Building protection in conditions of simultaneous availability of soil base substantial differential settlements and seismic hazard origins

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Summary. The problem of possible combination of soil base substantial differential settlements and seismic action is characterized. This theme is extremely urgent subject to significant negative influence of soil base substantial differential settlements evolution on the construction system seismic stability and also to possibility of continuation of base settlements after earthquake. The article's aim is to consider of building protection features in conditions of both complex influence simultaneous availability. Sequence of theme uncovering in the article consists of the building protection strategy selection in conditions under consideration; straight consideration of recommended protection measures; approaches to the calculation analysis of developed measures. Differentiation of building protection strategies and approaches to the calculation analysis is occurred on basis of the building responsibility class CC-1, CC-2, CC-3 and possible consequences and costs from damages and collapse of buildings. Approaches for building protection methods from separate influences of base settlements or seismic and also results of pre-existing investigations of such influences combination features are analyzed for separation of proposed possible protection measures complex.

Key words: differential base settlements, seismic loads, combination, construction system, protection.

INTRODUCTION

Complex geotechnical natural and anthropogenic conditions (undermined territories, slumping soils, creeps, karst and other suffosion kinds, new building influence, etc.) which result in substantial differential settlements of base (SDSB) are widely spread on large areas of Earth's surface. Significant seismic hazard that is basically associated with a tectonic activity are spread on Earth too and has consequential activization on all planet. Combination of such complex influences is common and natural. Thus, the protection of constructions affected by such combination is relevant.

Both substantial differential settlements of base and earthquake create significant load influence on the construction system and stress-strain state (SSS) with a high risk of constructions or all system collapse. It is logical to consider a possibility of such influences combination.

An increased complexity of research and consideration of substantial differential settlements of base and seismic combination results, as a rule, either in all-out removal of

SDSB causes (typical of West Europe or North America) or in avoidance of problem consideration by a standardized negation of such combination possibility (typical of the post-Soviet countries).

Individual attempts of studying seismic and different SDSB kinds combination occur on the exSoviet Union territory, for example, papers [1 – 5]. Series of studies [5 – 9] et al., which had been performed by Ukrainian Kyiv Zonal Scientific and Research Design Institute of Civil Engineering (KyivZNIIEP) from 1982 to 2009 with interruptions, was the most thorough for this theme. This series was started for the purpose of developing of protection methods for buildings in the slumping soils conditions of Odessa seismic region. Eventually, the range of problems had thoroughly been highlighted, the series of substantial differential base stiffness influence effects on the building seismic reaction had been revealed and the propositions for building analysis and protection in the slumping soils conditions in seismic areas had been suggested. However, a great number of questions and problems remained unexamined, for example, consideration of other substantial differential settlements of base causes, taking into account a standardized prohibition of peculiar (abnormal) influences combination, applied engineering analysis methods development, more solid theoretical substantiation of the problem and its solutions, development of universal complex of buildings protection subject to their responsibility class. In this connection the author conducts a complex of studies to solve the above problems (some results are presented in the article).

MATERIALS AND METHODS

The article's aim is development and substantiation of features of buildings protection in conditions of simultaneous availability of soil base substantial differential settlements and seismic hazard origins. Methods of analysis and synthesis of data from scientific and normative sources and also previously investigations of author are used in the article.

RESULTS AND DISCUSSION

Development of building protection system in compound conditions under consideration has to include complex, which consists of:

- general strategy, which depend on, for example, from the building responsibility class;
- measures, which are determined by their technical and economic efficiency;
- analysis and refining of taken protection system.

Meanwhile it is necessary to specify features of protection for designed and for existing buildings separately.

It is necessary by selection and development of building protection measers complex in conditions under consideration to adhere next strategies (subject to the building responsibility class):

- for class CC-3 [10] it isn't recommended to allow necessity for capital repair and(or) levelling after complex influences under consideration (1^{st} – 2^{nd} categary of technical condition after influence in conformity with DBN V.1.2-14:2009 [11]);
- for class CC-2 it is allowed necessity for planned capital repair and(or) levelling after complex influences but without emergency condition of a building (2^{nd} – 3^{rd} categary of technical condition after influence);
- for class CC-1 it is recommended to allow of limited deformations and damages corresponding with 3^{rd} categary of technical condition after complex influences with carrying out of capital repair and(or) levelling (3^{rd} categary of technical condition after influence).

Introduced approach has base on assumption of too substantuial costs and consequences (economic, social et al.) from necessity for restoring of CC-3 class building over the all period of operation, which will exceed additional costs for protection in the phase of building or reconstruction. Approach of allowance of reasonable and controlled damages and deformations from peculiar (episodical) influences for middle and low responsibility level (CC-2 and CC-1) buildings is general known and used [12].

Introduced connection of building damages and deformations level to corresponding categary of technical condition is founded on base of essence each such categary [13]:

- normal (1st) technical condition – total correspondence to requirements of working norms and building project, absence of substantial defects and damages;

- satisfactory (2nd) technical condition – presence of defects and damages, insignificant departures from requirements of norms and building project, which don't soundly limit using of building according to its intended purpose or can be ignored or removed by in-line repair;

- non-serviceable (in conformity with norms) (3rd) condition – there are defects and damages, departures from requirements of norms and building project, which don't permit to use building or its part in normal duty (without limitations), there is necessity in limited operating regime, capital repair or reconstruction, but safety can be guaranteed before achievement of 1st or 2nd technical conditions.

- emergency (4th) technical condition – defects and damages, departures from requirements of norms and building project create straight threat for safety at building (there is direct danger for life, health, environment, safety of valuable property).

General approaches and principles have to be characterized for detection of specific protection measures.

Following rules and regulations have to be taken into account for development of building protection measures in conditions of possibility soil base substantial differential settlements and seismic hazard simultaneous influence:

- to combine protection rules, provided by norms and standards for designing and protection in seismic hazard conditions and availability of substantial differential settlements of base origins [3, 12, 14] et al., which are useful for protection from both influence kinds, for example: to provide simple plan form; symmetry of stiffnesses and masses; to reduce construction and building mass for vertical and horizontal gravity and inertial loads abatement; to provide stability and geometry immutability of construction system (to use rigid construction system); to create fail-safe conjunction of floor and envelope rigid disks with vertical bearing structures;

- not to apply building protection methods, which are effective and permissible for protection from one complex influence kind, but are weakening for other influence, for example: not to use yielding and combined construction systems; to limit damages and yelding deformations spreading for more responsible building subject to expected combination of influences under consideration; not to use non-girder reinforced concrete frames; not to use enlarged column grids.

Three following approaches for protection of buildings by projecting in conditions of seismic and substantial differential settlements of base possible combination can be extracted:

- full removal of substantial differential settlements of base origins and earthquake-resisting projecting without their accounting (necessity in repairs can be in future after earthquake);

- partial reduction of possible substantial differential settlements of base and seismic influence (active seismic protection, preparation of base course et al.) together with building structural protection from reduced level of complex level (in future – limited necessity in repairs and(or) levelling of construction system);

- completely structural perception of complex influences (in future – rigorous necessity in repairs and(or) levelling of construction system).

Under their selection potential total building and future repairs costs have to be taken into account.

Similar approaches have to be used for existing buildings, which were builded before putting into operation of the rules under consideration and don't conform with them: reconstruction and strengthening of system foundation-soil base and also measures for levelling are used for removal or reduction of substantial differential settlements of base influence; arrangement of different active seismic protection kinds – for seismic influence

reduction; strengthening and reconstruction of construction system – for its stability rise.

Analysis of existing requirements to building protection by availability of seismic hazard or substantial differential settlements of base origins [12, 14 − 16] et al. and also results of already conducted investigations on theme of building in conditions of complex environment (under consideration) combination, which are presented in the present article and in [3, 6 − 9] et al., has allowed to develop series of conditions for structural requirements, that are introduced below.

It is necessary to provide compulsory arrangemen of buried basement and(or) undergrounds storeys (with height not less than 1.8 m) under all solum, the stories can't be taken into account as overground according to DBN V.1.1-12:2014 [12]. This storey (storeys) acts the part of buried rigid girt, which reinforces general construction system and reduces substantial differential settlements of base on overground part. In addition, appropriate systems for levelling and(or) active seismic protection of building.

Using of continuous panel-wall foundation (with or without piles) has to be effective for reduce of substantial differential settlements of base level. Herewith pressure level on the base and appropriate deformations (especially yielding and from slumping) are reduced. Effective load redistribution on neighbouring preserving base areas occurs by limited in plan crater or gap. Cantilevers along the building contour with overhung arris- prolongation of walls (the foundation has to be arranged in the form of continuous base plate) are also necessary by availability of formation factors for gaps and craters at the basis (karst, undermined territories etc.). These measures can redistribute the load even on basis outside the main spots of the building in plan.

It is useful and necessary to provide for the separation of complex or extended forms of buildings in the plan and also substantially different on the building decisions parts by deformation seams along the entire height of the structural system. Limiting seam step has to be taken with a combination of rules for seismic protection and protection from relevant substantial differential settlements of base origins, and width of the seam – as the sum of width for seismic and deformation seam. Increase of the limited step between deformation seams in terms of substantial differential settlements of base perception can be used for single-storey and low-rise buildings by calculation validation and arrangement of rigid buried storey(s).

It is necessary to apply the most stable designs such as monolithic reinforced concrete or composite systems by extreme (9-point) seismic hazard with accounting of possible substantial differential settlements of base pre-load of construction system.

Soils with III [12] (and worse) category of seismic properties are one of the negative factors that increases seismic load and can be substantial differential settlements of base origin. Removing, replacing or strengthening (with upgrade of the base soil seismic properties) of such soils have to be used for effective building protection.

Following measures for buildings with bearing walls have to be applied:

- at least one longitudinal wall, which increases overall system reliability for perception of complex influences and usually has fewer openings and also reduces system spans in the transverse direction, has to be arranged for buildings with height 3 and more floors. Walls fractures have to be limited and offset by through ribs at the level of floors and covering;
- to combine structurally flat arches and walls floor belts;
- it is necessary to increase the minimum requirements for construction materials with taking to account increasing the level of efforts and stresses in comparing with norms for the protection from separate complex influences [12,14] et al., for example, for walls floor belts concrete class should be at least C16/20 and reinforcement at least 4ø12A400C;
- all joints of the walls have to be securely reinforced, as one of key factor for strength and stability of the construction system is the preservation of single spatial work of constructions located in different planes;

- masonry walls have to be strengthened by reinforced concrete or steel inclusions or reinforced cases, which have to be the basis for the perception of tensile (in different directions and planes) efforts at too weak for this stone walls. Prestressing of reinforcement and other inclusions at masonry walls areas with the most tensile or shear overload is recommended for increase of protection effectiveness from tensile or shear efforts [3, 17] et al., for example, as shown in Fig.1;

- sections of walls, weakened by vents, have to be considered as cuts, because have general form of wall construction, but due to significant weakening by holes these areas are not able to perceive significant load.

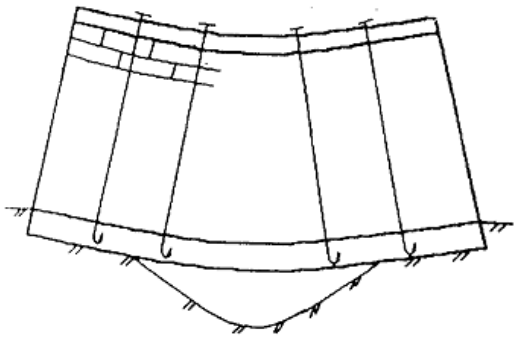

Fig.1. Using of prestressed vertical ties for strengthening of masonry walls by possible occurrence of basis gap: perception of tensile stresses in incline cuts and blocking of inclined cracks by prestressing (can be effectively complemented by horizontal ties)

Similar requirements for frame buildings:

- minimum class of structural concrete for frame linear elements – C20/25;

- diaphragms or braces have to be installed symmetrically and in extreme axes (rows of columns).

- near node section of columns have to be further strengthened (as at the node) on length at least 2 of the largest size of column cut. In this case all longitudinal rods have to be embraced by stirrups, because condition and serviceability of these areas have critical significance for efforts perception from horizontal and vertical skews in frames.

It is necessary to take into account possibility of substantial differential settlements of base and building heeling extension by selecting and developing of active seismic protection. Analysis of the possibilities of active seismic protection using is presented in [8]. It was determined that systems with increased damping and adaptive systems of seismic protection are the most potentially suitable for use by the presence of substantial differential settlements of base.

Following rules have to be observed for analyze of buildings in conditions of possible simultaneous influence of substantial differential settlements of base and seismic loads.

Individual calculations of complex loads (under consideration) influence are allowed for objects of class responsibility CC-1. It is assumed in this case that the stability and strength of building construction system are sufficient for perception of the complex influences. Using of combination of design requirements and protection from both influences allows to predict low probability of building collapse in the case of various complex influence combination, which is considered as with low probability for this responsibility class (subject to usually low period of operation and carrying out of timely repairs).

It is necessary to perform calculations by complex influence separately for analysis and(or) checking of construction cuts for buildings with class responsibility CC-2. In this case yielding deformation coefficient $k_1 = 1{,}0$ hase to be used for seismic analysis (appropriate flexibility coefficient $\mu = 1$, which implies the absence of yielding deformations) with the possibility of perception and structural testing system after earthquake. It can be allowed considering of combination of loads with seismic using following formula:

$$N_d = \gamma_n N_{stat} + \frac{N_p}{m\gamma_m}, \qquad (1)$$

Where $\gamma_m \leq 1/k_1$ – safety coefficient for construction materials, other designations adopted by DBN V.1.1-12 [12]. That is characteristic values of materials physical and mechanical properties for bearing structures can be taken into account for seismic loads as

emergency load for this influence value reducing (allowed, for example [18]). But the effect of such reducing may not exceed the effect of yielding deformation of construction system. Additional analysis for checking of accepted design has to be applied subject to emergency combination with sequential loading by substantial differential settlements of base (as prestressing of construction system) and seismic with considering of characteristic physical and mechanical properties of construction materials (by the principles based on progressive destruction [19]) using nonlinear static analysis (DBN V.1.1-12 [12]). Ground of such necessity is based on permanent nature of building stress-strain state (prestressing is considered as dead load [21]) from substantial differential settlements of base and the need to guarantee absence of this class building collapse from potential combination of complex influences under consideration.

All rules as for CC-2 have to be applied for buildings with class responsibility CC-3 except of using the formula (1).

CONCLUSIONS

1. Despite a widespread disregard of the problem of possible combination of soil base substantial differential settlements and seismic action that is observed in regulations and practice, this theme is extremely urgent subject to significant negative influence of SDSB evolution on the construction system seismic stability.

2. Introduced building protection system from the combination of complex influences under consideration consists of: the building protection strategy selection in these conditions; protection measures, which selection is provided by their technical and economic efficiency; approaches to the calculation analysis and refinement of developed measures.

3. Common approaches and principles for introduced protective measures choice state for develop of these measures. For example, combining of protection rules, provided by norms and standards for designing and protection in seismic hazard conditions and availability of substantial differential settlements of base origins, which are useful for protection from both influence kinds, is used and also building protection methods, which are effective and permissible for protection from one complex influence kind, but are weakening for other influence.

4. Common rules for building analysis in conditions of simultaneous availability of soil base substantial differential settlements and seismic hazard origins subject to the building responsibility class CC-1, CC-2, CC-3 are proposed.

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Защита зданий в условиях одновременного наличия источников значительных неравномерных деформаций и сейсмоопасности

Денис Хохлин

Аннотация. Охарактеризована проблема возможного совмещения влияний значительных неравномерных деформаций основания и сейсмики. Данная тема является особенно актуальной с учетом существенного негативного влияния развития значительных неравномерных деформаций на сейсмостойкость зданий, а так же возможность развития деформаций основания после землетрясения. Рассмотрены особенности защиты зданий при наличии возможности возникновения обоих сложных влияний с учетом выбора стратегии защиты зданий при рассматриваемых условиях; непосредственного рассмотрения рекомендованных мероприятий по защите; подходы по расчетной оценке разработанных мероприятий.

Разделение защиты зданий и подходов к расчету происходит на основании классов ответственности СС-1, СС-2 и СС-3, возможных последствий и затрат из-за повреждения и разрушения строительных объектов. Проанализированы методы защиты зданий от влияния деформаций основания и сейсмики отдельно, а так же результаты ранее проведенных исследованы особенности их совместного действия на строительные объекты. Использовано объединение и усиление правил, полезных для защиты от обоих видов влияний, а так же выделены способы, являющиеся эффективными или допустимыми для защиты от одного вида сложного воздействия, но ослабляющими для другого.

Ключевые слова: неравномерные деформации основания, сейсмические нагрузки, совмещение, конструктивная система, защита.