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Dredging Research Technical Notes

Interim Design Guidance For Nearshore Berm Construction

Purpose

This note provides interim guidance for siting and designing fine to medium sand nearshore berms constructed with dredged material. Available empirical observations and preliminary analytical work are summarized. Nearshore berms should be considered as engineered structures with predictable design lives and may require periodic maintenance to ensure functioning. Dredging Research Program (DRP) monitoring and modeling work units will update this guidance as the data base and predictive techniques are improved.

Background

The US Army Corps of Engineers has long been a proponent of the constructive use of clean dredged material. Such beneficial uses include creation of bird habitats, aquatic habitats, and wetlands, and placement of beach fills. In recent years, the concept of placing dredged material in shallow water in the form of shore-parallel berms gained acceptance as a means of enhancing the beach profile. Benefits of a berm to the nearshore zone include providing material to the littoral system and reducing erosive wave action on the beach landward of the berm. Dredging Research Technical Note DRP-5-01 (McLellan 1990) summarized ten ongoing and completed nearshore berm projects.

This note contains (1) an introduction and overview of considerations for the siting and design of nearshore berms, (2) simple quantitative techniques for berm siting and design, and (3) two examples illustrating the techniques, one for an East Coast situation and one for the West Coast.

Additional Information

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Nearshore Berm Concept

Nearshore berms are submerged, high-relief mounds constructed parallel to shore and composed of clean, predominately beach-quality dredged material. Specifically, the term "berm" refers to a linear feature that resembles a longshore bar, while the term "mound" applies to any configuration of artificially placed material.

Nearshore berms are generally divided into two categories—feeder berms and stable berms. Feeder berms are constructed of clean sand placed in relatively shallow water to enhance adjacent beaches and nearshore areas by mitigating erosive wave action and by providing additional material for the littoral system. Stable berms are intended to be permanent features constructed in deeper water outside the littoral environment. They may function to attract fish as well as reduce wave energy incident to the coast.

Benefits to the beach are conveniently classified as either direct or indirect according to the type of material, berm elevation and length, wave climate, and depth of berm placement. The direct benefit is widening of the beach by onshore movement of material from the berm. Indirect benefits are breaking of erosive waves, reduction of storm setup on the beach face, and creation of an artificial storm bar that will reduce erosion by satisfying part of the demand for sediment to be moved offshore during storms. Table 1 summarizes benefits associated with the two types of berms.

Table 1

Potential Benefits of Nearshore Berms

	Direct	Indirect		
	Nourish Beach	Attenuate Waves	Reduce Erosion	Stockpile Sand
Feeder berm	Yes	Yes	Yes	No
Stable berm	No	Yes	Yes/no	Yes

Feeder Berms

If a berm is placed in sufficiently shallow water and with sufficiently high relief, the higher erosive waves accompanying storms will break on its seaward slope and crest. Broken waves of reduced height then reform and progress toward the shore to break again with less energy. This energy-reducing mechanism provides an indirect benefit by reducing the erosional demand of storms for sediment to be moved to the offshore. Material removed from the berm and transported shoreward during periods of accretionary wave conditions supplements the beach profile by becoming part of the littoral system, contributing to the total volume of material available for beach recovery.

Stable Berms

A stable berm is intended to be a relatively permanent bottom feature that attenuates higher waves, and it may function as a fish habitat. Material from the berm is not expected to be transported to the littoral system and beach. Berms designed to be stable may be constructed of a wider range of materials and grain sizes than feeder berms. However, not all material will mound adequately or have the required stability to function as a stable berm. For some projects, material with low mounding potential has been intentionally spread over a large area using what is called thin-layer disposal (Nester and Warren 1987). If a stable berm or mound consists of beach-quality sand, it can be used as a stock pile for future beach nourishment projects.

Berm Design

Several steps must be followed to determine the potential for successful berm design and construction. These steps include evaluation of (1) quantity and quality of material to be dredged, (2) availability of suitable equipment, (3) local wave conditions, and (4) economics of berm construction and alternatives.

Material quality and quantity evaluations concern dredged sediment beach compatibility, mounding properties, and available volume. If the placed sediment grain size is compatible (that is, similar or coarser grain size) with beach samples, a feeder berm can be constructed. If the material is not compatible with the native beach material but does have mounding potential, a stable berm can be considered; if the material is low-density fluid mud, mound construction is unfeasible. Past projects indicate that at least 50 cu yd per lin ft are required to build a long feeder berm of significant height (4 to 6 ft). Conical-shaped mounds placed in the nearshore focus wave energy behind them and should be avoided. Berm length should be several times the average local wavelength, and the berm should be oriented parallel to the trend of the shoreline to minimize wave focusing and depth limitations of the dredge, and maximize the extent of the shoreline to be protected.

Local wave conditions determine the depth of placement for supplementing the supply of littoral material by feeder berms, as described below. Material to be placed at the design depth and crest elevation will require suitable equipment, usually a split-hull hopper dredge. McLellan (1990) lists shallow-draft hopper vessels currently available in the United States. Recent projects have shown that these dredges are capable of constructing mounds of elevation above the loaded draft of the vessel. Table 2 lists the maximum measured crest elevations below MLLW and loaded drafts of hopper dredges from several projects.

Currently, there is no guidance to perform a complete economic benefit analysis for nearshore berm construction. The main quantitative savings occur if haul distances are reduced by nearshore placement as compared to placement at previous disposal sites. As quantitative understanding of nearshore and berm physical processes is advanced, design guidance will be refined and a comprehensive economic benefit can be calculated to develop a cost-benefit ratio.

When the evaluation procedure has been completed, berm design can begin. The design process mainly entails determination of placement location, timing of placement, and berm length, width, and crest elevation for a given volume of material.

Table 2

Sand Berms Built to Near Hopper-Draft Depths*

Location	Year	Contractor**	Dredge	Volume 1000 cu yd	Peak Elev. ft†	Loaded Draft ft	Light Draft ft
Gilgo Beach, NY	1987	NATCO	Northerly Is.	420	-7.5	15.5	5.0
Lido Beach, NY	1987	NATCO	Northerly Is.	350	-8.0	15.5	5.0
Dam Neck, VA	1983	NATCO	Padre & Sugar Is.	850	-22.0	19.5	9.5
New River, NC	1979	Corps	Currituck	400	-3.0	7.2	2.4
Sand Island, AL	1987	GCTC	Atchafalaya & Mermentau	464	-10.0	14.0 14.0	5.0 5.0
Brazos/ Santiago, TX	1989	NATCO	Manhattan Is.	230	-20.0	19.5	9.5
Silver Strand, CA	1988	Manson	Newport	100	-9.0	18.6	9.0

* E. B. Hands, 1989, personal communication.

** NATCO = North American Trailing Co.; GCTC = Gulf Coast Trailing Co.; Corps = Wilmington District, Corps of Engineers; Manson = Manson Construction and Engineering Co.

† Mean lower low water (MLLW).

Location

Several factors must be considered in determining the site location including haul distance, location and longshore extent of the area to be protected, and shoreline and bathymetry perturbations. For more on location, refer to McLellan (1990).

Timing of Placement

The annual cycle of beach advance during the summer and recession during winter (in the Northern Hemisphere) is well known. Onshore sand transport tends to occur during periods of waves with low steepness during summer (wave steepness is defined as wave height H divided by wavelength L). Sand is moved offshore during periods of high steepness waves, as occur during local winter storms, hurricanes, and extratropical storms. Material placed in the nearshore in early or mid-summer will more likely reach the beach than material placed just prior to storm season when it will tend to be distributed in the offshore.

Numerous criteria have been proposed to predict whether a beach of a certain grain size will tend to erode or accrete under waves of a certain height and period. Here, discussion is limited to cross-shore transport, omitting consideration of longshore sand transport and wave angle. Larson and Kraus (1989) developed a criterion that incorporated deepwater wave steepness and the sand fall speed parameter $H_o/(wT)$, in which the subscript o denotes the wave height in deep water, w is the sand fall speed in quiescent water, and T is the wave period. Kraus (in preparation) further verified the criterion with a data set of accretion and erosion events recorded on beaches around the world and found the following simple approximation was consistent with the original conclusions of Larson and Kraus:

$$\frac{H_o}{wT} < 3.2, \quad \text{accretion}$$
$$\frac{H_o}{wT} > 3.2, \quad \text{erosion} \qquad (1)$$

If the fall speed parameter is less than 3.2, then a beach will tend to accrete; if it is greater than 3.2, a beach will tend to erode. In Equation 1, the significant deepwater wave height and peak spectral period should be used. Fall speeds for common water temperatures and quartz grain diameters are given in Table 3, calculated by equations given by Hallermeier (1981a). Examples of the use of Equation 1 are given later.

Because Equation 1 was developed from data describing large accretionary and erosional events, its application with all wave data should be viewed with caution at present. It is emphasized that the criterion applies to beach change resulting from cross-shore sand transport without consideration of longshore processes. Kraus (in preparation) describes limitations of Equation 1.

Table 3

Short Table of Fall Speed Values (m/sec) (Quartz Grains)

Temperature deg C	Median Grain Size, mm					
	0.15	0.20	0.25	0.30	0.35	0.40
10	0.016	0.023	0.029	0.035	0.042	0.048
15	0.017	0.024	0.030	0.037	0.043	0.050
20	0.018	0.025	0.032	0.039	0.046	0.053
25	0.019	0.026	0.034	0.041	0.049	0.055

Depth of Berm

If the design calls for a feeder berm, it is optimally placed as close to shore as possible within constraints of safe navigation of the dredge. A berm will break waves that have a height approximately equal to the water depth at its crest. Placing the berm closer to shore, thereby decreasing the depth at the berm crest, will increase its potential to break waves, better protect the beach from erosive wave action, and promote movement of material forming the berm into the littoral zone. A greater frequency of occurrence of wave breaking on a berm implies a greater potential for material to move off the berm and into the littoral environment. Conversely, if waves break infrequently on a berm and the berm is not exposed to strong currents, it will be stable.

Active beach profile change is an indication of the seaward extent of the littoral zone. This limiting depth is a function of the wave height, wave period, and sediment size and composition, and it is most reliably determined by reference to repetitive profile surveys and bathymetry maps for the site or a neighboring site that experiences the same wave climate. If adequate profile data do not exist, an analytic method introduced by Hallermeier (1981b, 1983) can be used to estimate the limiting depth. Hallermeier defined an annual seaward limiting depth d_{sa} of the littoral zone as

$$\frac{d_{sa}}{H_o} = 2.3 - 10.9\left(\frac{H_o}{L_o}\right) \qquad (2)$$

in which H_o is the significant deepwater wave height exceeded 12 hr per year, and $L_o = gT^2/(2\pi)$ is the deepwater wavelength calculated with the wave period associated with H_o, where g is the acceleration due to gravity.

In metric units, $g/(2\pi) = 1.56\ \mathrm{m/sec}^2$; whereas in American customary units $g/(2\pi) = 5.12\ \mathrm{ft/sec}^2$. In arriving at Equation 2, the original expression of Hallermeier was modified by restricting consideration to quartz sand particles. Birkemeier (1985) tested Equation 2 with high-quality data from the Coastal Engineering Research Center's Field Research Facility at Duck, North Carolina, and found that it held if the empirical coefficients were adjusted slightly for that site to give $d_{sa}/H_o = 1.75 - 9.2(H_o/L_o)$, thereby validating the basic functional dependence of the equation.

Berm Height, Width, Length and Side Slopes

The overall dimensions and mounding characteristics of the berm depend on several factors including type and compaction of material, dredging and placement method, waves and currents during placement, and grain size. See McLellan (1990) for additional information on mounding potential of different sediments.

Once the proper depth and mounding potential have been determined, the crest elevation will be directly related to the loaded and unloaded draft of the dredge (Table 2). Required loaded vessel drafts may be reduced by light loading the dredge. This most likely will not increase the final crest elevation, but will decrease the required depth for safe navigation.

The berm should be of sufficient length to avoid wave focusing by refraction. This phenomenon depends on the depth change at the berm, and wave height, period, and direction, and is presently under investigation. Existing berms are as short as 2.5 times the average wavelength and are not exhibiting wave-focusing effects. The only reported problem occurred during construction of a berm at a Durban, South Africa, in which the ends tended to focus wave energy. The construction plan was changed to have 1 V (vertical) on 150 H (horizontal) end slopes in order to reduce these refraction effects (Zwamborn, Fromme, and Fitzpatrick 1970).

No explicit guidance yet exists for designing the berm crest width, but it is generally true that a wider berm will break more waves. Zwamborn, Fromme, and Fitzpatrick (1970) performed scale-model tests for four berm crest widths (0, 30, 61 and 92 m) under the same wave heights and period. Table 4 lists the percentages of erosive waves passing over the berm for the four widths. The model tests indicated that increasing the crest width decreased the percentage of erosive waves passing unbroken across the berm. For the test conditions, an increase in crest width from 0 to 30 m provided an approximately 50 percent increase in protection from erosive waves.

The side slope achievable in berm construction is mainly a factor of grain size and sediment density, but the compaction of material, dredging and placement method, and currents during placement also determine the final slope. At present little information is available on the angle of repose of dredged materials placed offshore. Several fine to medium sand berms have been constructed with side slopes ranging from 1 V on 100 H to 1 V on 16 H.

A stable berm constructed off Mobile, Alabama, of fine sand, silt, and clay dredged using a clamshell dredge and placed with a split-hull scow attained slopes after construction of 1 V on 24 H to 1 V on 130 H (McLellan and Imsand 1989).

Table 4
Percentage of Erosive Waves on a Nearshore Mound*

	Without Mound	With Mound			
Crest width, m	—	0	30	61	92
Percentage of erosive waves**	30	10	5.5	3	2.5

* From Zwamborn, Fromme, and Fitzpatrick (1970).
** From laboratory data of wave heights scaled to the prototype range 2 to 16 m and periods scaled to the range 7 to 25 sec; berm crest scaled 7.3 m below mean sea level.

Example Calculations

Parallel calculations will be made for examples of two recently constructed feeder berms, one at Gilgo Beach (McLellan, Truitt, and Flax 1988), located on the south shore of Long Island, New York, and the other at Silver Strand Beach, located on the coast of southern California (Junke, Mitchell, and Piszker 1989). The sand used for the berm at Gilgo was dredged from Fire Island Inlet and that at Silver Strand from the entrance to San Diego Harbor. Haul distances to the project sites were considerably shorter than to traditional disposal areas, representing a costs savings to the dredging and placement operation.

The Fire Island Inlet berm was constructed in June 1987, and was approximately 7,500 ft long and 6 ft high. The 410,000 cu yd were placed along the 16-ft contour. The Fire Island Inlet medium-size beach quality sand (median diameter = 0.4 mm) was placed by the 16-ft-draft split-hull hopper dredge **Northerly Island**. A linear berm volume of 56 cu yd/lin ft was placed at the site with some depths reduced to as little as 7.5 ft below mean sea level at the crest. By December 1987 a survey showed only 130,000 cu yd of material remained, indicating that 68 percent of the placed material had moved out of the area.

The Silver Strand berm was constructed intermittently over a one-month period beginning 7 December 1988. The berm was designed to be 1,200 ft long and 600 ft wide, and it was placed between the depths -10 and -30 ft on the MLLW contours, located approximately 800 and 1,400 ft from shore. Depth at the crest was approximately 10 ft. The estimated dredged quantity placed on the berm was 91,000 cu yd, giving a linear berm volume of 76 cu yd/ft of shoreline. Preproject sampling indicated that the dredged material, derived from littoral transport of beach sand and cliff erosion, had a median grain size of 0.18 mm, while the native sand at the site had a median grain size of 0.25 mm. Periodic monitoring over 18 months after berm placement has indicated deflation of the berm, movement of its center of mass toward the shore, and progradation of the beach behind the berm exceeding that on the neighboring beach segments not protected by the berm.

Long-term wave hindcasts available from the Wave Information Study (WIS) will be used for both sites. Tables 5 and 6 give statistical summaries of significant wave height H_s and peak spectral period from waves incident from all possible directions for the 20-yr hindcasts (1956 to 1975). Table 5 was adapted from WIS Report 9 (Jensen 1983) and includes both sea and swell. Table 6 was adapted from draft WIS Report 20 (Jensen and others in preparation) and includes North Pacific sea and swell, but not southern Pacific swell. WIS tables contain wave information corresponding to 3-hr intervals; this results in 58,440 possible events for a 20-yr period that includes five leap years. Wave heights and periods in Tables 5 and 6 are representative of height and period intervals given in the original WIS reports, and the entries in the tables are the number of events as a percentage multiplied times 100. The subtotals do not equal 100 percent (for example, the right-hand column in Table 5 sums to 91.7 percent) because calm events are omitted from these tables. For Silver Strand, an approximate two-year wave record from a deep-water buoy was available which had been analyzed by wave direction to provide data for longer period waves incident from the southern quadrant, giving approximate statistics for the Southern Hemisphere swell; the record resulted in average wave height of 0.73 m and 14.4-sec period, occurring 36 percent of the year.

Table 5

Percent Wave Occurrence, Gilgo State Park, New York (WIS Station 50)

Wave Height* m	Wave period, sec 1.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11+	Total
0.25	361	712	343	230	711	1,040	465	49	64	106	4,081
0.75	—	283	787	297	138	925	687	143	93	113	3,466
1.25	—	—	63	264	119	251	178	51	77	53	1,056
1.75	—	—	—	11	78	134	82	16	29	25	375
2.25	—	—	—	—	15	63	46	13	4	4	145
2.75	—	—	—	—	—	9	20	9	2	1	41
3.25	—	—	—	—	—	—	2	5	1	—	8
3.75	—	—	—	—	—	—	—	—	1	—	1
4.25	—	—	—	—	—	—	—	—	—	—	0
5+	—	—	—	—	—	—	—	—	—	—	0
Total	361	995	1,193	802	1,061	2,422	1,480	286	271	302	—

* Calculated at 10-m depth; 58,440 events; percent times 100.
Mean H_s = 0.6 m; largest H_s = 4.2 m.

Table 6
Percent Wave Occurrence, Silver Strand, California (WIS Station 2)

Wave Height* m	Wave period, sec											
	<4.4	5.2	7.0	8.8	10.0	11.0	12.5	14.4	16.8	20.2	22.3+	Total
0.25	138	86	239	342	87	34	6	4	—	—	—	966
0.75	66	173	804	796	609	559	184	31	1	—	—	3,223
1.25	5	102	675	300	333	673	630	121	7	—	—	2,846
1.75	—	5	268	221	75	242	612	306	17	—	—	1,746
2.25	—	—	26	102	37	49	241	306	34	—	—	795
2.75	—	—	2	23	25	13	59	40	36	—	—	298
3.25	—	—	—	2	3	4	12	37	10	—	—	68
3.75	—	—	—	—	—	1	3	12	6	—	—	22
4.25	—	—	—	—	—	—	—	1	1	—	—	2
5+	—	—	—	—	—	—	—	—	—	—	—	0
Total	209	366	2,044	1,786	1,169	1,575	1,747	958	112	00	00	—

* Calculated at 22-m depth; 58,440 events; percent times 100.
Average H_s = 1.2 m; largest H_s = 4.1 m.

Seaward Limit of Littoral Zone

The seaward limit of the littoral zone is first calculated to estimate the depth which would approximately separate successful placement of feeder and stable berms. Of course, for feeder berm design, the shallower the berm is placed the greater the likelihood for material reaching the beach.

Equation 2 requires an estimate of the average of the highest waves in 12 hr of a year, which translates to 80 3-hr events in 20 yr of WIS summary tables. The 12-hr annual average highest wave occurs with a frequency of (80/58,440)*100 = 0.14 percent. By inspection of Tables 5 and 6 to determine an average wave height corresponding to this percentage, the following estimates are made: $H = 3.0$ m and $T = 9$ sec for Gilgo, and $H = 4.5$ m and $T = 13$ sec for Silver Strand, at the respective hindcast depths of 10 m and 22 m. Shoaling these waves out to deep water and neglecting refraction gives $H_o = 3.4$ m and $H_o/L_o = 0.025$ for Gilgo, and 4.7 m and 0.018 for Silver Strand. Substitution of these quantities into Equation 2 yields:

$$d_{sa} = 3.4*(2.3 - 10.9*0.025) = 6.9 \text{ m} = 23 \text{ ft for Gilgo}$$

$$d_{sa} = 4.7*(2.3 - 10.9*0.018) = 9.9 \text{ m} = 32 \text{ ft for Silver Strand}$$

From the calculations of d_{sa} it is seen that both berms were placed well inside their respective annual seaward limit of the littoral zone. Accordingly, the berms are expected to function as true feeder berms, providing both the indirect benefits of wave attenuation and reduction of erosional stress, as well as directly nourishing the beach.

Beach Nourishment Potential

To obtain a qualitative estimate of the beach nourishment potential of the two berms under their respective wave environments, wave data in the modified WIS summary Tables 5 and 6 were entered in Equation 1 to predict erosional and accretionary conditions. For the two examples, the grain sizes of 0.20 and 0.40 mm were used, yielding fall speeds or 0.025 and 0.053 m/sec at a water temperature of 20 deg C. The results of the calculations are given in Tables 7 and 8 for Gilgo and Silver Strand, respectively. In these tables, the symbols (a, A) denote a predicted accretionary condition for the (0.20 mm, 0.40 mm) sand, and the symbol (-) denotes predicted erosion.

Table 7

Gilgo State Park, New York, Erosion/Accretion Frequency

Wave Height m	Wave Period, sec 1.5	3.5	4.5	5.5	5.5	5.5	8.5	9.5	10.5	11+
0.25	-A	aA	aA	aA	aA	aA	aA	aA	aA	aA
0.75	—	—	-A	-A	-A	-A	-A	-A	aA	aA
1.25	—	—	—	—	—	-A	-A	-A	-A	-A
1.75	—	—	—	—	—	—	—	—	-A	-A
>2.25	Erosion									

Note: Symbols (a, A) accretion condition for (0.20 mm, 0.40 mm) quartz sand; symbol (-) denotes erosion.

Table 8

Silver Strand, California, Erosion/Accretion Frequency

Wave Height m	Wave Period, sec <4.4	5.2	7.0	8.8	10.0	11.0	12.5	14.4	16.8
0.25	aA	aA	aA	aA	aA	aA	aA	aA	aA
0.75	—	-A	-A	-A	aA	aA	aA	aA	aA
1.25	—	—	—	-A	-A	-A	-A	-A	aA
1.75	—	—	—	—	—	-A	-A	-A	-A
2.25	—	—	—	—	—	—	—	-A	-A
2.75	—	—	—	—	—	—	—	—	-A
3.25	Erosion								

Note: Symbols (a, A) accretion condition for (0.20 mm, 0.40 mm) quartz sand; symbol (-) denotes erosion.

Interpreted in combination with the frequencies of wave occurrence, Tables 7 and 8 provide estimates of frequency of erosion and accretion by cross-shore wave processes. A number of observations on the behavior of feeder berms and beach nourishment projects are obtained by this methodology:

1. Accretion is favored for lower wave heights and longer periods, as is evident from the form of Equation 1.

2. The longer period waves existing on the West Coast tend to promote accretion for episodes of higher waves than is possible on the East Coast. Because onshore movement of material in a feeder berm is expected to occur more rapidly under higher waves, this result indicates feeder berms of the same grain size at the same depth will move onshore more rapidly on the West Coast than on the East Coast.

3. For Gilgo Beach, approximately 40 percent of the waves are accretionary for the 0.20-mm sand. In contrast, the 0.40-mm sand is predicted to experience accretionary conditions more than 75 percent of the time at Gilgo, a strong indication that the material will move into the surf zone and on to the beach.

4. At Silver Strand, the 0.20-mm sand experiences accretion 32 percent of the time from the northern hemisphere sea and swell and 36 percent of the time by the southern hemisphere swell. Although the northern and southern hemisphere wave events are not strictly additive, the relatively high probability for accretion indicates the 0.20-mm sand will move onshore. Table 8 also indicates that a berm composed of 0.4-mm sand will have high probability of moving onshore.

By employing any convenient wave breaking criterion involving depth, the approximate frequency of occurrence of erosive waves breaking on the berms can be calculated from knowledge of the berm crest depth.

The above analysis involved cross-shore transport effects. In the overall project design, characteristics of longshore sand transport at the site should also be considered. For example, at Gilgo Beach there is a tendency for strong net transport to the west, and a significant portion of the material that moved from the berm is believed to have been transported to beaches downcoast. In contrast, at Silver Strand, the net longshore transport is believed to be weak, and most of the berm volume has remained on the profiles where it was placed. It is particularly important to consider longshore sand transport if the possibility exists for the material to enter a navigation channel or inlet.

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