elements, bringing the safety and usability bars higher. This will also allow for longer and safe operational periods between the major maintenance procedures for a variety of urban assets.

4. Conclusion

Creating and continuously populating the database of soil sensory data, using it for periodic evaluation of soil erosion emerging during both construction and operation of existing structures, will allow for higher quality decision making in establishing general and assigning individual seismic safety norms for future constructions.

Using a unifying Geographic Information System to manage digital passports of every major object of urban infrastructure will allow for better control over the current state and will also enable the planners to evaluate and analyse probable scenarios with technological accidents. All of these will improve the ecological safety and quality of living of urban population in seismic regions of Russian Federation.
It is particularly of interest for urban zones of Primorsky Krai, and city of Vladivostok especially, where significant roles are played by partially unknown span and state of historical underground infrastructure, infill multi-storey development, fragmental knowledge of geological and seismic nature of the territory.

Utilization of the systems of geocontrol of urban territories located in seismic regions, will allow for a better decision-making process in providing safety and quality of living, more efficient mitigation of natural disasters, foresee and prevent technological accidents in highly populated areas.

Creation and operation of such systems needs to be financially supported at all levels of budget of Russian Federation, as well as by the funds of the developers.

References
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