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EDITORIAL

Coastal and Port Engineering: Synergistic Disciplines from the Overarching Purview of Integrated Coastal Management

The principle objectives of maritime engineering fall broadly into two classifications: (1) transportation, and (2) reclamation and conservancy. The first category includes works that are directed at providing facilities for the safe and economical transfer of cargo and passengers between land vehicles and ships; fishing ports for the landing and distribution of the harvest of the sea; harbors of refuge for ships and small craft; and marinas for the mooring or laying up of small private craft. Reclamation and conservancy works, on the other hand, focus on protection of the land area from encroachment by the sea, to the recovery and conversion of land use areas occupied by the sea, and to the maintenance of river estuaries as efficient means for the discharge of inland runoff. The civil-engineering techniques used for either of these objectives are broadly similar, coming within the purview of coastal and port engineering. Indeed, the realization of both objectives at the same time is frequently a feature of the same project. With these goals of maritime engineering in mind, it is also important to remember that construction in the coastal zone takes place with consequences to the often-fragile littoral environment.

The presence of ports and harbors around the world brings one to the staggering realization that these maritime works, and the facilities associated with them, must number many thousands of installations. Lloyd's Register of Shipping (*Maritime Guide* 1998), for example, provides worldwide lists that locate over 14,500 'places of maritime significance.' These locations include ports, places of shipbuilding, marine machinery manufacture and shiprepairing; places where ships are owned or managed; selected canals, rivers, offshore anchorages, roadsteads, gas/oil fields, straits and channels. Also included are locations of shipbreakers, pontoons, linkspans, and other docking installations (incl. dry docks). Although it is difficult to obtain in a single document a global list of all ports in the world, summaries of port facilities and statistics are compiled nationally and regionally by various governmental and proprietary sources. There is, for example, much useful information compiled by the U.S. Army Corps of Engineers, American Association of Port Authorities, Association of British Ports, Maritime Information Systems, and so on. More information is becoming available in electronic format and some interesting sites on the World Wide Web include: Ports and Port Authorities (access.digex.net/~rjeffrey/Ports), The Seaports Infopage (seaportsinfo.com), and Maritime Global Net (mglobal.com). Smaller ports are generally not included in these lists, especially those of importance only to local economies. In contrast to the large numbers of smaller ports that go unreported, Table 1 lists several hundred ports of international and national significance. Although the list is far from complete, it serves to emphasize the point that there are numerous major port and harbor facilities around the world's coastline. The numbers of facilities, their size, and frequency of occurrence along coastal stretches bear consideration from several points of view. It is thus perhaps worth while to briefly summarize the important place of ports and harbors in global and local economies. The figures in Table 2 emphasize, by way of one example, the importance of port, harbor, and waterway commerce in the United States by reference to ton-miles and average tonnage hauled by type of traffic from 1996 to 1997. Table 3 summarizes U.S. waterborne foreign commerce for ports ranked by cargo value. More complete summaries may be found in *Waterborne Commerce of the United States* (COE, 1997). Although not comprehensive, Tables 1–3 illustrate the points that port and harbor installations around the world are numerous and that they are important to international, national, regional, and local economies. Their mere presence impacts the littoral zone and demands attention from coastal specialists.

The World Port Index (WPI) (Defense Mapping Agency Hydrographic-Topographic Center, 1986) provides useful ways for defining or categorizing ports by location, size, and type. By definition, a harbor is any part of a body of water that is sufficiently sheltered from wind, waves, and currents such that it can be used by vessels for safe anchorage or the discharge and loading of cargo or passengers. A harbor is distinguished from a port in that it does not necessarily have facilities for the transfer of cargo that a port always has. Even though the two terms (*i.e.* port and harbor) are differentiated from a technical point of view, in common parlance they are often used interchangeably in a broad sense without engineering connotations. The most important aspect of a harbor is the amount of shelter it provides. Some, such as the harbors of New York, Tampa, Seattle, and San Francisco (United States), and Sydney (Australia), are naturally sheltered from the open sea by narrow straits and land barriers. Harbors that have open exposures must be protected by engineering works such as breakwaters. On some open coasts, such as Madras (India), building breakwaters has literally created harbors.

In addition to shelter from open water, one of the most

Table 1. *List of world ports registered with the Maritime Information Systems, Inc. and other selected ports and harbors.*

AFRICA

Algeria
Annaba (Ex Bone)
Arzew
Bejaia (Ex Bougie)
Cherchell
Collo
Dellys
Ghazaouet
Mostaganem
Oran
Skikda (Ex Philippeville)
Tenes

Angola
Cabinda
Lobito
Luanda
Namibe
Palanca Terminal
Porto Amboim
Soyo-Quinfuquena Terminal
Sumbe

Brunei Darussalam
Kuala Belait
Lumut
Muara
Seria
Tanjong Salirong

Cape Verde
Mindelo
Porot Grande

Comoros
Dzaoudzi
Moroni
Mutsamudu

Congo
Djeno Terminal
Pointe Noire

Cote D'ivoire (Ivory Cost)
Abidjan
Djibouti

Egypt
Abu Zenima
Adabiya
Ain Sukhna
Damietta
El Dekheila
Geisum Terminal
Hamrawein
Hurghada
Mersa El Hamra
Port Said
Ras Gharib
Ras Shukheir
Safaga
Suez El Suweis
Wadi Feiran

Equatorial Guinea
Bata
Cogo
Luba

Eritrea
Assab
Massawa

Gabon
Cap Lopez
Gamba
Libreville
Lucina
M'bya Terminal
Nyanga
Owendo
Port Gentil

Gambia
Banjul

Ghana
Saltpond
Takoradi
Tema

Guinea
Conakry
Port Kamsar

Guinea-Bissau
Bissau

Kenya
Lamu
Malindi
Mombasa

Liberia
Buchanan
Cape Palmas
Greenville
Monrovia

Libya
Abu Kammash
Bingazi (Benghazi)
Derna
Es Sider
Marsa Brega
Marsa el Hariga
Misurata
Ras Lanuf
Tobruk
Tripoli
Zawia Terminal (Azzawiya)
Zuara

Madagascar
Antsiranana
Fort Dauphin (Toalagnaro)
Majunga (Mahajanga)
Mananjary
Morondava
Port Saint Louis
Tamatave (Toamasina)
Toamasina
Tulear

Mauritania
Nouadhibou
Nouakchott

Morocco
Agadir
Casablanca
Dakhla
El Jadida
Essaouira
Kenitra (Ex Port Lyautey)
Laayoune (Al Aaiun)
Larache
Mohammedia
Safi
Tangier

Mozambique
Beira
Chinde
Inhambane
Macuse
Maputo
Matola
Nacala
Pebane
Pemba
Quelimane

Namibia
Luderitz
Walvis Bay

Nigeria
Antan Terminal
Brass
Burutu
Calabar
Escravos
Forcados
Koko
Lagos
Okrika
Onne
Port Harcourt
Sapele
Tincan/Lagos
Warri

Reunion
Pointe des Galets

Sao Tome and Principe
Santo Antonio
Sao Tome Island

Senegal
Dakar
Lyndiane
M*bao Terminal

Seychelles
Port Victoria

Sierra Leone
Freetown
Pepel

Somalia
Berbera
Kismayu
Merca
Mogadishu

South Africa
Cape Town
Durban
East London
Mossel Bay
Port Elizabeth
Port Nolloth
Richards Bay
Saldanha Bay
Simonstoen

St. Helena
Georgetown
Jamestown

Sudan
Port Sudan

Tanzania
Dar Es Salaam
Kilwa Kivinje
Kilwa Masoko
Lindi
Mtwara
Pangani
Samanga
Tanga
Zanzibar

Togo
Kpeme
Lone

Tunisia
Ashtart Terminal
Bizerte
Gabes
La Goulette Nord (Halque)
La Skhirra
Menzel Bourguiba
Rades/Tunis
Sfax
Sousse
Tunis

Zaire
Ango-Ango
Banana
Boma
Matadi

ASIA

China
Basuo
Beihai
Chiwan
Dalian
Fancheng
Fuzhou
Guangzhou
Haikou
Lianyungang
Mawan
Nantong
Ningbo
Qindao
Qinhuangdao
Quanzhou
Rizhao
Sanya
Shanghai
Shantou
Shanwei
Shekou
Tianjin
Wenshou
Ziamen
Yangpu
Yantian
Yingkou
Zhanjiang
Zhoushan
Zhuhai-Gaolan
Zhuhai-Jiuzhou

Table 1. *Continued.*

Hong Kong
Port of Hong Kong
Hong Kong Shipping Directory

India
Jawaharlal Nehru Port Trust
Mumbai Port Trust
Port of Bombay
Port of Cochin
Port of Madras
Port of Mangalore
Port of Mumbai
Port of Visakhapatnam

Japan
Port of Kobe
Port of Nigata
Port of Osaka
Port of Tokyo
Port of Yokohama

Malaysia
Port of Bintulu
Port of Johor
Port of Klang
Port of Kuantan
Port of Kuching
Port of Malacca
Port of Penang
Port of Rajang
Port of Singapore Authority
Port of Tanjong Berhala

Pakistan
Port of Karachi
Port of Pasni

Phillipines
Asian Terminals, Manila

Australia
American Samoa
Pago Pago

AUSTRALIA
Abbot Point
Albany
Ardrossan
Ballast Head
Ballina
Barrow Island
Bell Bay
Botany Bay
Bowen
Brisbane
Broome
Bunbury
Bundaberg
Burnie
Cairns
Cape Cuvier
Cape Flattery
Carnarvon
Catherine Hill Bay
Coffs Harbour
Cooktown
Dampier
Darwin
Devonport
Eden
Esperance
Exmouth
Fremantle
Geelong
Gladstone
Gove
Haypoint
Port of Hobart
Ipswich
Kingscote
Klein Point
Kurnell
Kwinana
Launceston
Lucinda
Mackay
Maryborough
Melbourne
Milner Bay
Mourilyan
Newcastle
Perth
Port Adelaide
Port Alma
Port Arthur
Port Augusta
Port Bonython
Port Giles
Port Hedland
Port Kembla
Port Latta
Port Lincoln
Port Pirie
Port Stanvac
Port Walcott
Portland
Rapid Bay
Rockhampton
Saladin Marine Terminal
Spring Bay
Stanley
Strahan
Sydney
Thevenard
Thursday Island
Townsville
Trial Bay
Urangan
Useless Loop
Varanus Island
Wallaroo
Weipa
Westernport
Whyalla
Wyndham
Yampi

BENIN
Cotonou
Seme Terminal

FIJI
Labasa
Lautoka
Levuka
Savusavu
Suva

FRENCH POLYNESIA
Bora Bora
Papeete

GUAM
Apra
Guam

INDONESIA
Ampenan, Bali
Arjuna, Java (duplicate)
Balikpapan, Kalimantan
Balongan Terminal
Banjarmasin
Bekapai Terminal
Belawan, Sumatra
Bangkulu, Sumatra
Benoa, Bali
Biak, Irian Jaya
Bima Terminal, Jv
Bima, Sb
Bitung, Sulawesi
Blang Lancang, St
Bontang, Kl
Celukan Bawang, Bl
Cigading, Jv
Cilacap, Java
Cinta, Java
Cirebon, Java
Dabo, Singkep
Dumai, Sumatra
Gilimanuk, Bali
Gorontalo, Sulawesi
Gresik, Java
Gunung Sitoli, St
Jakarta, Java
Jambi, Sumatra
Jayapura, Irian Jaya
Kasim, Ij
Kempo, Sb
Kendari, Sulawesi
Kuala Kapuas, Kl
Kupang, Timor
Lalang Terminal, St
Lawe-Lawe, Kl
Lhokseumawe, St
Malili, Sulawesi
Manado
Manokwari, Irian Jaya
Maumere, Flores
Merak, Java
Muntok, Banka
Nunukan
Palembang, Sumatra
Panarukan, Java
Pangkal Balam, Banka
Pangkalan Susu, Sumatra
Pantoloan, Sv
Penuba
Pladju, Sumatra
Pomala, Sulawesi
Pontianak, Kalimantan
Poso, Sulawesi
Probolinggo, Java
Prointal, Jv
Pulangpisau
Pulau Sambu, Riau
Rengat, Sumatra
Sambas, Kalimantan
Santan Terminal, Kl
Selat Pendjang, Sumatra
Semangka Bay, St
Semarang, Java
Senipah Terminal
Sibolga, Sumatra
Singkawang, Kalimantan
Sorong
Sungai Pakning, Sumatra
Surabaya, Java
Susoh, Sumatra
Tanjung Balai
Tunjung Pandan, Belitung
Tanjung Perak/Surabaya,
Tanjung Pinang, Riau
Tanjung Priok
Tanjung Sekong, Jv
Tanjung Uban, Riau
Tarakan, Kalimantan
Tegal, Java
Teluk, Bajur/Padang, Suma
Ternate, Halmahera
Ujung Pandang, Sulawesi
Waingapu, Sumba

Kiribati
Tarawa

MIDDLE EAST

Iran
Bandar-e Shahpur
Kherg Island

Israel
Port of Haifa
Port of Ashelod

Lebanon
Port of Beirut

Turkey
Port of Antalya
Port of Istanbul
Port of Izmir

MICRONESIA
Pohnpei (Ex Ponape)
Nauru
Nauru Island
New Caledonia
Baie Ugue
Kouaoua
Nepoui
Noumea
Poro
Thio

New Zealand (Aotearoa)
Auckland
Bluff
Dunedin
Gisborne
Greymouth
Lyttelton
Napier
Nelson
New Plymouth
Onehunga (Manukau Harbour)
Opua (Bay of Island)
Otago Harbour
Port Taranaki/New Plymouth
Tarakohe
Tauranga
Timaru
Wanganui
Waverley Harbour
Wellington
Westport
Whangarei

Northern Mariana Islands
Saipan
Papua New Guinea

Table 1. *Continued.*

Aneway Bay
Buka
Daru
Kavieng
Kieta
Kimbe
Lae
Lorengau, Manus Island
Madang
Orobay
Port Moresby
Rabaul
Vanimo
Wewak

Philippines
Anakan/Masao
Aparri, Luzon
Bacolod, Negros
Bais/Dumaguete
Batangas, Luzon
Bislig, Mindanao
Cagayan de Oro, Mindanao
Cebu
Claveria/Aparri
Currimao
Dadiangas, Mindanao
Davao, Mindanao
Dumaguete
General Santos/Dadiangas
Gingoog/Masao
Hondagua/Siain
Iligan, Mindanao
Iloilo, Panay
Isabel
Isabela de Basilan/Basil
Jimenez/Ozamis
Jolo
Jose Panganiban, Luzon
Legaspi, Davao
Limay/Bataan
Manila
Mariveles, Luzon
Masbate
Masinloc/Sual
Mati, Mindanao
Medina/Cagayan De Oro
Nasipit/Masao
Olongapo
Ozamis, Mindanao
Polloc
Puerto Princesa Palawan
Pulupandan
Sabang
San Fernando, Luzon
Santa Anna/Aparri
Siain, Luzon
Subic Bay
Surigao, Mindanao
Tabaco/Legaspi
Tacloban, Leyte
Tanauan/Tacloban
Villanueva
Zamboanga, Mindanao

Samoa
Apia

Solomon Islands
Gizo Is
Honiara, Guadalcanal Is
Noro, New Georgia
Ringi Cove, Kolombangara
Shortland Harbour, Short
Tulagi, Ngella
Viru Harbour
Yandina, Pavuvu Island

Tonga
Neiafu
Nuku*alofa-Tongatapu
Pangai

Tuvalu
Funafuti

Vanuatu
Port Vila
Santo

EUROPE

Cypress
Port of Limassol

Belgium
Port of Antwerp
Ghent
Zeebrugge

Denmark
Port of Aalborg
Port of Aarhus
Port of Copenhagen
Esbjerg
Frederica

Finland
Finnish Ports
Port of Kemi
Port of Kokkola
Port of Kotka
Nowerail, Finland
Port of Oulu
Port of Pietsarsaari
Port of Raahe
Port of Tornio

France
Port of Bordeaux
Port of Brest
Cannes
Marseille
Port of La harve
Toulon

Germany
BLG - Ports of Bremen &
Bremerhaven
Hamburg
Rostock
Wilhelmshaven

Greece
Port of Thessaloniki

Iceland
Arkanes
Bjarney
Dalatangi
Dalvik
Fontur
Grindavik
Grimsey
Hafnarfjorour-Straumsvik
Husavik
Miobakki
Porlakshafn
Reykjavik
Seley
Siglingastofnun Islands
Siglunes

Italy
Port of Genova
Port of Livorno
Port of Savona
Port of La Spezia
Port of Ravenna
Port of Trieste
Venice Port Authority

Latvia
Engure
Lielupe
Liepaja
Mersrags
Pavilosta
Riga
Salacgriva
Skulte
Ventspils

Norway
Port of Bergen
Port of Narvik
Port of Oslo
Port of Stavanger
Port of Trondheim

Portugal
Port of Sines
Port of Setubal

Spain
Port of Barcelona
Port of Carboneras
Port of Cartagena
Port of Santander
Port of Valencia

Sweden
Swedish Ports

Ukraine
Odessa, A Major Black Sea Port

United Kingdom
Associated British Ports
Ayr
Troon
Barrow
Barry
Cardiff
Colchester
Fleetwood
Garston
Goole
Grimsby
Hull
Immingham
King's Lynn
Port of London
Lowestoft
Newport
Plymouth
Silloth
Southampton
Swansea
Port Talbot
Teignmouth
Whitby

NORTH AMERICA

Canada
Port of Bayside
Port of Chatham
Port of Charlottetown
Port of Dalhousie
Halifax Port Corporation
Port of Georgetown
Port of Hamilton
Port of Montreal
Port of Mulgrave
Port of Newcastle
Port of North Sydney
Port of Pictou
Saint John Port Corporation
Port of Summerside
Port of Souris
Port of Sydney
Port of Toronto
Port of Vancouver

United States
Port of Anacortes
Port of Baltimore
Port of Bellingham, WA
Port of Charleston
Georgia Ports Authority
Port of Grays Harbor
Port of Houston Authority
Indiana Port Commission
Port of Kalama
Port of Los Angeles
Port of Mobile
North Carolina State Ports Authority
Port of Oakland
Port of Philadelphia and Camden
Port of Pittsburgh Commission
Port of Port Arthur
The Saint Paul Port Authority
Port of San Diego
Port of Seattle
Port of Tacoma

SOUTH AMERICA

Argentina
Bahia Blanca
Buenos Aires
Caleta Cordoba
Caleta Olivia
Campana
Comodoro Rivadavia
Concepcion del Uruguay
Diamante
Ibicuy
La Plata
Mar Del Plata
Necochea
Punta Colorada
Punta Quilla
Quequen
Ramallo
Rio Gallegos
Rio Grande
Rosario
San Antonio Este
San Julian
San Lorenzo
San Nicolas De Los Arroy
San Pedro
San Sebastian
Santa Cruz

Table 1. *Continued.*

Santa Fe
Ushuaia
Villa Constitucion
Zarate

Belize
Belize City

Brazil
Angra Dos Reis
Antonina
Aracaju
Aratu
Areia Branca
Belem
Cabedelo
Corumba
Fortaleza
Gebig
Ilheus
Imbituba
Port of Itajai
Itaqui
Macau
Maceio
Manaus
Munguba
Natal
Niteroi
Paranagua
Pelotas
Ponta do Ubu
Porto Alegre
Portocel
Recife
Rio De Janeiro
Rio Grande
Salvador
Santana
Santos
Sao Francisco do Sul
Sao Sebastiao
Sepetiba, Bahia De
Suape
Tramandai
Tubarao
Vitoria

Chile
Antofagasta
Arica
Barquito
Cabo Negro
Caldera
Caleta Parillos
Castro
Chanaral
Coronel
Corral
Guayacan
Huasco
Iquique
Isla Guarello
Lirquen
Lota
Mejillones
Patillos
Puerto Montt
Puerto Natales
Puerto Percy
Punta Arenas
Quemchi
Quintero
San Antonio
San Vicente
Talcahuano
Taltal
Tocopilla
Tome
Valdivia
Valparaiso
Victoria

Colombia
Port of Barranquilla
Port of Buenaventura
Port of Cartagena
Port of Pozos Colorados
Puerto Bolivar
Port of Tumaco
Port of Turbo

Ecuador
Bahia De Caraques
Balao
Esmeraldas
Guayaquil
La Libertad
Manta
Puerto Bolivar
San Lorenzo

French Guiana
Cayenne

Guyana
Georgetown
New Amsterdam

Mexico
Acapulco
Das Bocas
Fontera
Las Cardenas
Manzaanillo
Matamoros
Mazatlan
Santa Cruz
Veracruz

Peru
Ancon
Atico
Cabo Blanco
Callao
Chancay
Chimbote
Eten
General San Martin
Huacho
Huarmey
Ilo
Iquitos
La Pampilla
Lobitos
Matarani
Pacasmayo
Paita
Paramonga
Pimentel
Salaverry
San Juan
San Nicolas
Supe
Talara

Uruguay
Port of Buceo
Port of Colonia
Port of Fray Bentos
Port of Fray Bentos
Jose Ignacio Terminal
Port of La Paloma
Port of Montevideo
Port of Nueva Palmira
Port of Paysandu
Port of Piriapolis
Port of Punta del Este
Port of Salto
Port Sauce (Juan Lacaze)
Port of Jose Ignacio (Terminal del Este)

Venezuela
Araya
Bachaquero/Maracaibo L
Bajo Grande/Maracaibo L
Cabimas/Maracaibo L
Caripito
Carupano
Chichiriviche
Ciudad Bolivar
Cumana
Cumarebo
El Guamache
El Palito
Guiria
La Ceiba/Maracaibo L
La Estacada
La Guaira
La Salina/Maracaibo L
Las Piedras
Maracaibo
Matanzas
Palua
Paradero
Pertigalete
Puerto Cabello
Puerto De Hierro
Puerto La Cruz
Puerto Sucre
Punta Camacho
Punta Cardon
Punta Cuchillo
Punta de Palmas
Punta de Piedra
San Felix

Sources: Marine Information Systems, Inc. (URL at mglobal.com.) [MIS, 69 Franklin Street, Bristol, RI 02809, USA], The Seaports Infopage (seaportsinfo.com), and Ports and Port Authorities (access.digex.net/rjeffrey/ports.htm); Lloyd's Register of Shipping, 1998. *Maritime Guide 1998.* London (100 Leadenhall Street, London EC3A 3BP): Lloyd's Register, v.p.; and Per Bruun, personal communication.

important physical parameters in a modern port is the water depth in the approach channel, turning basin, holding ground, and berthing areas. The size of modern ships requires that large, major harbors have designated minimum depths in excess of 20–30 m (see subsequent comments). Because few natural harbors have such depths, periodic dredging is needed. In order to provide for safe navigation, many harbor channels or entrances are stabilized by jetties (Morgan, 1988).

The construction of ports and sea works offers some of the most unusual problems and challenges in civil engineering. As Nature's most dynamic, variable, and powerful element, the marine environment provides the engineer with an adversary that discovers any weakness or fault in the structure. It is assumed that there is some degree of correlation between the size of a port and the extent of coastal modification. The eight types of harbor (based on the WPI classification) give some idea of the extent of coastal modification that has occurred: (1) coastal natural (CN), (2) open roadstead (OR), (3) river natural (RN), (4) river basin (RB), (5) canal or lake (LC), (6) river tide gate (R), (7) coastal breakwater (CB), and (8) coastal tide gate (CT). Protection of the port and its navigational entrance with engineering structures or sea works (see, for example, Thorn and Roberts, 1981; Pilarczyk, 1990),

Table 2. *Total waterborne commerce, 1996–1997, in terms of ton-miles, short tons, and average haul by type of traffic.*

Year	Grand Total	Foreign Total	Foreign Great Lakes Ports	Foreign Coastal Ports	Domestic Total	Coastwise	Lakewise	Internal	Intraport
Ton-Miles* (millions)**									
1977	692,527.4	93,527.4	*37,734.3	**55,793.1	599,000.0	343,536.6	52,416.9	201,784.2	1,262.3
1978	928,297.7	101,034.4	*42,108.8	**58,925.6	827,263.3	540,373.2	76,284.0	209,266.2	1,339.8
1979	931,846.4	103,086.9	*43,146.4	**59,940.5	828,759.5	532,290.3	77,968.8	217,090.2	1,410.2
1980	1,016,085.2	94,249.4	*33,679.6	**60,569.8	921,835.8	631,149.2	61,747.1	227,343.0	1,596.4
1981	1,023,636.5	94,223.1	*35,294.0	**58,929.2	929,413.4	634,765.3	62,148.4	231,184.1	1,315.6
1982	964,896.9	78,428.2	*27,165.5	**51,262.7	886,468.7	632,707.1	35,623.3	217,026.7	1,111.7
1983	989,161.6	69,596.0	*24,309.4	**45,286.7	919,565.6	649,749.5	43,088.2	225,628.3	1,099.7
1984	966,478.2	78,758.2	*32,249.4	**46,508.8	887,720.0	593,923.1	49,784.4	242,855.4	1,157.1
1985	964,911.2	71,941.2	*27,171.8	**44,769.4	892,970.0	610,976.5	48,184.0	232,707.5	1,102.0
1986	944,910.5	71,509.4	*24,235.3	**47,274.2	873,401.0	580,888.7	43,198.2	248,116.9	1,197.3
1987	968,403.7	72,988.2	*22,003.3	**50,985.0	895,415.5	586,818.4	50,076.7	257,336.4	1,183.9
1988	970,685.0	80,656.6	*24,448.4	**56,208.2	890,028.4	561,594.9	58,159.5	269,035.7	1,238.4
1989	911,232.2	95,682.3	*27,118.9	**68,563.4	815,549.9	483,888.6	58,307.6	272,157.4	1,196.3
1990	+932,151.4	+98,607.6	*24,330.8	**+74,276.9	833,543.8	479,133.6	60,929.9	292,393.3	1,087.0
1991	+938,671.3	+90,272.3	*17,102.6	**+73,169.7	848,399.0	502,133.0	55,339.1	289,959.0	968.0
1992	+949,344.7	+92,660.1	*21,027.6	**+71,632.5	856,684.6	502,311.0	55,784.6	297,638.7	950.3
1993	+882,605.8	+92,947.9	*26,106.8	**+66,841.1	789,657.9	448,404.2	56,438.1	283,893.6	921.9
1994	909,405.0	94,485.8	*28,299.6	**66,186.2	814,919.2	457,600.7	58,263.4	297,762.4	1,292.7
1995	914,362.5	106,634.9	*31,656.5	**74,978.4	807,727.7	440,345.1	59,703.8	306,329.1	1,349.6
1996	**870,193.4**	**105,506.9**	***34,259.9**	****71,247.0**	**764,686.5**	**408,086.1**	**58,335.3**	**296,790.6**	**1,474.5**
Tons* (millions)**									
1977	1,904.6	935.3	69.2	866.1	969.3	248.1	109.1	528.7	83.4
1978	2,018.1	946.1	70.6	875.5	1,072.0	305.3	142.7	534.5	89.5
1979	2,069.8	993.4	73.8	919.7	1,076.3	304.7	143.6	535.0	93.1
1980	1,995.3	921.4	60.6	860.8	1,073.9	329.6	115.1	535.0	94.2
1981	1,938.4	887.1	63.2	823.9	1,051.3	322.0	115.4	520.7	93.2
1982	1,773.9	819.7	50.4	769.3	954.2	311.1	72.1	495.5	75.6
1983	1,704.5	751.1	48.4	702.7	953.4	309.6	83.4	487.1	73.1
1984	1,832.6	803.3	58.8	744.6	1,029.3	307.7	98.0	542.5	81.1
1985	1,785.0	774.3	51.3	723.0	1,010.7	309.8	92.0	534.7	74.3
1986	1,870.5	837.2	45.8	791.4	1,033.2	308.0	87.4	560.5	77.4
1987	1,962.8	891.0	45.9	845.1	1,071.8	323.5	96.5	569.8	82.0
1988	2,082.9	976.2	52.5	923.7	1,106.6	325.2	109.7	588.1	83.7
1989	2,135.2	1,037.9	54.8	983.1	1,097.3	302.0	109.1	606.0	80.2
1990	2,159.3	1,041.6	50.5	991.1	1,117.8	298.6	110.2	622.5	86.4
1991	2,087.6	1,013.6	41.8	971.8	1,074.0	294.5	103.4	600.4	75.6
1992	2,127.9	1,037.5	45.5	992.0	1,090.4	285.1	107.4	621.0	76.8
1993	2,123.3	1,060.0	43.6	1,016.4	1,063.2	271.7	109.8	607.3	74.4
1994	2,208.8	1,115.7	50.1	1,065.6	1,093.1	277.0	114.8	618.4	82.9
1995	2,233.5	1,147.4	51.9	1,095.5	1,086.2	266.6	116.1	620.3	83.1
1996	**2,276.7**	**1,183.4**	**56.4**	**1,127.0**	**1,093.4**	**267.4**	**114.9**	**++622.1**	**++89.0**

* Based on distance transported on Great Lakes and St. Lawrence River to International Boundary at St. Regis, Quebec, Canada.
** Based on distance transported on United States Waterways from entrance channels to ports and waterways.
*** Excludes intraterritory traffic for which ton-miles were not compiled.
† An error in the routing network caused the coastal port foreign-ton-mile totals to be slightly inflated for calendar years 1990–1993. The corrections are reflected in these revised totals. Ton-miles for individuals ports were not affected.
†† Beginning in 1996, fish were excluded.
Source: COE, 1997. Waterborne Commerce in the United States, Calendar Year 1996. Part 5—Waterways and Harbors: National Summaries. New Orleans, Louisiana: U.S. Army Corps of Engineers.

Table 3. *U.S. Waterborne foreign commerce—1994. U.S. port rankings by cargo value. (in Millions of Dollars—000s Omitted)*

Rank	Port	Imports	Exports	Totals
1	Los Angeles	$58,181	$15,252	$73,433
2	Long Beach	$55,720	$15,157	$70,877
3	New York/New Jersey	$44,685	$17,846	$62,531
4	Seattle	$27,398	$ 8,837	$46,315
5	Oakland	$18,180	$10,835	$29,015
6	Houston	$12,881	$15,114	$27,995
7	Hampton Roads	$10,262	$12,644	$22,902
8	Tacoma	$17,310	$ 3,541	$20,851
9	Baltimore	$11,608	$ 7,735	$19,343
10	Miami	$11,604	$ 8,072	$18,676
11	Charleston	$10,325	$ 7,952	$18,277
12	New Orleans	$ 7,473	$ 6,639	$14,112
13	Savannah	$ 6,371	$ 5,549	$11,280
14	South Louisiana	$ 2,495	$ 7,479	$ 9,974
15	Portland (OR)	$ 5,055	$ 4,897	$ 9,952
16	Jacksonville	$ 6,476	$ 2,938	$ 9,414
17	Port Everglades	$ 4,427	$ 2,936	$ 7,183
18	Philadelphia	$ 5,274	$ 1,134	$ 6,408
19	Baton Rouge	$ 3,182	$ 1,789	$ 4,971
20	Wilmington (NC)	$ 1,223	$ 3,079	$ 4,302
21	Corpus Christi	$ 3,236	$ 1,014	$ 4,250
22	Port Arthur	$ 3,449	$ 601	$ 4,050
23	Boston	$ 3,311	$ 678	$ 3,989
24	Detroit	$ 3,818	$ 144	$ 3,962
25	Wilmington (DE)	$ 2,230	$ 1,318	$ 3,548

Source: U.S. Bureau of the Census U.S. Waterborne Exports & General Imports (TA-94-ANN) Annual, pp. 409, 17–22.
NOTE: Rankings are based on waterborne foreign commerce and do not include cargo moved domestically between U.S. ports.

which is required under most circumstances, interrupts the dynamic fluctuations of natural systems associated with rivers, estuaries, and shores. Navigational entrances stabilized by jetties, for example, have pronounced and deleterious impacts on downcoast shores where sediments erode away and shorelines retreat landward (see discussion of coastal impacts associated with littoral drift barriers in Bruun, 1995). The impacts of such sea works in Florida, for example, are notable because stabilized inlets are estimated to be responsible for interrupting the natural littoral drift cycle and for causing shoreline retreat. Recent studies by Finkl and Esteves (1998) and Esteves and Finkl (1998) indicate that 72% of the overall shoreline retreat in twenty-five Florida coastal counties can be attributed to stabilized inlets. The problem is particularly severe on the lower southeast coast of the state (Palm Beach, Broward, and Dade counties) where up to 90% of eroded beach length is due to jetted inlets. These estimates of a nexus between stabilized inlets and the beach erosion problem approximate Dean's (1990) proposal for 80–85% inlet culpability. Whatever the value of the shore-erosion impact estimate, which fluctuates by location (*viz.* the actual value is site-specific), it is now clear that construction in and around ports and harbors has major, usually deleterious, impacts on coastal environments.

In the past, coastal and port engineering were typically regarded as separate disciplines but it is now becoming more evident that the two areas of study, although distinct in their own right, are more closely related than previously recognized. Indeed, engineering efforts in one area (*e.g.* port and harbor development) may affect endeavors in another specialization (*e.g.* coastal stabilization), and visa verse. Because of this close association between coastal and port engineering, the geographical location of ports and harbors along the coast, and increased concern among coastal managers for maintaining the integrity of coastal-marine environments as part of our global heritage, the *Journal of Coastal Research* (JCR) will make a concerted effort to encourage contributions that consider interactions between coastal systems and ports. We interpret the term "port" (and harbor *inter alia*) in the broadest sense to include approach channels, offshore anchorage and staging areas, sea defenses and other protective works, and associated infrastructure including transportation and energy supply routes, *etc.* This is not a new direction for the JCR but rather a slight adjustment that refocuses on a problem that we recognized when the journal was started more than fifteen years ago. Since the inception of the overriding philosophy for the JCR, coastal management has matured to the point where governmental agencies and NGOs (non-governmental organizations) actively promote the concept of "coastal care" in a vein similar to the ethics of "land care" (*e.g.* Duff, 1989) as developed and deployed in Australia (*e.g.* Miller and Mumford, 1989), New Zealand, and the United Kingdom. This movement or philosophical approach to integrated coastal management (see discussions related to coastal management strategies in Clark, 1996) is relatively new to the Americas but we anticipate that it will become an evermore important thrust as the majority of the world's population becomes "coastal" by virtue of its geographical location on the shores of oceans, seas, and great lakes.

Today, nine in ten of the world's largest cities are located in the coastal zone. Further, of the world's largest 50 cities, 33 are located coastally. By the year 2025 AD, it's estimated that the coastal zone will contain more than 3 billion people (*cf* previous discussion in Finkl, 1998). That's two billion more people than today who will be living in the coastal zone! Environmental problems such as pollution, waste disposal, water supply, land subsidence, erosion-sedimentation, saltwater intrusion, and increased vulnerability to coastal storms and flooding (for a review of the standard suits of coastal hazards, see chapters in Finkl, 1994) will increase as population becomes greater.

Last, but not least, ports serving most of those coastal cities will have to increase their infrastructure to keep up with demand for imports and exports. Port development, shore protection and coastal conservation are not only important but crucially interrelated management issues that will require increasingly more focused attention in future. Because the issues are complex, perceptions are often prejudiced, and because the subject matters of engineering, management, economic, and political disciplines are not closely intertwined, creative solutions must be sought to the multifaceted problems of the coastal zone. Many of these problems deal with aspects of port management, ship and port operations, multimode transportation in ports, environmental quality in ports, multiuse ports including tourism, marinas and port financial and legal issues, information systems for ports and shipping, multimedia and other advanced training techniques, systems of loading and unloading, man-machine in-

Table 4. *Channel depths for selected ports and harbors of the Americas.*

Port Name, Authority, or Navigation District	Location	Depth (m)[1]
PORTS AND HARBORS OF THE UNITED STATES OF AMERICA (USA)		
Alabama State Docks Department	Mobile, Alabama	15.0
Albany Port District Commission	Albany, New York	10.5
Port of Beaumont, Navigation District of Jefferson County	Beaumont, Texas	13.1
Port of Bellingham	Bellingham, Washington	9.8
Port of Brownsville, Brownsville Navigation District	Brownsville, Texas	13.8
Cleveland-Cuyahoga County Port Authority	Cleveland, Ohio	8.8
Port of Corpus Christi Authority	Corpus Christi, Texas	14.8
Seaway Port Authority of Duluth	Duluth, Minnesota	8.9
Port of Everett	Everett, Washington	13.1
Port of Freeport, Brazos River harbor Navigation District	Freeport, Texas	14.8
Port of Galveston	Galveston, Texas	13.1
Georgia Ports Authority	Savannah, Georgia	13.8
Port of Grays harbor	Aberdeen, Washington	11.8
Port Authority of Guam	Piti, Guam[2]	36.7
Hawaii Department of Transportation	Honolulu, Hawaii[2]	14.8
Port of Houston Authority	Houston, Texas	11.8
Port of Hueneme/Oxnard Harbor District	Port Hueneme, California	11.5
Humboldt Bay Harbor	Eureka, California	11.5
Port of Kalama	Kalama, Washington	13.1
Lake Charles harbor & Terminal District	Lake Charles, Louisiana	13.1
Port of Long Beach	Long Beach, California	24.9
Port of Longview	Longview, Washington	13.1
Port of Los Angeles—Worldport LA	San Pedro, California	14.8
Port Manatee/Tampa Bay	Palmetto, Florida	13.1
Maryland Port Administration	Baltimore, Maryland	16.4
Massachusetts Port Authority	Boston, Massachusetts	13.1
Port of Miami	Miami, Florida	13.8
Port of Milwaukee	Milwaukee, Wisconsin	8.5
Port of New Orleans	New Orleans, Louisiana	11.8
Port Authority of New York & New Jersey	New York, New York	14.8
North Carolina State Ports Authority	Wilmington, North Carolina	13.1
Port of Olympia	Olympia, Washington	9.8
Port of Palm Beach District	Riviera Beach, Florida	10.8
Port of Pascagoula	Pascagoula, Mississippi	12.5
Port of Pensacola	Pensacola, Florida	10.8
Port of Philadelphia & Camden	Philadelphia, Pennsylvania	13.1
Plaquemines Port, Harbor & Terminal District	Braithwaite, Louisiana	18.0
Port of Lavaca—Point Comfort Calhoun County Navigation District	Point Comfort, Texas	11.8
Port of Ponce	Ponce, Puerto Rico[3]	16.4
Port of Port Arthur Navigation District	Port Aurthor, Texas	13.1
Port Everglades	Fort Lauderdale, Florida	15.4
Port of Portland	Portland, Oregon	13.1
Port of Redwood City	Redwood City, California	10.5
Rhode Island Economic Development Corporation	North Kingston, Rhode Island	11.5
Port of Richmond	Richmond, California	11.5
Sacramento-Yolo Port District	Sacramento, California	9.8
San Diego Unified Port District	San Diego, California	13.5
Port of San Francisco	San Francisco, California	16.8
Port of Seattle	Seattle, Washington[4]	278
Port of South Louisiana	LaPlace, Louisiana	14.8
Port of Stockton	Stockton, California	11.5
Port of Tacoma	Tacoma, Washington	12.2
Port of Vancouver, USA	Vancouver, Washington	13.1
Virginia Port Authority	Norfolk, Virginia	16.4
Port of Wilmington	Wilmington, Delaware	12.5
Average Depth USA[2]		13.5
Average Depth for Great Lakes		8.7
Average Depth for East Coast		13.6
Average Depth for Gulf Coast		13.5
Average Depth for Pacific Coast		14.1

Table 4. *Continued.*

Port Name, Authority, or Navigation District	Location	Depth (m)[1]
CANADIAN PORTS AND HARBORS		
Montreal Port Corporation	Montreal, Quebec	11.0
North Fraser Harbour Commission	Richmond, British Columbia	8.8
Port Alberni Harbour Commission	Port Alberni, British Columbia	19.7
Port of Quebec Corporation	Quebec, Quebec	15.5
Saint John Port Corporation	Saint John, New Brunswick	9.2
Prince Rupert Port Commission	Prince Rupert, British Columbia[5]	35
Port of Sept-Iles	Sept-Iles, Quebec[5]	100
Thunder Bay Harbour Commission	Thunder Bay, Ontario	8.9
Toronto Harbour Commissioners (Port of Toronto)	Toronto, Ontario	8.8
Windsor Harbour Commission	Windsor, Ontario	8.5
Average Depth for Canadian Ports		11.3
CARIBBEAN PORTS AND HARBORS		
Aruba Ports Authority N.V.	Oranjestad, Aruba	12.5
Bahamas—Freeport Harbour Company	Freeport, Grand Bahama	15.4
Bahamas—Nassau Port Authority	Nassau, New Providence	12.7
Barbados Port Authority	Bridgetown, Barbados	9.6
British Virgin Islands Port Authority	Tortola, BVI	13.1
Port Authority of the Cayman Islands	Grand Cayman, Cayman Islands[6]	Open Roadsted
Curacao Port Authority	Werfe de Wilde, Curaco	13.1
St. Lucia Air & Sea Ports Authority	Castries, St. Lucia	12.9
Average Depth for Caribbean Ports		12.8
LATIN AMERICAN PORTS AND HARBOURS		
Sociedad Portuaria Regional de Barranquilla	Barranquilla, Colombia	11.5
Junta de Admisistracion Portuaria y de Desarrollo Economico de la Vertiente Atlantica (JAPDEVA)	Puerto Limon, Costa Rica	14.0
Empresa Nacional Portuaria	Puerto Cortes, Honduras	12.0
Admisistracion Portuaria Integral de Tampico	Tampico, Mexico	11.0
Administracion Portuaria Integral de Veracruz	Veracruz, Mexico	13.1
Autoridad Portuaria Nacional	Panama, Panama	13.1
Administracion Nacional de Puertos	Montevideo, Uruguay	10.0
Instituto Puerto Autonomo de Puerto cabello	Puerto Cabello, Venezuela	14.4
Average Depth of Latin American Ports		12.4
Average Depth for Ports of the Americas[456]		12.5

[1] Minimum main channel depth.
[2] Included with U.S. Pacific west coast ports and harbors.
[3] Included with U.S. east coast ports and harbors.
[4] The very deep natural depth of Puget Sound is excluded from calculations of main channel depth.
[5] Very deep-water depths in Canadian approaches are excluded from calculations of main channel depth.
[6] Very deep-water depths in Caribbean approaches are excluded from calculations of main channel depth.
Source: AAPA, 1997. *Seaports of the Americas: 1996 AAPA Directory.* Alexandria, Virginia: American Association of Port Authorities, 134p.
Notes: Information has been adapted from AAPA (1997) and most channel depths were converted from Customary units to metric equivalents. Conversions were rounded off to the nearest tenth of a meter. Some channel depths were reported directly in metric units, mostly to one decimal place. Some ports and harbors were not included in this summary table because information relating to channel depths was not given in the AAPA (1997).

terfaces, standardization, ergonomics in shipping, marine engineering works, maintenance problems, construction of ports, and systems and structural reliability, *etc.* (see, for example, appropriate entries in Bruun, 1989; Clark, 1996; Herbich, 1991; and Guedes Soares, 1998).

Due to increasing coastal populations and trade, maritime works and ports are experiencing rapid changes. Waterborne foreign commerce for the top twenty-five U.S. ports averaged more than half a billion dollars (Table 3) in 1994. Some authorities predict that U.S. ports will continue growing at a rate of 6% to 10% per year into the near foreseeable future. Already U.S. port authorities are scrounging for space because in the last several years port activity has increased. The port authorities of Long Beach and Los Angeles, California, for example, are undergoing major expansions with capital outlays exceeding $1.9 billion between 1997 and 2001, according to the U.S. Maritime Administration (*Civil Engineering,* 68(5), 10–11). The search for expansion space on land is alleviated somewhat because the federal government's military base realignment and closure process has left some key port property vacant. Port Hueneme, California, for example, was literally surrounded by the Naval Civil Engineering Laboratory and the port could not expand until the lab was closed and the property transferred to the port. When other options are unavailable, ports expand into the existing waterways using fill for substrate (*e.g.* Singapore, Hong Kong). In October 1997 the port of Los Angeles (California) started building the $300 million, 585-acre Pier 400 from dredged and other fill material. The project will be completed in 1999.

Not only are ports looking for more space on land, but they are also deepening their channels to accommodate larger ships that require at least 13–17 m operating depths. Figures in Table 4 show that average control depths (about 13 m) for U.S. east-, Gulf-, and west-coast ports are marginal. Many Canadian, Caribbean, and Latin American ports also require dredging to achieve deeper channel depths. The situation is somewhat better in Europe, but only for the major ports. Main channel depths in some important British ports are, for example, about 10 m or less, *viz.* the Port of Plymouth (8.5 m) and the Port of Hull (10.4 m). European examples of some deeper navigational entrances include, but are not limited to: the ports of Amsterdam (12 m), Rotterdam (15 m), and Europort (18–20 m) (The Netherlands); Port of Southampton (15 m) (Great Britain); Port of Santander (12 m) (Spain), and Porto de Sines (18 m) (Portugal). Entrances to many Asian ports are also deeper than 10 m, *viz.* Japanese ports of Kobe (16 m), Nigata (14 m), Osaka (12 m), and Yokohama (16 m) and some in India (*e.g.* ports of Bombay, 12 m; Cochin, 12 m; Madras, 15 m; Paradup, 14 m; Mangalore, 12 m) or Pakistan (*e.g.* Karachi, 12 m). Most harbors and approaches are charted to a controlling depth that indicates the shallowest areas that may be encountered. The need for deeper ports in the U.S. is being driven by the increasing size of ships in the world fleet, both liners and bulk carriers. Many ports now need to accommodate vessels with greater drafts. Tankers for crude oil have reached close to 0.6 million dwt (dead weight tons). Ore carriers of almost 0.4 million dwt have been built. In the bulk trades these larger vessels are common and require channel depths up to 16.5 m or more. The largest container vessels, which can attain speeds up to 34 knots, are now 60,000 to 80,000 dwt with space to hold about 6,000 TEUs (20-ft equivalent units, *i.e.* containers). When fully loaded, these container ships may require a channel depth of 13 m or more. Increased channel depth is crucial to improved facilities at modern ports but is potentially detrimental to coastal environments. But, for many ports, sediment disposal is a problem where dredged material is contaminated.

Thus, there must exist a synergism between the two disciplines if coastal management issues are to be resolved. Because deeper channels will inevitably interrupt the natural littoral drift of nearshore sediments, ports must become actively engaged in sand bypasing so that downdrift shores do not become sand starved. Traditional and innovative methods can be deployed to mechanically move sediments from the updrift (accumulation) side of the inlet to downdrift (erosion) side. With new equipment entering the market (*viz.* hydraulic pipeline dredges, hopper dredges, punaise pump, Kit Kat, Crawl Kat, water injection dredge, jet pumps for fluidization, and shallow water over-the-bow pumper dredges, *etc.*) there is potential for increased dredging in shallow zones, environmentally sensitive areas, or in high-traffic lanes where surface dredging would interrupt shipping schedules. The problems are much more complicated than these samples suggest and it is hoped that coastal and port engineers will follow the call by the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro for action to be taken on integrated coastal zone management (ICZM). Strategies for implementation of ICZM were explored at the 1993 World Coastal Conference (held in The Netherlands) and it is now hoped by many that there will be international cooperation that will foster international coordination and development of common concepts and techniques. Also in 1993, the European Union for Coastal Conservation (EUCC) developed the concept of a European Coastal Code: a strategic framework for pan-European coastal management and conservation. Most coastal countries outside of The Netherlands lack a national coastal plan and it behooves maritime nations like the United States and Canada to initiate national and pan-American plans that will codify conservation and protection of coastal environments in and around ports and harbors, among other areas. Such efforts are desperately needed along developed stretches of coast and must be integrated now, before it is too late, within port and harbor development plans. Port and coastal engineers not only need to coordinate their efforts amongst themselves but also with environmentalists and coastal planners and managers. Hopefully, such concerted efforts, coordination and cooperation will reach new levels that will safeguard coastal resources and conserve natural environments in tidal areas, dune lands, nearshore zones, and along the shore in general. The challenge is there and we at the JCR hope to see more ports and harbors launch environmental research into water systems.

The liaison between coastal and port engineering will be our yardarm from which we encourage submission of collaborative papers that bridge the gap between disparate disciplines that attempt to meet the challenge of best management practices in the coastal zone via sound engineering. The alliance between coastal and port engineering will, no doubt, initially be achieved in civil engineering departments at colleges, universities, and technical schools. Complete or universal solutions, as opposed to ones that are tied to engineering doctrine alone, must perforce involve other specialists in the biological and geological sciences, socio-economic fields, and planning and management arenas. These new alliances of the future will be used to solve coastal environmental problems incurred by societal demands for increased trade and transportation to and from ports and harbors of the world.

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