CHAPTER 226

BEACH NOURISHEMENT VERSUS SHORE PROTECTION STRUCTURES

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ABSTRACT

The problem of coastal erosion in Russia became especially urgent in 50th-60th during the extensive river damming, taking place mainly in the regions valuable for society. To prevent erosion, which spanned thousands of kilometres of new shoreline different shore protection techniques were used, including hard structures, shoreface and beach nourishment as well as hybrid methods. Most if not all of these techniques were previously applied on Novosibirsk Reservoir, one of the first Russian large man-made lakes. Long-term observations of structures state and recent studying of response of the coastal environment on the projects emplacing testify the greater efficiency of coastal stabilization by beach nourishment programs and hybrid structures.

INTRODUCTION

Novosibirsk Reservoir was created in Western Siberia in 1956 when the Ob River was dammed ca. 20 km upstream the city of Novosibirsk (latitude 55° N, longitude 83° E). It is a freezing reservoir which ice season lasts about 180-190 days from November till April or May. Like many man-made lakes seasonal changes in water level of Novosibirsk Reservoir occur because of the river flow fluctuations; they reach more than 5 m/yr in amplitude and include: (i) Water level rise in May-June: mean duration - ca. 50 at a rate of ca. 0.1 m per day, (ii) Water 00level stabilization: mean duration - ca. 120 days, and (iii) Water level subsidence in October-April: mean duration - ca. 195 days at a rate of ca. 0.02 m per day.

The fetch of Novosibirsk Reservoir is 220 km from northeast to southwest up to town of Kamen-on-Ob, its minimal, mean, and maximum width are 2, 10,

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and 22 km, respectively, water plane area is 1070 km^2, depth is up to 25 m, total storage is 8.8 km^3, effective storage is 4.4 km^3, and shoreline length is 550 km.

The principle basin morphometries of Novosibirsk Reservoir are: a shallow area in the south-western edge of the lake basin under fetch of about 60 km, an area of transitional depths, and a deep-water area with typical depths exceeding the average reservoir depth in the north-eastern part of the lake basin under fetch of 100-120 km. These areas correspond to main types of dynamical relief-forming and depositional sedimentary environments of the lake basin, namely: the deltaic/fluvial-dominated environment, the wave-dominated one with significant influence of the channel flows, and wave-dominated environment itself.

The wave heights are among the most significant features of dynamic relief-forming and depositional sedimentary environments of the reservoir. Within delta-like environment wave heights do not exceed 0.5 m even under severe storm. As for transitional zone the waves of up to 1.5-1.7 m height occur, while the waves of more than 3.5 m were observed in deep water area.

High rate of erosion of Novosibirsk reservoir coasts is primarily caused by wave. Two more factors contribute to erosion. First, the reservoir coasts are formed mainly of loose and soft grounds - sands, sandy loam, and loss-like loam. Second, like natural lakes and other man-made lakes, its beach berms are narrow or even absent at all. That is why the mean erosion rate reaches here 7-10 m/yr and more and the extention of eroding shores makes up 350 km.

Coastal erosion caused the most serious problems in wave-dominated area of Novosibirsk Reservoir. It is precisely here where the coast protection started before the reservoir filling. At present more than 40 km of its coasts have been protected already. As this takes place different shore protection techniques, including hard structures, shoreface and beach nourishment as well as hybrid methods were used.

Long-term observations of structures state showed considerably different reliability and effectiveness of hard structures, filled natural and artificial beaches as well as hybrid projects which combine a shoreface and/or beach nourishment with stabilization of sand by breakwaters, groins, artificial headlands, etc.

Recent studying of response of the coastal environment on the different projects emplacing allowed to reveal some causes of these phenomena.

METHODS

The work on the project began from the studying of data on long-term visual and tool supervision of seawalls, bulkheads, revetments, filled natural and artificial beaches as well as other coastal engineering sites of Novosibirsk Reservoir. This allowed to determine the key sites for special investigations. These investigations include repeated topographic surveys, continuous meteorological observations, synchronized with measurements of waves and studies of swash interactions by wire gauges, measurement of nearshore currrents by omni-directional and two-component impeller current meters, measurement of bedload and suspended sediment concentration by *in-citu* samplers, sand tracers movement observations and piezometric studies of beach groundwater interactions.

For comprehensive evaluation of the affect of protective measures on coastal environment, all observations are conducted not only on the coastal engineering sites, but on the upcoast and downcoast areas as well. Investigations on the key sites started a year ago. In this connection only the preliminary results of the observations are presented here.

BEACH MORPHOLOGY AND NEARSHORE PROCESSES NEAR A SEAWALL

As development increases along the shoreline and property is lost, engineers, developers as well as planners need quantitative descriptions and models of how coastal processes affect the shoreline (Dean, 1987) and how the projects, emplaced to protect the threatened structures, affect the surrounding coastal environment. In recent years, many of the investigations were devoted to the studying of the nearshore processes near a seawall and the resultant beach morphology under marine conditions (Kraus, 1988; Tait and Griggs, 1990; Plant and Griggs, 1992, and others). The definite severity of the environment occur at the man-made lakes, because of the long-term water level fluctuations from weeks to months.

Just as the seawalls, so bulkheads and revetments were built at the Novosibirsk Reservoir; as this took place, the first hard structure was emplaced before its initial filling. The concrete curved-face seawalls, concrete combination inclined and curved-face seawalls and rubble-mound seawalls as well as concrete and rubble-mound revetments had common occurance at the reservoir. Since 1956 more than 25 km of the seawalls were built here, but only about 12 km still persist to date.

For an understanding of the reasons of improper operation and destroying of the structures, beach morphology and nearshore processes were studied near seawalls of several types. The noted effects were both seasonal and long-term ones. According to observations, in the case typical for natural and man-made lakes, when a seawall is placed on the water edge or near it, and the adjacent beaches have a narrow berm or have not it at all, these effects are: (a) the bottom erosion rate increases after the seawall construction and on the fronting beach and its value is always higher than on the adjacent beaches without structures, (b) the bottom erosion in front of seawall before erosion on the protected beaches, (c) the coastal erosion increasing downcoast of seawalls. Near the seawall placed at the backshore, the erosion of beach berm in front of the structure had arised before equivalent erosion on the flanked beaches, because the erosion increses with the reflectivity of the seawall and the mobility of the fronting beach as the result of altering of the pattern of groundwater flux.

That is why, though under such sea-wall position the beach slows down the scour at the toe and ends of the structure, however as the result of the berm erosion the final response of the coastal environment will be equivalent to the first case.

In this manuscript the attention is focused on the effect of the nearshore currents on beach processes near a seawall that protrude into the surf zone. Dean (1976), Berkemeir (1980), and McDougal et al, (1987) noted, that structures of such type can effect longshore currents, trap sand upcurrent of wall and, perhaps, induce scour in front and downcoast of the seawall. However, the observations, conducted by Plant and Griggs (1992) in Monterey Bay, did not reveal this effect neatly.

The study site on Novosibirsk Reservoir consisted of a gently curving shorelines and a 350 m concrete combination inclined and curved-face seawall flanked by the continuous natural beaches at the upcoast and a 200 m beach at the downcoast. The flanked beaches, all backed by 3-5 m escarpment, had the berm the slope of which is 1:35, the width from 3-5 m (downcoast) up to 10 m (upcoast) and initial bottom slope was of order 1:25. The seawall protrude into the surf zone by 2:1 sloping revetment at its toe. The present investigation involved the pre-storm, storm, and post-storm beach surveys to capture morphological changes as well as measurement of the longshore and cross-shore currents at 10 cm level above the bottom in front of the seawall and in the flanked beaches. The storm surveys were carried out under the waves of Hsig 0.5 m, 1.2 m, and 2.3 m; the angle between wave crest and shoreline varied from 35o to 42o in all three events.

The beach surveys in the upcoast, seawall-backed, and downcoast sections of the site showed that the behavior of morphological changes within these sections differs greatly. Total losses of the bottom sediment per one metre of the shoreline made up 0.15, 2.75, and 4.25 m^3 within the upcoast section, 1.00, 5,14, and 8.00 m^3 within the seawall-backed section and 2.5, 4.25, and 6.25 m^3 for the 1st, 2nd, and 3rd storm events, respectively (Table 1).

Table 1.

Beach profile changes near the seawall and on the flanked beaches under different storm events

Beach profile area	Storm event	Net total volumetric changes in beach erosion and sediment accretion, m^3		
		Upcoast section	Seawall-backed section	Downcoast section
Beach Berm	1	+120	-	-150
Breacker Zone	1	-850	-1650	-1000
Offshore	1	+700	+1300	+1000
Beach Berm	2	-350	-	-450
Breacker Zone	2	-1500	-3900	-1900
Offshore	2	+1300	+2100	+1500
Beach Berm	3	-500	-	-650
Breacker Zone	3	-2450	-6700	-3400
Offshore	3	+2100	+3900	+2800
Note. Sign <+> corresponds to accretion, sign <-> corresponds to erosion				

Measurements of the nearshore currents during the storms in the front of seawall and on the flanked natural beaches correlate with beach surveys data, and to all appearances, explain the observed morphological changes. The absolute values of time-averaged longshore and cross-shore current velocities at the seawall-backed and downcoast sections of the study site were higher than the current velocities within the upcoast beach during the steady stage of all the storms (Table 2). Alongside, it is hard to state, that the observed rather higher rates of the nearshore currents at the downcoast beach are directly related to hydrodynamic processes in front of the seawall. It is stipulated by the fact that under small width of beach berm at the downcoast section, the backed cliff can induce nearshore processes, in principal similar to the processes caused by the seawall.

Table 2.

The range of the absolut values of time-averaged longshore (V) and cross-shore current (U) velosities near the seawall and on the flanked beaches during the steady stage of storms

Beach profile area	Storm event	Longshore and cross-shore current velosities, m/s		
		Upcoast section	Seawall-backed section	Downcoast section
Breacker Zone	1			
V		0.08-0.22	0.12-0.31	0.10-0.25
U		0.07-0.23	0.10-0.35	0.10-0.27
Offshore	1			
V		0.02-0.11	0.02-0.12	0.02-0.12
U		<0.03	<0.04	<0.04
Breacker Zone	2			
V		0.10-0.27	0.12-0.38	0.12-0.32
U		0.10-0.31	0.15-0.39	0.10-0.35
Offshore	2			
V		0.02-0.14	0.02-0.15	0.02-0.15
U		<0.05	<0.05	<0.05
Breacker Zone	3			
V		0.18-0.50	0.20-0.65	0.17-0.58
U		0.16-0.52	0.21-0.72	0.20-0.60
Offshore	3			
V		0.05-0.18	0.05-0.21	0.04-0.20
U		<0.10	<0.10	<0.10
Notes.1)Time averaging interval by hardware is of 30 sec. 2)Time of continuous measurment is of 5 hours for all the storm events.				

Visual observations of the seawall reliability started immediately after construction of Novosibirsk Reservoir. During the period of observation the most typical were the cases of seawalls destroy during several years or decades. At this time some events were noted, when the wall was completely destroyed under a prolonged severe storm with Hsig exceeding 3-3.5 m or under series of 2-3 such storms.

The survey of the walls destroyed showed that the main reasons of their destruction were not the construction failures but a scour at the toe and ends of the structures. No doubt, the scour was caused not only by the nearshore currents, but by wave reflection from a seawall, and the effect of groundwaters as well. However, in all cases of wall breakdown on the reservoir nearshore currents appeared to be of a prime consideration.

COASTAL ENVIRONMENT RESPONSE TO BEACH NOURISHMENT AND EMPLACING OF HYBRID PROJECTS

The first event of seawall damage on Novosibirsk Reservoir occured in 1959 near the Novosibirsk Academic Center. This wall was constructed in an effort to protect the shore site associated with federal highway and railway as well. Thus at this site renovation of shore defence, wherein the combined shoreface and beach nourishment were used for the first time in Russia, began.

At Novosibirsk Academic Center stretching 3 km alongshore, approximately 5,000,000 m^3 of sand have been nourished during three years. The constructed open artificial beach was located within the curved shoreline site where the longshore transport rate is not more than 20,000-25,000 m^3/yr. Owing to appropriate location the beach provided a powerful shore protection for 25 years without renourishment.

In spite of reasonable results of shore protection by beach nourishment, this technology became widely used on Novosibirsk Reservoir only at the end of 70th . At present there are more than 7 km of the open artificial beaches on the man-made lake.

The continuous monitoring of the beach morphology changes showed that under the environmental conditions of Novosibirsk Reservoir the equilibrium beach profile has shapes of several years. The process of profile formation usually begins from intensification of beach face erosion and is followed by cross-shore sediment transport. Superimposed terrace is formed in consequence of the sediment accretion at the outer border of the beach profile. As development progress of the profile the terrace edge is shifting to the seaward direction and the beach profile becomes level out. When two-three years elapse the terrace edge position has become fairly stable and the longshore sediment transport begins to dominate among the nearshore processes (Table 3). It seems likely that profile formation is completed.

The occurence of abnormal conditions with erosion of the accretive terrace at the outer border of the beach is mainly stipulated by severe storms effects during the lake's water level subsidence in autumn or water level rise in spring. It resulted in increaing of bottom slope (Table 3), that finally brought to intensification of berm beach erosion, cross-shore sediment transport and decreasing of longshore sediment rate.

Table 3.

Temporal morphological changes and prevailing trends in the nearshore processes on the nourished beach near the Novosibirsk Academic Center

Year	Total amount of the sediment losses			Total amount of the sediment accretion		Observed trends of the sediment transport
	Beach berm, m^3	Nearshore, m^3	Outer border of the beach, m^3	Near-shore, m^3	Outer border of the beach, m^3	
1	-82,000	-63,000	-	+21,000	+110,000	Cross-shore
2	-81,500	-52,000	-	+24,000	+97,000	Cross-shore
3	-78,000	-51,000	-	+54,000	+64,000	Cross-shore
4	-49,300	-51,000	- 5,000	+53,000	+35,000	Longshore
5	-46,500	-52,000	-35,000	+70,000	+15,000	Longshore
6	-54,500	-63,000	-	+38,000	+73,000	Cross-shore
7	-48,000	-54,000	-11,000	+49,000	+42,000	No clear trend
8	-46,700	-52,000	-27,000	+61,000	+21,000	Longshore
9	-39,200	-47,000	-	+34,000	+45,000	Cross-shore
10	-45,000	-54,000	- 4,000	+51,000	+34,000	Longshore
11	-40,500	-51,000	-31,000	+54,000	+19,000	Longshore
12	-46,100	-55,000	-23,000	+62,000	+20,000	Longshore
13	-59,200	-64,000	-16,000	+55,000	+49,000	No clear trend
14	-35,000	-40,000	-10,000	+54,000	+11,000	Longshore
15	-40,300	-53,000	-21,000	+59,000	+20,000	Longshore
16	-42,500	-55,000	-37,000	+53,000	+23,000	Longshore
17	-46,100	-57,000	-	+40,000	+47,000	Cross-shore
18	-45,400	-58,000	-9,000	+57,000	+25,000	Longshore
19	-45,500	-54,000	-10,000	+64,000	+18,000	Longshore
20	-53,000	-65,000	-23,000	+65,000	+30,000	Longshore
21	-62,500	-78,000	- 7,000	+68,000	+47,000	Longshore
22	-63,000	-83,000	-10,000	+64,000	+58,000	No clear trend
23	-70,300	-81,000	-14,000	+68,000	+62,000	No clear trend
24	-69,000	-86,000	-15,000	+71,000	+65,000	No clear trend

Within the wave-dominated region of Novosibirsk Reservoir the net longshore transport rate at the open shores varies from 25,000 m^3/ yr to 150,000-200,000 m^3/yr. In term of this, the priorities in policy of beach nourishment are established as following:

1. Initial beach nourishment and periodic replenishment after ten and more years existence of protective beach.
2. The accomplishment of hybrid projects, which combine beach nourish ment with the use of isolated groins, breakwaters or their systems.

Practically all attempts to prevent erosion along the Novosibirsk Reservoir shores by beach nourishment and hybrid structures were rather succesful and these projects offer numerous benefits. Firstly, unlike the seawall and similar hard structures the main part of nourishment-based projects are in good condition (Table 4). Secondly, groin systems and/or detached breakwaters retain the desired shape of beach berm. Thirdly, the longshore transport of borrow material from filled beaches allowed tangibly to mitigate the coastal erosion at downcoast areas and the costs on shore protection were reduced by virtue of this phenomenon.

Table 4.

General results of the Novosibirsk Reservoir shore protection

Shore Protection Type	Length km	Modern condition		
		Destroyed km	Indamage, km	In good condition, km
Seawalls and similar hard structures	11.88	5.51	4.50	1.87
Beach nourishement	7.50	–	0.50	7.00
Hybrid projects:				
protective beach + groins	9.00	–	1.50	7.50
protective beach + segmented breakwaters	5.20	–	1.20	4.00
protective beach + segmented breakwaters + groins	3.30	–	–	3.30
protective beach + artificial headlands	5.00	–	–	5.00

CONCLUSION

Preliminary data based on over one year of observations provide some information that can assist in future efforts to mitigate shoreline erosion. The construction of hard structures like seawalls under a man-made lake's environmental conditions marked by strong storms and long-term water level fluctuations had failed measure. This type of shore protection structure presumably will be admissible only in case of feeder beach creation on the upcoast area.

Beach nourishment and fulfilling of hybrid projects are considered to be the most efficient ones. There are numerous benefits providing these measures, among which are the significant mitigation of the shoreline erosion, fair reliability, and improvement of coastal environment on adjacent shore sites. It resulted in serious changes in shore protection policy in Russia, because Novosibirsk Reservoir is a study site for a full-scale testing of various ideas in applied coastal engineering.

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