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Dynamic certification of landslide protection structures in a seismically hazardous region of Ukraine: Experimental and analytical research

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ABSTRACT: Methods of dynamic certification of landslide protection structures (PS) in a seismically hazardous region of Ukraine have been developed. The methods include: visual and vibrodynamic examination of PS; development of calculation model and calculations taking into account the actual seismicity of the area; comparative analysis of experimental and estimated data; recommendations for the repair and restoration; further operation of PS. Determination of dynamic characteristics of building structures for their free fluctuations of low amplitude, which are disturbed by the influence of natural microseisms, includes: registration of fluctuations of the PS with the help of highly sensitive (in our case, seismic) sensors; calculation and analysis of Fourier spectrum in order to allocate resonance peaks corresponding to different forms of free oscillations; obtaining of impulse realizations of the selected resonance peaks on each form of optical oscillations of constructions by means of Fourier inversion; identification and graphic representation of different forms of constructions oscillations. Two examples of dynamic certification of PS have been considered: drainage gallery and rail sustaining wall.

KEYWORDS: dynamic certificationprotection structuresaccelerationfrequencydefects

1 INTRODUCTION

Seismic risk is unavoidable companion of our civilization and demands adequate response. Thus, dynamic certification of buildings and structures (including landslide protection ones) is high priority step towards provision of necessary and cost-effective level of seismic resistance of constructions under conditions of obsolescence and physical deterioration, assessment of seismic vulnerability of buildings and structures (BS) or possible degree of their defects during the earthquakes of different intensity. Issue of dynamic certification of BS, cost effectiveness of earthquake resistant construction have been considered in works by national and foreign researchers (Alonso-Rodriguez A. et al. 2018), (Anastasopoulos I. et al. 2018), (Antolini F. et al. 2014), (Balducci M. et al. 2011), (Bardi F. et al. 2018), (Barla M. et al. 2014), (Basile G. et al. 2018), (Borja R. et al. 2011), (Burghignoli A. et al. 2016), (Burton H. et al. 2018), (Buttiglia S. et al. 2011), (Callisto L. et al. 2016), (Casagli N. et al. 2010, 2011, 2018), (Catani F. et al. 2010), (Ciampalini A. et al. 2018), (Dao S. et al. 2014), (Del Ventisette C. et al. 2010), (Di Traglia F. et al. 2018), (Frodella W. et al. 2018), (Gigli G. et al. 2011), (Kaliukh I. et al. 2013, 2015, 2015), (Kampas G. et al. 2018), (Knappett J. et al. 2018), Lacasse S. (2013), (Liu X.Y. et al. 2011), Lollino G. & Chiara A. (2006), (Luzi G. et al. 2010), (Martinelli M. et al. 2016), (Nikitas N. et al. 2018), (Piccioni R. et al. 2011), (Regni R. et al. 2011), (Salvatici T. et al. 2018), (Shokrabadi M. et al. 2018), (Stewart J. et al. 2018), (Trofymchuk O. et al. 2015), (Venanti L. et al. 2011), Wang Y. & Rathje E. (2018), (White J. et al. 2011), (Wu W. et al. 2011) and others. According to their researches, the current certification methods can be nominally divided into three groups: *method of expert assessment, calculating and analytical method, and technical diagnostics method.* Due to advantages and disadvantages peculiar to each of three approaches, methodic problems of certification can be reduced to two main issues. The first issue is valid identification of criterion during assessment of seismic resistance of structures under investigation. The second issue is identification of required level of influence where dynamic structure of the building is investigated: micro dynamic level under elastic stage of constructions operation or load level relevant to the construction operation beyond the elasticity. Unfortunately, today there is no unique legal method of constructions dynamic certification in Ukraine. Since, improvement of methods of constructions investigation for assessment of their real seismic resistance including physical deterioration of the structures is actual problem in Ukraine.

2 METHODS

We offer applicable method of certification and assessment of technical state of the landslide protection structures (PS) in seismically hazardous regions of Ukraine. The method includes: visual and vibrodynamic examination of PS; development of calculation model and calculations taking into account actual seismicity of the area; comparative analysis of experimental and estimated data; recommendations for the repair and restoration and further operation of PS. Determination of dynamic characteristics of building structures for their free fluctuations of low amplitude, which are disturbed by the influence of natural microseisms, includes following operations:

- registration of fluctuations of the PS with the help of highly sensitive (in our case, seismic) sensors;
- calculation and analysis of Fourier spectrum in order to allocate resonance peaks corresponding to different forms of free oscillations; obtaining of impulse realizations of the selected resonance peaks on each form of optical oscillations of constructions by means of Fourier inversion;
- Identification and graphic representation of different forms of constructions oscillations.

Two examples of dynamic certification of PS have been considered: drainage gallery (DG) and rail retaining wall (RRW).

3 CASE 1

More than 9% of Chernivtsi region area is occupied by landslides. Local seismological station registers nearly 110-130 seismic events per year. 70-80% of the above events occurs within 100 km radius and are of 2-4 earthquake intensity. Sometimes more than 100 mm of precipitation may fall in Chernivtsi over a few hours (in some cases, 222 mm in a few hours). As a result, DG is one of the effective types of landslide protection structures on the territory of the city. DG for Chernivtsi landslide slope drainage is a concrete tunnel with the diameter of 2,5 m and the length of 1363,68 m (entry into DG, Figs 1-2). The deepening of DG below the surface layer of the soil reaches from 25 to 35 m. The greatest dynamic loads are caused by transport when moving along the section of the carriageway lying opposite the DG. The placement of vibration sensors on the adjacent ground in p. 1, p. 2 and on the upper platform of the DG retaining wall in p.3 is presented on Figure 2. Figure 2 also shows the position of the axes X, Y and Z in the direction of measurement of horizontal and vertical vibration acceleration. Maximum amplitude

Figure 1. General view of PS of ground slope and entry into DG.

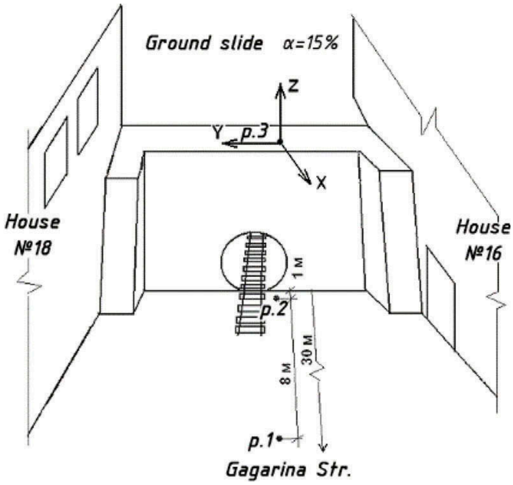


Figure 2. Location of vibration sensors in point 1, point 2 and point 3 for researches performance.

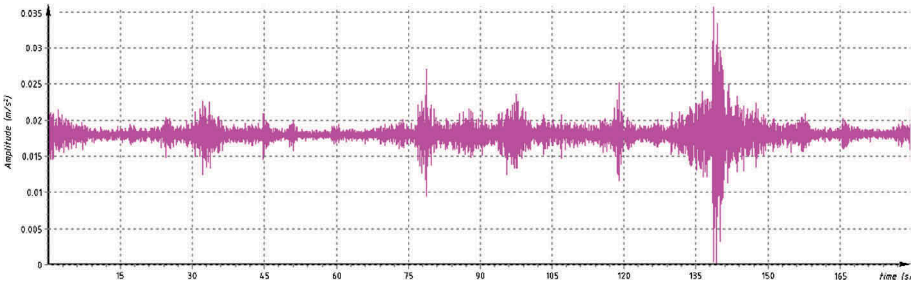


Figure 3. Z in point 3 retaining wall vibrations accelerating graphics.

of the soil vibration acceleration in the vertical and horizontal directions at the sites near the PS 0,08m / s^2 with the simultaneous influence of microseismic oscillations and ground transport movement has been registered. The frequency range is 10 -15 Hz. However, as a result of intensive storm activity in Chernivtsi, in combination with dynamic influences, it is possible that some DG rings settle down, which was discovered during the visual inspection of DG. The maximum amplitude of the vibration accelerations of the PS DG during the action of the microseismic oscillations and the movement of ground transport in the direction of X and Z does not exceed 0.17-0.25 m / s^2. The proper frequencies of the PS of the DG on the basic forms are slightly higher than the specified range of frequencies of external dynamic influence, which are caused by moving of the ground transport. On vibrations accelerating graphics the one is shown in Figure 3, the resonance phenomenon is not observed yet.

The DG armature has a circular outline and is made of prefabricated reinforced concrete rings, which in their turn are made of four tubes - elements with a ribbed inner surface. In general, there are 60 water lowering wells and one ventilation shaft. These wells have a diameter of 0.12 to 0.26 m and almost all are salt up wells. The tubing of the tunnel has transversal cracks, and there is a significant exposure of the working armature in the ribs and its corrosion (Figs 4-5).

There is a significant damage of the concrete protective layer and corrosion of the working armature on the reinforced concrete rings approximately to the 60th ring from the entrance on the side of Haharin street (tunnel turning) that was exposed to the greatest influence of external climatic factors. The transverse cracks in the central part of the upper tubing of rings N 110, 720, 1110 (upper level of the gallery) (Figure 5) and in the lower level of the gallery, which is

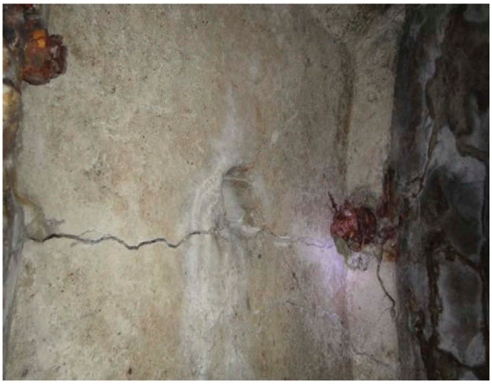


Figure 4. Crack in the concrete of the DG armature upper tubing.

Figure 5. Damage of the protective layer of concrete and tubing armature in the DG central part.

about 5% of surveyed top tubing, were detected during ultrasonic surveys of the gallery reinforced concrete upper and lower levels. It is conceivable that the same percentage of the top tubing with cracks can also be found in the uninspected rings of the gallery. The strength of the PS concrete corresponds to the class B25, and the rings of the drainage tunnel - B30.

4 CASE 2

The PS keeps the soil underneath the track bed owing to the cross-section which is shaped like a rectangular trapezoid with 4.5 m length of the upper base, 1.5 m bottom and 5 m height (Figure 6). On the bulk soil there is a base for one-track railroad. Structurally retaining wall is assembled from separate identical elements “wall in the ground” of 130 cm wide, mounted on a foundation with a pile roaster. There is monolithic reinforced concrete belt with a cross section of 0.6x6.6 m in the upper part the retaining wall.

4.1 *Stage 1. Experimental investigations*

Directions for measuring vibration acceleration indicate the position of the X and Z axes on Figure 6. Fluctuations records have been made for 180 s, repeating twice for each of the scheme of the vibration detectors, although directly the dynamic effect from the train on the retaining wall was carried out for 20 s at its speed of about 50 km / h. There is a graph of

Figure 6. Location of vibration sensors during retaining wall investigation.

horizontal vibration accelerations in the direction X (perpendicular to the railroad) during the movement of the passenger train on Figure 7. Horizontal vibration accelerations are fixed in the range of 0.21-0.42 m / s^2 on the end sections of the retaining wall and 0.63 m / s^2 in the middle section of the retaining wall. Recording of vibration accelerations time signals was carried out in the frequencies range from 0.3 Hz to 100.0 Hz. The range of prevailing frequencies in case of the train moving for the extreme and middle sections is close – within the range of 0.3 - 25.0 Hz. The amplitude spectra of oscillations in point 1 - point 3 are presented for the assessment of the dynamic properties of the retaining wall above sections when passengers train moving. The amplitude spectra are developed for the A-B diagram of the time signal (see Figure 7). Figure 8 shows the amplitude spectra of horizontal oscillations in X, respectively, for p.1 - p.3. The first prevailing frequency of the amplitude spectrum of horizontal vibrations at the PS extreme sections towards the X is 6.8 Hz (Figure 8, upper and lower figures). The area in the middle part of the RRW does not have such an obvious peak of prevailing frequencies (Figure 8, middle figure). This suggests that the retaining wall in the middle section has a reduced rigidity in the horizontal direction during the vibration test.

The above could be caused both by the design features of the PS and the internal defects accumulated during PS operation. As an explanation, let’s pay attention to the structural features of the wall after its construction. As a result of the visual inspection, it has been established that the upper distribution beams on separate plots of the PS only adhere to the elements of the “wall in the ground” under their own weight, and are not bounded to them, as is observed in other areas and should be according to the project. An important factor in the

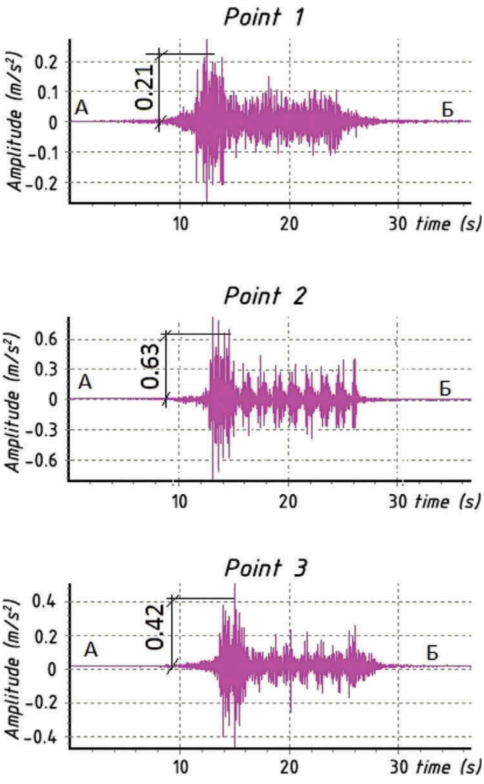


Figure 7. Time signal of the PS horizontal vibration accelerations (X direction) in case of passengers train moving from point 1 to point 3 (Figure 6).

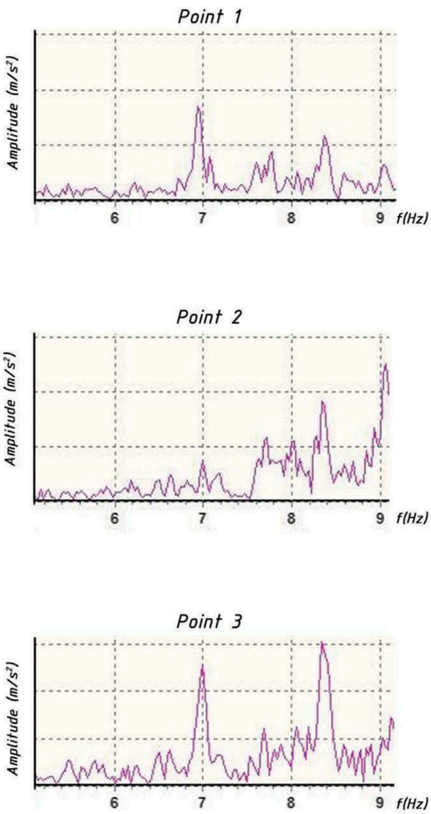


Figure 8. Amplitude spectrum of the PS horizontal vibration accelerations (X direction) in case of passengers train moving from point 1 to point 3 (Figure 6).

negative dynamic effect on the PS is the presence of a connecting junction of the tracks on this area of the railroad canvas.

4.2 *Stage 2. Development of the PS mathematical and design model*

Calculations of the RRW stress-strain state (SSS) with the help of well-known software of building mechanics. For numerical modeling of the PS SSS we used the "Lira" software complex 9.6. (Kaliukh I. 2015). From 5 to 15 sections of 1.3 m width each were taken into account during RRW SSS numerical modeling (Figure 9).

Lack of a sufficient amount of initial information on the RRW design, the pile foundation, the composition of soils and their physical-mechanical characteristics, the accelerograph of dynamic actions on the PS structure from the passing trains gave reason to set the following parameters: the mass of vehicle is 70 000 kg; soils are loamy loams (semi-verticulus loams with normative characteristics in accordance with Tables B.2 and B.3 Tsytovich N. (1963)). The calculated characteristics of the soil were determined by the provisions of the annex to the Ukraine Building Code (2009). Strain transmitted to the wall at its top and bottom is calculated using limit equilibrium formula given by Tsytovich N. (1963).

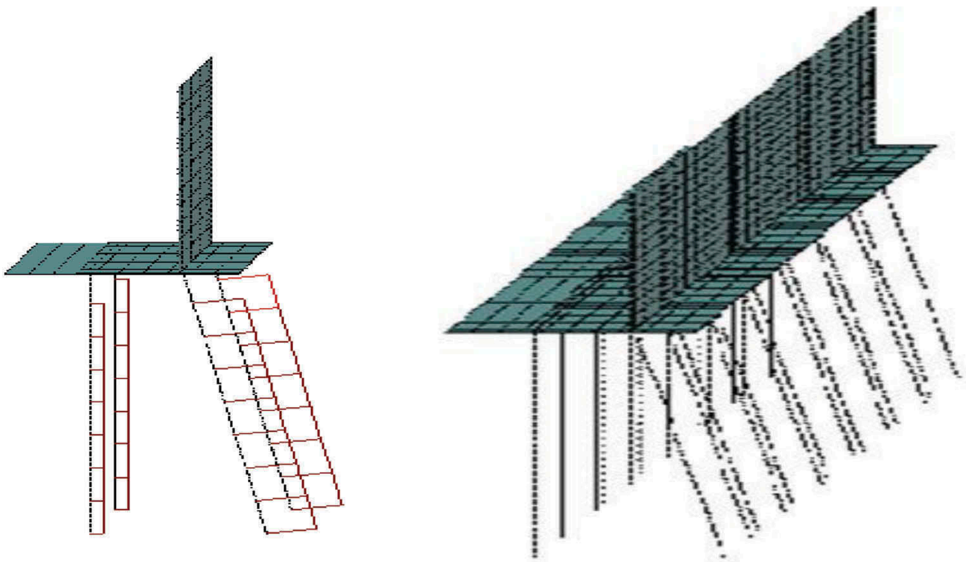
In numerical modeling, calculations were made on 12 variants of PS loading: seismic impact - 7 points. The results of the calculation show that: the period of proper oscillations in the first form is equal to 0.157 s; the corresponding self-frequency is 9.46 Hz.

4.3 *Stage 3. Comparative analysis of experimental and calculation data*

Based *on experimental studies*, the following conclusions have been made:

1. The maximum amplitudes of the RRW vibration accelerations with the action of micro seismic oscillations and the motion of railway trains do not exceed the axis X 0,0025 m/s^2, along the Z axis - 0,008 m/s^2. Compared to micro seismic fluctuations, the vibration acceleration during the movement of railway trains near the retaining wall increases by 4 times.

2. The structure of the retaining wall during the oscillations has a range of prevailing frequencies of 5.0 - 8.0 Hz in the direction of the X axis and 9.0 - 12.0 Hz - in the direction of the



a) b)

Figure 9. Some graphic RRW models used during numerical modeling within LIRA complex LIRA 9.6 (a, b).

Z axis. The maximum acceleration values of the wall foundation are 0,008 m/s^2 smaller than permissible (0.15 m/s^2). The strength of the concrete retaining wall corresponds to the class B25.

Based *on the mathematical modeling* of the RRW, the following conclusions have been made:

1. Estimated values of RRW SSS correspond to the project ones, taking into account the registered deformations and the time of its prolonged operation (deterioration of characteristics depending on the operating time).

2. The results of the calculation show that: the period of free oscillations in the first form is equal to 0.157 s; the corresponding free oscillation frequency is 9.46 Hz.

3. It should be noted that the experimentally registered maximum amplitude of transverse oscillations arises at a frequency of 8 Hz. The difference with the estimated frequency of oscillations is 1.46 Hz, which corresponds to a deviation of ~ 18%.

5 CONCLUSIONS

1. A visual inspection of the DG and the railway PS allows us to state that their condition is satisfactory. For their further operation, it is desirable to eliminate existing defects in the form of cracks and split joints in the city, separate deposits and angular deformations.

2. It is known that the decrease of the self-frequency of oscillations of the structure indicates the presence of destruction in the construction itself, and its increase envisages its strengthening and repair and restoration work. It is necessary to note the sufficient accuracy of the calculation model, as well as the presence of cracks in the body of DG and PS during visual inspection. The research shows that experimental methods of non-destructive testing and mathematical modeling can be used to determine the current technical state of the PS and to draw up a dynamic passport of the structures. It should be noted that the experimental methods of vibration diagnostics will help in identifying even minor changes in the stress-strain state of DG and PS.

3. As a result of the dynamic certification of the RRW and DG of Chernivtsi city, the necessary data are obtained. These data will be taken into account in the future during the identification of the RRW and DG calculation models, for comparison with the new experimental data to determine the degradation of the RRW and DG technical condition in the future. According to the results of the dynamic certification and technical inspection of the RRW and DG, appropriate recommendations have been prepared that have already been taken into account by the local authorities of Chernivtsi city for conducting of the restoration works and reconstruction of the DG and RRW in the nearest future upon getting of the relevant financing.

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