Modern Approaches to Protecting Urban Areas from Flooding

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Abstract. The article notes that natural-anthropogenic emergencies often arise with the co-occurrence of factors of both man-caused and natural origin of very rare recurrence. In order to avoid such situations, it is necessary to provide for special arrangements and technical measures. The authors analyzed the conditions for preventing flooding of the territory built up with residential multi-storey buildings and social infrastructure. The territory has low surface elevation marks and is surrounded by water bodies: the Volga and Samara Rivers, as well as the oxbow channel path. At the same time, practically along the entire border of the territory, there are infrastructure engineering facilities and lines (roads, dams) with surface elevations that are significantly higher than the existing elevations of the built-up area. The authors present the results of the survey of these facilities, on the basis of which recommendations for the reconstruction of their individual sections are developed. When justifying the minimum elevation of protective lines, the parameters of a rise of water level in water bodies (at the times of discharge in the Samara River of rare recurrence) were taken into account. The conditions of originating wind waves and other disturbances of the free surface of the adjacent water area at maximum water levels and the damping effect of natural and artificial obstacles along the main line of wave acceleration were taken into account. The conclusion is formulated that the implementation of the developed measures for the reconstruction of protective borderline objects with the addition of soil or the installation of parapet structures in certain areas will guarantee the protection of the built-up area from flooding

Keywords: Urban area, flood, area protection.

1 Introduction

In recent years, in the Russian Federation and many foreign countries, catastrophes caused by the forces of nature, in particular water forces, have become more frequent [1, 2]. Depending on the conditions and causes of occurrence, the emergency situations involving destructive effects of the water environment can be grouped into three categories: natural, man-caused and natural-anthropogenic [3].

It is advisable to introduce into the first group the poorly predictable effects of the water environment, the severity of which does not depend on the results of human activity. These include, first of all, floods caused by tsunamis, typhoons, prolonged and intense precipitation, wind surges of sea water on the coast, mudflows, etc. The examples of such natural disasters are: the tsunami near Japan (2011) with a wave height of more than 40 m, the typhoon Morakot in the Philippines and Taiwan (2009). Floods caused by the lingering rainfall in Europe in June 2013 in Austria, Germany, Czech Republic, as well as in the territories of Northern China, Cambodia, Russia (in the Amur region, Khabarovsk territory), flooding in the city of Tulun, Irkutsk Region in June 2019, etc.

The causes of man-caused emergencies involving the destructive forces of water (second group) are mainly due to the human factors and occur in connection with engineering facilities. The examples of emergencies in this group include: partial destruction of the Oroville Dam in the United States and the forced discharge of water through the crest of the dam, as well as accidents in Russia: at the Sayano-Shushenskaya HPP (2009), Zagorskaya PSP-2 (2013), erosion of the Moscow Canal dam in Tushino (January 2019), and also a large number of various accidents involving utility water supplies and collectors in cities and settlements. Almost all the accidents of this group involving the destructive forces of water could have been avoided by timely and regular monitoring of the technical condition of the infrastructure facilities and timely high-quality performance of preventive maintenance work [4-6].

A feature of the group of natural-anthropogenic emergencies involving the destructive forces of water is that they occur under the confluence of circumstances of both natural and anthropogenic nature. Here we are talking about the the factors manifested in cooperation. Separately, the forces of nature, for example, prolonged intense rainfall, or anthropogenic manifestations, such as the construction of a large facility, do not cause emergency situations. However, their combination in time and space can cause emergencies with catastrophic consequences and destructions [7]. Natural circumstances in such cases, as a rule, refer to rarely recurring events. For example, the destruction of a temporary dam on the Seiba River in the Krasnoyarsk region (October 2019). Examples from this group also include flooding of territories occupied by housing, infrastructure, industrial or other facilities during flood periods of rare recurrence. On the one hand, we have anthropogenic objects. On the other hand, there are natural phenomena that were not observed in the foreseeable previous period of time, but which, theoretically, with a very low probability, can still occur.

It should be noted that ideally such situations should not be allowed under any circumstances [8]. For this purpose, it is necessary to justify, develop and make special arrangements, as well as take particular technical measures in the form of complex technical regulations for already existing building codes.

2 Methods

The authors study and solve the issues of ensuring safe operating conditions for waterworks facilities and the reliability of structures that ensure the protection of coastal residential areas in case of high levels of flood waters [9]. At the same time, engineering solutions are being developed in accordance with the regulatory documents and taking into account modern requirements in terms of environmental protection [10]. In particular, the authors investigated the operating conditions of the urban complex in the large residential area «Volgar» (future homes for 37 000 inhabitants) under construction, located in the southwestern part of the city of Samara (Russia) on the left bank of the estuary section of the Samara River (Figure 1).

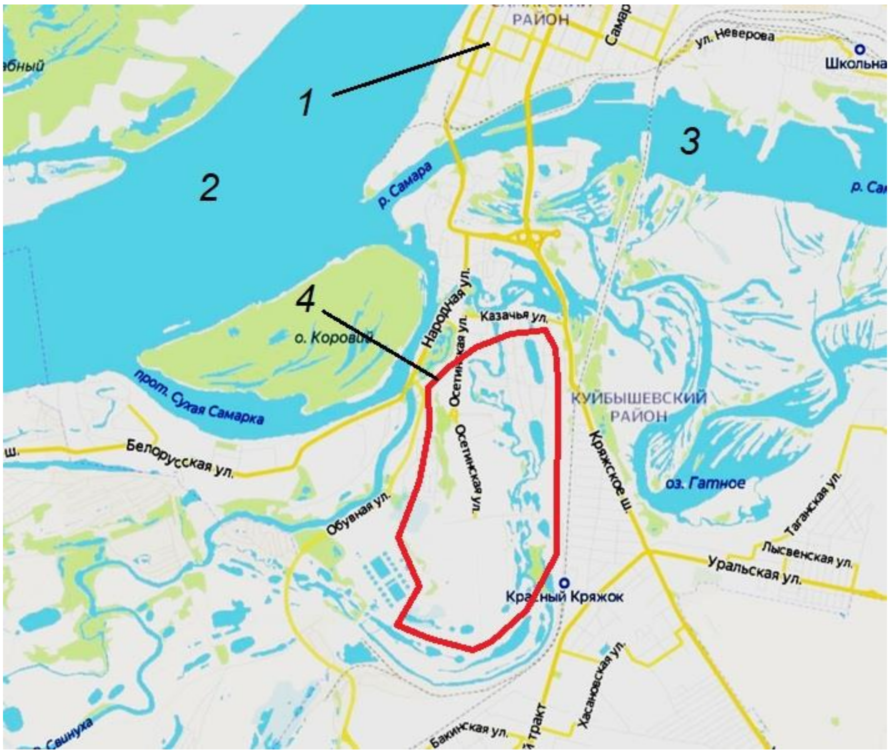

Fig. 1. Layout of the residential area under construction: 1 – central part of the city of Samara, 2 – the Volga River, 3 – the Samara River, 4 – borders of the area under construction

The area under study (118 hectares) is a floodplain with characteristic elements of microrelief, woods and shrub vegetation. At the same time, part of the territory is occupied by water bodies, such as lakes, eriks and scours, as well as abandoned artificial irrigation ditches. Its significant area has relatively low absolute land surface elevations of 30.00 ÷ 33.50 m with flooded or swampy areas. The groundwater level is notably high. In some areas, water is observed at a depth of 0.5 m from the soil surface [11]. At the same time, according to the construction design of a residential area, there is an active development of residential sectional multi-storey buildings, as well as public infrastructure, socio-cultural and retail facilities.

The development area is surrounded by hydraulically interconnected water bodies: the rivers Volga and Samara, as well as the channel path of the Dubovy Erik oxbow.

At the same time, practically along the entire border of the territory, there are infrastructure engineering facilities and lines with surface elevations that are significantly higher than the existing elevations of the built-up area. So, in the west and south of the territory under consideration there are earth dams of Narodnaya and Obuvnaya streets, in the north – Shosseynaya street is also located on the dam. In the east, the Moscow-Samara railway runs along a high dam with crest marks of up to 45.70 m. In the south, there is a site of the city's sewage treatment plant adjoined by an earth dam.

Thus, the study area with residential buildings has an already established protective contour in the form of an almost completely enclosed earth dam, which under certain hydrological conditions, protects the inner territory from direct flooding by high flood waters of the Volga and Samara Rivers.

The primary task of the study was to determine the degree of protection of the territory from flooding by the existing contour and to approve the optimal elevation mark of its crest as required by the current regulations.

The survey found that the maximum levels of the water body surrounding the area under consideration are related to the hydrological conditions of the Volga River in the operating schedules of the Saratov reservoir, and are determined by the modes of joint operation of the system of upstream hydroelectric complexes of the Volga-Kama cascade in the flood period (spring flood), and in the dry periods (summer, autumn and winter) - the backwater of the Saratov hydroelectric complex and the water releases of the Zhigulyovsk hydroelectric power station, depending, in turn, on the daily and weekly regulation of its capacity.

3 Results

To justify the required elevation of the crest of the protective outline dam, the following main factors were taken into account:

1) the calculated maximum permissible rise in the water level of open water bodies near the city of Samara was adopted based on the annual probability of an increase in the level depending on the class of protective structures for the main design case (probability $P = 1\%$);

2) transformation of the maximum water flow passing through the downstream Saratov and upstream Kuibyshev reservoirs was taken into account;

3) influence of the operating conditions and hydropower modes of the downstream Saratov hydroelectric complex on the water level of the Saratov reservoir was taken into account;

4) the condition of inadmissibility of high flood waters overflowing through the crest of the dam protecting the built-up area was adopted, taking into account the swell of the wind wave and its wind setup on the upstream slope;

5) the conditions of originating wind waves and other disturbances of the free surface of the adjacent water area at maximum water levels and the damping effect of natural and artificial obstacles along the main line of wave acceleration were taken into account [12];

6) availability of a parapet wall on the crest of the protective dam, designed for wave effects, was taken into account, which made it possible to consider the top of the parapet wall a MWL of the protective structure.

The analysis of the initial data and the results of the calculations showed that the first and second factors have the greatest influence on making an informed decision when choosing the height of the crest of the protective contour dam, in other words, the maximum water level of the Volga River in the course of flood with 1% supply, taking into account the transformation of the maximum flow by the upstream reservoirs of the cascade. Moreover, the presence on the acceleration line of the flooded Koroviy Island (with quite sufficient tree vegetation) significantly suppresses the wind wave.

4 Discussion

The technical survey of the existing condition of the protective contour dams, the total length of which is 12.5 km, showed that in some sections of the roadway the elevation marks are lower than required and do not provide reliable protection of the territory of the residential area under construction from flooding. In this regard, engineering measures were recommended to increase the elevation of the contour crest within the two sections along Narodnaya street with a total length of 2240 m (1910 m and 330 m), within the section of Shosseynaya street (600 m), as well as on a partially destroyed dam that blocks the hydraulic connection of Dubovy Erik with the Tatyanka river, located between Krasny Kryazhok street and the territory of water treatment facilities.

It is recommended that the final elevation mark of the protective contour crest be set equal to at least 35.55 m. At the same time, the use of a solid parapet in lowered sections allows a decrease in the elevation mark of the dam crest to a height of 34.55 m.

Carrying out comprehensive measures for the reconstruction of engineering facilities of the protective contour with additional soil and (or) the installation of parapet structures on certain sections of the dam noted above will guarantee that no flooding of the residential area is happening and the negative impact of the water environment is prevented.

5 Conclusions

As a result of the study, the following conclusions were obtained:

– In order to prevent natural-anthropogenic emergencies involving the destructive forces of the water environment under circumstances of very rare recurrence, it is necessary to develop, justify and make special arrangements, as well as take particular technical measures in the form of complex technical regulations approved by the interested organizations.

– The authors examined the territory of a residential area under construction in the southwestern part of the city of Samara on the left bank of the mouth of the Samara River with an area of more than 118 hectares with low surface elevations. Engineering lines (roads, dams), located along the border of the territory and partially performing the function of its protection from flooding with low flood waters, have been identified.

– Taking into account the complex of influencing factors, the minimum elevation of the crest of the existing borderline dam protecting the residential area was determined, at which the flooding of the territory of the built-up area with flood waters is excluded and the negative impact of the water environment on the territory facilities is prevented.

– The state of the protective dam was determined, areas with unacceptably low elevations of the crest surface were identified, and practical recommendations were given for carrying out repair work on the dam and its reconstruction with the recommended increase of crest elevation. The values of m for spillways with a fusible link in the calculations for a step-curved edge with a 1:3 interval are recommended to be taken equal to at least 0.4.

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