Samenvatting - H 1 - 10

Coastal Dynamics I (Technische Universiteit Delft)

Coastal Dynamics I

Chapter1:

Soft measures: beach nourishments; land reclamation; maintenance dredging
Hard measures: seawall/revetment (permeable), Groyne, Jetty, Breakwater
Tidal inlet: Tide prevents inlet from closing
Obliquely approaching waves: non-zero angle between wave crests and depth contours
Shelf break; overgang naar echt diep water (100-200m depth)
Shoreface: part of sandy profile affected by waves

- Shoalzone: waves gain amplitude until they break
- Breaker/surfzone: waves break

Coastal morphodynamics (positive/negative): mutual adjustment of morphology and hydrodynamic processes involving sediment transport
Regression (of sea): advance of coast
Transgression (of sea): retreat of coast

Chapter 2:

Surge level higher for **wide shelves**; wave energy lower (lot of damping due to bottom friction); higher tidal amplitude
African coast: Less sediments provide due to absence of real mountains due to fact that Africa is in middle of crustal
Eustatic change: absolute sea level change (movement of mean sea level w.r.t. land)
Isostatic deformation: deformation of earths crust due to Eustatic sea-level changes

- Glacio-isostasy: due to ice
- Hydro- isostasy:

Continental sediments: originating from rock
Carbonate sediments: formed of calcium carbonate from shells/remains of marine life
Mud: fluid-sediment mixture of (salt), water, silt, clay and organic materials (created via chemical weathering.)
Ratio mud/sand: increases for more chemical weathering which is for higher temperatures and humidity
Reef: needs enough sunlight and warm water
Fringing reef: reef bordering the coast
Barrier reef: reef positioned offshore closing of a lagoon
Atoll reef: reef encircling a lagoon
Salt Marshes: found at moderate climates
Mangroves: found in (sub)tropical regions
Formation of Delta: depends on the relative influence of river(&provided sediment), waves and tide
Ria: drowned river
Elongated sand bars: typical for tide dominated system

Chapter3:

Wave steepness: ratio of H/L

Period wind generated gravity waves: 0.25s – 30s (Gravity is restoring force)

'sea': relatively short (order 10s) random & irregular oscillations of surface generated by local wave fields

'swell': sea that travelled for a while and has transformed due to frequency dispersion and damping

Capillary waves: small ripples (0.25s) that die out due to surface tension

Infra gravity waves: longer gravity waves (5min); merely shallow water phenomenon

Wave record stationary: short enough to be statistically stationary, long enough to get reliable averages (15-30min used, 20min most common)

Short term statistics wave record: 1. Via wave-by-wave analysis. 2. Spectral analysis

Root-mean-square wave height: wave energy measure (since wave energy is related to H^2)

Smallest frequency (longest wave) that can be determined: $f_{min}=1/T_r$ (restricted by record length)

Highest frequency: f_{max}=1/2deltat (from sampling interval)

Standard deviation can be estimated via area under variance density spectrum

Phase: in not too steep waves and deep water independent of each other and uniform distributed

Spectral peak: indicates point in the spectrum where most energy occurs

Waves at area of generation: relatively steep and short-crested

White-capping: steepness induced wave breaking (H/L>0.14)

JONSWAP: characteristic for developing wind sea in oceanic waters

Pierson-Moskowitz: fully developed sea

Phase velocity(=propagation velocity=wave celerity): rate at which any phase of the wave (for instance a crest) propagates in space

Shallow water for: kh<0.31 or h/L<1/20

Group speed: is speed at which energy of waves move

Phase velocity > group speed in deep water; same for shallow

Groupiness: caused by interference of waves with different wave length

Dissipation processe(white capping&currents): more effects on shorter waves

Period of **decades** conditions may **not be stationary** (due to for instance climate change)

Gravitational acceleration: varies due to varying distances and angles to the centre of the attracting mass

Centripetal acceleration: everywhere parallel to line connecting gravitational centers

Differential pull/tide generating force: difference between gravitational pull on ocean water masses that are located at different distances from the sun and the moon

- **Normal components:** small w.r.t. earth's own gravitational attraction
- **Tangentianal/horizontal:** same order as normal components but perpendicular to earth's gravity field and therefore cannot be neglected

Horizontal component: shifts water to side of earth facing sun(moon) and opposite side in tidal bulges (pilling up of water = balanced by **pressure gradients)**

Solar tide: 12 hours (1/2 of **solar day)**

Lunar tide: 12h25min (1/2 of **lunar day)**

Sidereal day: time needed for earth to rotate around own axis (=23h56min)

Sidereal month: 27.3 days (moon's revolution around earth)

Lunar month: 29.5 days

Spring tide: sun, earth and moon in one line

Neap tide: lunar and solar tide 90 degrees out of phase
Daily inequality: highs/lows on 1 day are not equal

- caused by earths (time-varying) declination
- zero at equator; increases with latitude
- at high latitude only on high and low
- period of one year

Spring/neap tide variation: result of linear summation of M2 and S2 having a slightly different period
Tidal wave: long wave; small amplitude (order 1m)
Propagation of tide:

- influenced by friction and resonance which are set by shapes and depths of ocean basins
- Influenced by Coriolis

Amphidromic system: rotary system under influence of Coriolis and 'blocking' by land masses
Amphidromic point: node; place where amplitude of vertical tide is zero
Co-tidal lines/co-phase lines: lines of simultaneous HW
Co-range lines: lines connecting points with same tidal range
Geostrophic balance: balance between Coriolis and pressure gradient

Chapter 4:

Incoming radiation: strongly dependent on latitude (also seasonal effect)

- Net gain at equator
- Net loss of heat at poles
- Balance at approximately 37 degree N & S
- Unequally distribution causes heat(advection) transport (wind 60% & ocean currents 40%)

Inter Tropical Convergence Zone: band of low air pressure around equator (eerste cel vanaf evenaar; over opp naar equator in atmosfeer van equator af)
Doldrums: prevailing winds near equator
Tropical storms:

- Hurricanes: Near Americas
- Cyclones: Near India & Africa
- Typhoons: near SE-Asia and Australia

Wind in (sub)Tropical area:

- Some are governed by trade winds
- Others by seasonally reversing **Monsoons (**result of larger amplitude of the seasonal cycle of land temperature compared to that of nearby oceans)

Zonal winds:

- Polar easterlies high latitudes (>70)
- Strong westerlies at mid-latitudes (30-70)
- Extensive but moderate trade winds in sub tropics (10-30)
- Quieter Doldrums aroud equator (10N-10S)

Regional and local effects:

- Monsoons
- Cyclones
- Land and sea breezes (thermal winds)

Thermohaline: heat distributing ocean water circulation (density driven)

Wave environments:

- **Storm wave climate:** most important and energetic wave climate (driven by westerlies)
- **West coast swell climate**
- **East coast swell climate**
- **Protected sea climates:** areas protected from arrival of swell

Tidal range:

- Micro-tidal regime: mean spring tidal range <2m (mostly at open coasts and fully enclosed seas)
- Meso-tidal regime: mean spring tidal range 2-4m
- Macro-tidal regime: mean spring tidal range >4m (often occurs at semi enclosed seas which enhance tidal amplification

Form factor F: characterizes tidal character: $F=(K_1+O_1)/(M_2+S_2)$

Relative tidal range (RTR): delineates between wave/tidal dominated. $RTR=MSTR/H_b$

- MSTR=mean spring tidal range
- H_b= wave height just before breaking
- RTR<3 wave dominated beach; RTR>15 beaches gradually approach pure tidal flat situation

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Chapter 5:

Waves feel bottom: when the water depth becomes less than half the wave length

- Wave slows down
- Certain harmonic component retains frequency; c & L decrease (due to dispersion relation)
- Eventually **Shoaling:** concentration of wave energy due to waves 'cathing-up' when starting to feel bottom. Increase in wave height is result

Current present: wave energy not conserved anymore (might transfer between waves and current)

- In this case use wave action as conserved quantity

Assumptions spectral integration:

- The irregular wave field at one location can be represented by single value for theta
- Total energy propagates at wave group speed c_g. (only case for narrow spectrum)

Group velocity c_g:

- Deep water: independent of location (can be taken outside derivative)
- Intermediate/shallow depths: depend on location and therefore inside derivative

Additional energy input (S): due to wind; generally neglected for small near-shore zone

Dissipation of wave energy (D):

- Most effective is wave breaking in surf zone (also deeper but then called White-capping)
- Other mechanism are bottom friction and interaction with vegetation

Shoaling also occurs for tidal waves/tsunamis when they encounter relatively shallow water

Refraction: depth induced 'bending' of oblique waves

Wave rays **converge:** accumulation of wave energy -> increasing wave height

Wave rays **divergence:** energy is spread over a larger part of wave crest -> reducing wave height

Current refraction: refraction due to mean currents (takes place if current velocity varies along wave crest)

Diffraction: energy transfer along wave crests induced by large (initial) variation of wave energy along crest. (waveheight will decrease along crest of the wave).

- Spreading behind obstacle dependent on ratio of a characteristic lateral dimension of the obstacle (e.g. length of detached breakwater to wavelength L)

Wave breaking: starts to occur when particle velocity exceeds the velocity of wave crest (wave celerity). Breaking corresponds to crest angle of 120

- In general: $[H/L]_{max}$=0.142tanh(kh)
- In Deep water: $[H_0/L_0]$=0.142=1/7 (white capping; only limited part of energy dissipated)

Iribarren number: tan(a)/sqrt(H_0/L_0) (=ratio slope steepness vs. deep water wave steepness)
Spilling breakers: found along flat beaches; wave breaking at great distance from shore; gradually breaking; very little reflection; low Iribarren number
Plunging breaker: curling top; some energy reelected
Surging breaker: along rather steep shore for long swell waves; surging up and down the slope; narrow breaker zone; almost half of the energy reflected back in deeper water
Surface roller: air-water mixture which moves land inward; act as temporary storage of energy and momentum. (Organized wave energy is transferred in turbulent kinetic energy; ultimately dissipated via turbulence)
Skewness: asymmetry relative to horizontal axis (peaking of crest; flattening of trough due to shoaling) (=zero for first order sinus component; for higher order sinuses the crests will give much more weight)

- Skewness for irregular deep water wave field = 0

Asymmetry: asymmetry w.r.t. vertical axis due relative steepening of wave face resulting in pitched-forward wave shape (crest travels faster than trough since c=sqrt(gd)

- Primary and secondary harmonic are not in phase

Non linearity's: become important in shallow water (a/h isn't small anymore)
Stokes higher order terms: correct for the non-linear surface elevation

- Second harmonic does not travel with speed as expected on own dispersion relation, but with speed of the primary harmonic (same phase)
- Therefore permanent wave form
- Narrow, peaked crests and long, flat troughs

Changes towards shore: first more skewed due to shoaling (remaining symmetric w.r.t. vertical axis); closer to surf zone phase shift -> increase in wave asymmetry and eventually decrease in wave skewness; ultimately pitching forward results in wave breaking
Ursell number: indicator of skewness: $U=HL^2/h^3$
Wave orbital motion: becomes also more skewed and asymmetric in shallow water. ->

- -> higher on-shore velocities at the crest; lower off-shore velocities at the trough
- Therefore net sediment transport in direction of the waves

Wave boundary layer: transition layer between the bed and layer of 'normal' oscillating flow (aprrox 1-10cm thick). Layer where orbital motion is affected by the bed

- Vortices generated (not included in linear wave theory
- Flow is generally turbulent
- Large shear stresses (due to large velocity gradient)
- Flow sticks to bed (no slip condition) due to viscosity and turbulence
- Thickness of layer restricted since it cannot develop because of changing wave directions
- Orbital motion incurs **bed shear stress**: can set sediment into motion

1. Under waves will vary in time and reverse with direction of orbital motion
- Friction in boundary layer: dissipation of energy from the flow above
- The thinner the layer; the larger the velocity gradients and hence the stresses

Water column above boundary layer: generally no vortices (in boundary layer however there might be)

Viscous stresses-> overshadowed by turbulence stresses in shallow waters

- Use however for turbulence stresses analogue to find a measure for turbulent viscosity

Turbulent viscosity: from: wave boundary layer; wave breaking; slope or wind driven current

Longuet-Higgins streaming: wave force pushing flow forward in boundary layer (causes net onshore directed sediment transport) Caused by turbulent shear stress.

Particle excursion amplitude: movement of particles due to orbital motion (dependent on wave period)

- Increases for longer periods

Adding bed shear stress & wave current: not possible because would mean linear adding but velocities included are not linear. So only adding via velocities

Current friction factor: relates the bed shear stress to depth averaged current velocity

Wave friction factor: relates the bed shear stress to free stream velocity

- Lower for longer periods since value for particle excursion amplitude will be larger
- Explained by idea that larger wave period gives boundary layer more time to develop resulting in a ticker boundary layer and smaller velocity gradients/shear stresses/friction factor

Momentum: product of mass and velocity (vector quantity; direction is same as velocity)

- Only contribution from wave trough level to wave crest (below wave trough velocity varies harmonically in time due to orbital motion giving zero time-avg result)
- Mean momentum: $q_{non\text{-}breaking}$:rho*g*a^2/2c=E/c (valid outside surfzone)
- Non-linear quantity in amplitude a (therefore mass flux = second order effect)
  1. In linear small amplitude approximation q=0
- In surf zone mass flux is substantially larger
  1. $Q_{drift}=q_{non\text{-}breaking}+q_{roller}=E/c+aE_r/c$
  2. E_r=roller energy

Undertow: return current in the surf zone (required based on continuity)

- Important for seaward sediment transport
- Responsible for the severe beach erosion during heavy storms
- Uniform over water column

Newtons second law: rate of change of momentum of fluid element= force on the element

Radiation stress: depth-integrated and wave averaged flow/flux of momentum due to waves

- If there is radiation stress (change in wave induced momentum flux) wave forces act on fluid resulting in:
  1. Lowering MWL in shoaling zone (**set down)**
  2. Raising MWL in surf zone (**set up ->** for irregular waves use H_{rms})
  3. Driving longshore current (in the case of waves obliquely approaching the shore)
- Components:
  1. transfer of momentum (in direction of wave crest); nE
  2. wave-induced pressure(acts normal to the plane); (n-1/2)E

- mainly focused in the region of water column above wave trough (below there is a much smaller uniform part until the bottom) -> has to **balance with Undertow,** since values change over water column **Circulation current**
- (normal) radiation stress in shallow water is larger than in deep water
- In breaking surf zone effect of surface roller will delay momentum release (therefore in reality landward shift of set-up)
- Changes caused by changes in: n, E & theta
- Increases in shoaling region (since n becomes larger)->wave setdown
- Decreases in surf zone due to wave breaking-> wave set up
- dS_{yy}/dy only can be non-zero for gradient in wave height along coast (so is zero for along shore uniform)
- dS_{yx}/dx= transport of y momentum in x direction; Cross shore gradient herein gives a net force in y-direction.

Shear stress due to waves: is zero for irrotational ideal fluid

Shear component of radiation stress: is zero for normal incident waves

Momentum flux is non zero for ENTIRE water depth: since u^2 is involved and is not zero

Longshore current:

- **Wave induced**
    1. Forced by cross-shore rate of variation of shear component S_{yx}
        - Function of dissipation (=-crossshore gradient of wave energy)
        - Long shore current is **confined to surfzone**
        - Decreases from border breaker zone to zero at water line
        - No there for normally incident waves
    2. In cross-shore direction balance was made with pressure gradient; but not possible for infinitely long coastline-> **balance with bed shear stress**
    3. **Turbulence:** due to waves only present in wave boundary layer (significantly increases bed shear stress; use free-stream velocity); due to currents(depth avg u) present in entire water column
        - since currents and waves may not have same direction -> bed-shear stress varies continuously during wave cycle
        - **mean bed-shear stress:** depends on angle between waves and current
    4. In case of **wave sheltering** (due to for instance detached breakwater) **wave set-up** is expected to be lower in sheltered area -> generates near-shore current towards sheltered area
- **Wind induced**
    1. Wind shear stress moves upper part of the water layer in direction of wind resulting in some sort of current
    2. Wind set up is inversely proportional to water depth -> shallow coastal water can pile up very high (storm surge)
    3. Most effect near surface (less velocity near bottom)
    4. Effect on long shore current in littoral zone can be neglected; morphological impact is also limited due to limited velocity near bottom
    5. More impact in coastal lagoons (Wadden sea)
- **Tidal induced**

Rip current: due to long shore currents generated by set-up differences (can be generated by convergence and divergence of wave energy due to depth-refraction or sheltering effects). Will only develop for **(nearly) normal incident waves)**
Flood current: current velocity in the tidal wave propagation direction
Flood/ebb velocity: max around high and low water (characteristic for propagation of tide in relatively deep water, where bed friction has relatively little effect on the propagation -> result is **progressive wave,** so in phase**)**
Rising period: time it takes for water level to get from lowest elevation to highest elevation
Falling tide; time it takes for water level to get from highest elevation to lowest elevation; does not necessarily coincide with ebb currents
Slack water: tidal flow reversal
Along Dutch coast: **falling period** > **rising period** (this phenomenon is called: **tidal asymmetry)**

- Can be explained by phase velocity for shallow water
    1. For high water the water depth is larger so larger c and larger velocity
    2. Opposite holds for low water
    3. Generally holds for open coast, might differ for basins

Phase relationship between horizontal- and vertical tide:

- Very complex
- Phase difference due to friction (also reduces the magnitudes of both tides)
- But also: tidal wave
- If phase difference it will be such that velocity peaks before tidal elevation

Phase differs along coast: getting larger northward
Along shore differences in tidal amplitude: related to position of amphidromic points
Tidal asymmetry:

- Tide propagates up estuary: water depth and basin width change -> **shoaling** effects increase amplitude
- **Friction** reduces amplitude on the other hand. Has **extra effect** at **low tide** because flow will feel bottom more (also effect on **velocity**)
- **Net effect** depends on specific situation
    1. Case with no friction and reflection -> vertical and horizontal tides are in phase
    2. Friction included-> phase shift between tides which increases land inward
        - Extreme case: horizontal tide leads by phase difference of pi/2
        - Shorter rising period correspond to shorter flood duration than ebb duration
        - This means that max flood velocities are higher (since net avg discharge should be zero in absence of discharging rivers)
        - This is called **flood dominant;** expected for:
            - Large tide (large ratio tidal amplitude/waterdepth -> a/h)
            - For that case propagation of high water > low water ->rising
            - **Increases** for **long basins**
            - Might be **counteracted** by **river flow** which increases seaward directed velocities
            - In absence of river flow might be counteracted by intertidal storage areas (small water depths on flats cause high tide to propagate slower

- Case where ebb velocities are higher than flood is called: **ebb dominant**
    - Enhanced by fact that water level avg. over flood period is larger than over ebb period but discharge is the same -> ebb velocities must on avg be larger because of smaller flow cross-section

Tidal Bore: abrupt migrating rise in water level

- Uncommon; special combination of tidal conditions and morphology in estuary needed

Asymmetries in horizontal tide (i.e. ebb/flood dominant) have important influence on net import/export of sediment. (flood dominated-> import and ebb vice versa

Seiches: Free oscillations in basins of moderate size. Standing waves with frequency equal to resonance frequency of the basin

Bound long wave: long wave motion on wave group scale due to set-up differences due to difference in radiation stress in the different waves (with different size) in the wave group.

- 180 degrees out of phase with wave group (for perfect bound wave)
- In reality smaller correlation between long wave motion and group (negative offshore from surf zone; positive when entering surf zone)

Surf beat: low frequency water level oscillation (caused by time varying set-up due to waves in group might break at different moment)

Chapter 6

Sediment transport: movement of sediment particles through a well-defined plane over a certain period of time

Sediment:

- **D_x=** sediment particle diameter (in meters) for which x% by weight is finer
- **Sediment well sorted:** D_{90}/D_{10}= small (<1.5)
- Grain shape of importance
- Grain density (for quartz 2650 kg/m^3); relative density is rhosediment/rho = 2.65
- Fall velocity (varies from 0.01 to 0.05 m/s
- Angle of repose
- Porosity (ratio of pore space to the whole sediment volume); 40% is frequently applied
- Sediment concentration c; In mass concentration or volume concentration; volume of solid particles/total volume

Fall velocity: balance between downward directed gravity force(minus buoyancy effect and upward directed drag force)

Hindered settling: in high concentration mixtures fall velocity of single particle is reduced due to presence of other particles. (particle down->flow must go upward)

Critical shear stress: point of imitation of motion

- Drag force: combination of skin friction and pressure difference
    1. Proportional to u^2
    2. Proportional to D^2
    3. Proportional to water density rho
- Lift force": from flow separation & flow concentration
    1. Also proportional to D^2 & u^2

Bed load transport: transport of particles in thin layer close to bed

- Particles more or less constant in contact with bed
- Lower shear stress:

    1. Shear stress > critical value -> particles start rolling/sliding over bed. Further increase make particles jump called **saltations**
- At higher shear stress, entire layer of sediment is moving -> called **sheet flow**
    1. Particles closer to bed start moving in *multiple l*ayers

Suspended load transport: transport of particles suspended in the water without any contact with bed

- Particles supported by turbulent diffusive force (keep them into suspension preventing them to settle)
- Suspended in relatively low concentrations (intergranular forces not of importance)
- However when Shield parameter is somewhat lower (below0.8-1.0 instead of above) bed will not remain plane bed:
    1. Smaller en larger bed forms arise
    2. Orbital ripples have length in order of free stream orbital velocity amplitude
    3. Non orbital ripples are much smaller (scale with grain size)
    4. Bed roughness is now related to ripple geometry (instead of grain diameter)
    5. Flow separates behind ripple crest -> organized pattern of vortices is formed near bed
        - Vortices bring large amounts of sediment into suspension
        - So instead of for a plane bed in this case sediments keep into suspension due to the organized upward motion (instead of turbulence for plain)

Total load: sum of bed load and suspended load

Extra category called **wash load**: very fine particles that will only settle in in still water'; these particles do not contribute to bed level changes -> not taken into account

Modeling of transport:

- *Bed load transport:*
    1. Exclusively determined by bed shear stress
    2. Hence formulations expressed in terms of bed-shear stress due to currents and waves
    3. Quasi steady approach: assumed that sediments reacts instantaneously to shear (inertia plays minor role)
- *Suspended load transport:*
    1. Often modeled as flux via product of sediment concentration and horizontal velocity of water transporting sediment
    2. Does not respond instantaneously to hydrodynamic conditions
    3. Other approach: energetics approach
        - Assumes that a certain portion of fluid energy is expended to keep sediment in motion
        - Result is quasi-steady formulation

For use of **shield in near shore:** influence of waves needs to be taken into account:

- Using time-averaged (wave averaged) bed shear stress for combined wave-current motion
- Or by instantaneous shear stress (varying over wave motion)

Particle in suspension: turbulent upward force > submerged weight of particle; particle than loses contact with bottom for some time

- Assumed to move with velocity of flow

1. Velocity can be thought of as mean and oscillatory part (averaged zero)
2. Substituting of this velocity components in expression for sediment flux gives:
    - **Current related part:** due to (wave induced currents)
    - **Wave-related suspended part**: due to oscillatory motion; **skewness** of velocity signal might cause **net transport**
    - In general current part > wave related part

Sediment is non-uniform distributed over vertical: higher concentration near bottom

- Might give rise to net sediment transport even if depth-averaged velocity is zero

Cross shore sediment transport:

- in surfzone: bed load directed **onshore** (due to short wave skewness); suspended load **offshore** due to undertow

Long shore sediment transport:

- refraction causes oscillatory motion to be almost perpendicular to the coast
- because of this transport is governed by slowly varying longshore current (wave- or tide induced)
- Role of waves in this direction is to stir up sediment

Sediment continuity: horizontal advection often<<vertical advection therefore often neglected

Rouse number: non-dimensional number; defines sediment concentration profile, determines mode of transport. Is the ratio between downward sediment fall velocity and upward velocity on the grain

- Rouse number >2.5 all transport is bed load
- Rouse number < 0.8 only wash load
- In between sediment suspension

Energetics approach: basic idea is that certain amount of energy is needed to keep bed load moving and suspended load at certain height above bed.

- Therefore **proportional** to **rate of energy dissipation of stream**

Suspended load in morphological modeling:

- One type which is determined entirely by hydrodynamic conditions and sediment properties at point of consideration
- One which includes a **memory effect** and responds to conditions in all points it has come through in the past (rather important in Tidal inlet)

Chapter 7

Response of coastal profile to wave action: depth depended; much faster for shallower depth

Upper shore: consists out of surf zone; beach and first dune or cliff face

- Shallow depths -> responds fast to wave action
- Response is nearly instantaneously to wave action
- **Surf zone bars**: respond on time scale of events

Lower shore face: extends from outer surf zone to shelf break

- Large depths -> responds slowly to wave action
- On engineering time scales (hours to few decades) negligible activity compared to upper shoreface (on time scale of decades to millennia there are however changes!)

Back shore: dune or cliff high enough to prevent overwash and without alongshore gradients

- Shallow depths -> responds fast to wave action

Coastal engineering assumptions:

- **Morphological active zone:** extends from first dune/cliff face to just a little offshore of surf zone
- Active zone profile remains at dynamic equilibrium when averaged over time (might however have instantaneous changes)
- When no long shore sediment transport gradients; amount of sediment in active zone remains unchanged (no structural loss

Oscillation dynamic behavior of real beach profile: caused by the fact that in reality waves and water levels vary a lot and therefore cause to profile to oscillate around equilibrium.

- Seems however to oscillate confined to a **steady envelope**
- Mean position is defined as: **dynamic equilibrium profile**

Bruun:

- Simple power law relating water depth to offshore distance
- Dimensional constant A used.
    1. Shape factor which depend on stability characteristics of bed material
    2. The larger A, the steeper the profile

Dean:

- Supported Bruun on semi-emperical grounds:
    1. For certain grain size nature strives towards uniform energy dissipation/unit volume of water across the surf zone
    2. Energy dissipation /unit volume = measure for 'destructive force' (responsible for offshore sediment transport) on sediment particle
    3. Energy dissipation rate depends on particle diameter
    4. A furthermore related to fall velocity (which depend on grain size)

In surf zone/intertidal area sand bars are found: Bars determine locations and rates of energy dissipation (due to wave breaking) and are therefore may dictate the morphological response

Several beach states(6 in total): Two ends:

- **Reflective beaches:**
    1. Relative steep and narrow beach face with berm and narrow surf zone without bars.
    2. Nearshore & beach slopes 0.1-0.2
    3. Relatively coarse sandy material
    4. Large Irribarren parameter
    5. Collapsing or surging breakers
    6. Corresponding waves have a low steepness(long and small amplitude waves)
    7. -> reflective beaches are result of period of mild wave climate that transport sediment onshore.
    8. Found in swell/monsoon climate
    9. Morphodynamic behavior is less dynamic
- **Dissipative beaches:**
    1. Wide and flat sandy coastal zone
    2. Multiple linear bars
    3. Dunes backing wide beach
    4. Nearshore slope is about 0.01 beach slope abount 0.03
    5. Fine sandy material
    6. Small Irribarren numbers (spilling breakers)

7. Result of high energy waves which break far offshore
8. Typical for storm climate
9. High variability

- Two ends are in principle **2D** structure of morphology
- Intermediate states act **3D** structure of morphology (in less energetic conditions)
- **Reset event** can cause diverse 3D variability system into 2D variability (alongshore uniform) due to high energetic conditions
    1. **Difference in flow velocities from Dissipative to Reflective or vice versa:**
        - Dissipative to reflective:
            - Rips are being formed (at first large scales)
            - Later on they merge into large scales
            - You'll get circulation cells and bars at first still more or less parallel (rhythmic bar and beach)
            - When continues bars become almost perpendicular to coast (Transverse bar and beach)
            - When energy becomes less; hardly any 3D more and everything confined to coast
        - Reflective to dissipative (from less energetic to more energetic):
            - Length scales of rip current grow with width of surfzone
            - Formation of rhythmicity has large length scale a diss. to refl.
- **Summer:** high beach profile; high slope -> reflective beach (NL)
- **Winter:** low beach profile; gentle slope -> dissipative beach (NL)

Rips:

- Spacing approximately: surf zone width x4
- On open swell coast spacing from 100 to 500m (150-250 common)
- Multi bar beaches spacing increases seaward
- Lower the slope (hence wider surf zone) -> wider rip spacing

Dimensionless fall velocity: H_b/w_sT

- For reflective beaches <1
- For dissipative beaches >6

Bars (longer timescales i.e. years):

- Move offshore under more energetic conditions
- Move onshore under during less energetic but skwed waves'
- Cycle:
    1. Initial formation in intertidal zone
    2. Bar moves offshore and grows until max size around initiation of surf zone
    3. Then gradually decrease in size and amplitude
    4. Finally disappear at end of active shoreface profile
    5. Cycle takes 4-5 years in SH coast
    6. Around 15 years in NH
    7. Difference because steeper shoreface slope and larger bars in NH

Dune erosion: during high storm surges when waves can reach dune face; strong undertow transports sediment offshore

- High surge is requested to erode dune; if not available similar process occur on beach called a **scarp**

- Further offshore transport capacity of flow decreases-> sediments settles forming new coastal profile that better fits storm surge condition
- Sooner or later return of sediments (in a stable case)
- Sedimentation until depth of approximately 75% of the incoming wave height

Dune foot: position of slope change between gentle beach slope and steeper dune slope

- In Netherlands mostly above MSL
- During surges sometimes under water

Cross-shore Transport on bottom:

- Bottom transport = more important in surf zone
- Suspended load = more important outside surf zone
- Three contributions to velocity:
    1. Time mean component (streaming outside surf; undertow inside) (u)
    2. Low frequency motion at wave-group scale (u_{lo})

    3. Oscillatory motion at short wave scale (u_{hi})
- After Taylor series three most important terms are:
    1. Mean flow as transport velocity: **$3<u|u_{hi}|^2>$**
        - Short waves will stir up sediment ($|u_{hi}|^2$) and mean flow (u; = undertow in surfzone) will transport it
        - Outside surf zone u is streaming (directed onshore)
        - So 0 far offshore; shoreward directed component outside surf zone; and offshore directed component in surf zone; getting to 0 at shore line.
    2. Short wave skewness: **$<u_{hi}|u_{hi}|^2>$**
        - Product of orbital motion (u_{hi}) and something interpretable as proportional to concentration ($|u_{hi}|^2$)
        - In offshore waves are pure sinusoidal -> no contribution of this term since averaging sinus gives 0
        - But near shore waves get skewed (shoaling) and not perfect sinus anymore hence average is not 0 (larger forward motion (concentration) than backward motion (concentration)
        - Result of this is positive shoreward contribution until surf zone
        - In surf zone **saw-tooth wave**-> symmetrical again and avg =0
        - So contribution=0 offshore; has value towards surf zone (positive shoreward contribution); zero again in surf zone
    3. Correlation bound long waves and short wave envelope: **$3<u_{lo}|u_{hi}|^2>$**
        - Again short waves ($|u_{hi}|^2$) stir up sediment, which is now transported by **long wave velocity which changes:**
        - Wave group-> variation in radiation stress-> gradient over wave group -> need force to compensate -> done by surface making a slope (water level gradient) -> **Bound long wave**
        - **Bound long wave is present** as long as wave group exists
        - Bounded because bounded by short waves
        - Peak of bounded wave during low waves of group and trough vice versa
        - During peak shoreward directed flow -> during low waves shoreward directed flow and during high waves opposite

- At the end there is an net offshore movement of sediment; because during high group waves the stirred up concentration is larger and at that time the bound long wave forces the sediment to flow offshore.
- But when entering surf zone the transport becomes shore ward, because **in the surf zone wave groups disappear due to depth limiting wave breaking**
- Because of this **all waves get approximately the same height** and **bound long wave is free**
- Now long wave starts to modulate waterline (reflects against water line) -> positive correlation, because larger water level allows larger waves (since larger depth)

4. **Summation:** gives that usually in surf zone the return flow (under toe) is governing; but will be different under low waves which asymmetry dominated

- **Onshore directed:**
  - LH streaming (outside surf)
  - Wave asymmetry
  - Free long waves (in surf zone)
- **Offshore directed:**
  - Undertow (in surf)
  - Bound long waves (outside surf zone)
- **Down-hill (on average outside surf)**
  - gravity

Cross-shore Transport suspended:

- basic idea: equilibrium profile (purely suspended load) exists if $<I_s>=0$
- in general 3th power of u corresponds to bed load; 4th power to suspended
- in this case: $u=U_0+U_1=u_0\cos(wt)+U_1$. With generally $U_0>>U_1$ and U_0=symmetrical orbital velocity and **U_1=perturbation:**
  1. mean flow perturbation(outside surf; longuet higgens) = $U_1=u_1$
     - after Taylor leading terms:
       - $4U_1\mathbf{U_0^2|U_0|}$; again **fat** brings in suspension (via orbital motion) and normal causes carrying by mean flow (onshore transport because U mean outside surf is onshore directed LH)
       - Moreover a gravity component (due to slope) working against it (directed offshore); gamma*$U_0^4|U_0|$; with gamma=$\tan(a)/w_s$
       - Both have to balance.
       - Note that gravitational term is determined by fall velocity whereas first term is not -> Larger particles will decrease gravitational effect whereas onshore transport stays the same
       - **Hence coarser grains will transport on shore**.
  2. second harmonic of primary wave $U_1=u_2\cos(2wt)$
     - now also a symmetry contribution

Chapter 8

Coastal changes: occur where there are spatial sediment transport **gradients** and/or sediment sinks or sources.

- Dominated by alongshore effects in case of human-induced changes on high-wave energy coasts

Actual transport: might be lower than **transport capacity** (based on hydrodynamics) due to process which prevent particles to erode (bottom protection; vegetation etc)

Short wave motion: small in long shore direction due to shoaling (fi is small)

- This means that the mean water motion is the main contributor to longshore sediment transport
- Although not involved with transport of sediment; have other function:
    1. Magnitude in bed shear stress varies over wave cycle due to orbital motion ->peaks twice every wave cycle -> lot of sediments mobilized during peak
    2. Breaking waves-> increase turbulence in water column -> suspended sediments easily brought up into upper part of flow

Bulk transport formulas: robust and easy to calibrate; no distribution of longshore transport over cross-shore:

- **Cerc formula:**
    1. Gives total longshore sediment transport over breaker zone
    2. Only effect of wave-generated longshore current included (no tidal current enz)
    3. Limitations: 1: only wave-induced longshore current; 2: sand transport independent of sand properties as grain size; 3:only total sediment transport in breaker zone given

Annual longshore transport: take variability of **wave climate** into account:

- Can be done by schematization of wave climate in classes
- Requires that wave climate is divided into sectors with a certain percentage of occurrence

Gross transport rates: important to determine coastal response near breakwaters and groynes

Net longshore transport rate: generally much higher than net cross-shore transport rates

In Mediterranean: very difficult and totally different

Long term (years/decades) changes of shoreline on high energy coast: predominately due to human-induced longshore effects

Cross shore movement: occurs typically on short scale (days), therefore little impact on longer term changes in beach position (only when material is lost from system)

Solving coastal changes from sediment balance:

- **Complex morphological computer models** (Delft3D); sediment balance per cell in fine grid. Used in complex areas or in complex applications in which both long- and cross shore transport are important
- **Single line/ one-line theory**. Behavior of coast is mapped onto single line (coast line). Can be used if wave-induced longshore transport is dominant
    1. Basic assumption: shape of cross shore profile does not change in time (eq. profile)
- **Multiple line theories;** same principle as one line but cross-shore profile is schematized into a number of sections (depth zones)

Littoral transport rates: dependend on near shore wave exposure and wave incidence angle

- ➔ For given offshore wave climate coastal changes are determined by changes in depth contours, shoreline orientation and degree of which waves shoal, refract and diffract

Spit: develop where longshore transport capacity is diminished due to coastline interruptions

Chapter 9:

Shoreline wave dominated environments: characterized by elongated sediment (mainly sand) bodies

Pocket beaches: also fall in category of wave dominated systems

Tidal conditions: dominate in general in conditions where wave energy is relatively low

- Relative is the key; relative influence of waves and tides determine morphology
- Can be dominant in situations with restricted fetch or where incident wave energy is trapped or reflected (include **tidal basins)**

Tidal basins: result of breaktroughs and flooding of low lying areas due to global rise of post-glacial sea-level

- Other contributions: tectonic subsidence, fluvial erosion and glacial action
- Also subsidence due to human activity (impoldering, water extraction etc)
- Can also evolve due to formation of barriers enclosing body of water
- Fundamental characteristic is interaction of fresh- and salt water

Types of tidal basins :

- **Tidal lagoons(tide dominated):** basin enclosed by wave-shaped coastal barriers islands/spits
- **Tidal bays:** basins that are more open to deep water of sea/ocean in absence of barrier islands
- **Estuaries (mix tide and river):** different from bays in the sense that the experience a strong fresh-water run-off; different from river mouths in the sense that estuary is more controlled by tide than by river discharge. Sedimentation also imported from adjacent coastal region

Sabkhas: lagoon for which seawater inflow>outflow (due to evaporation); common on low latitude arid coasts

Tidal inlet: an opening in the shore that provides a connection between ocean or sea and a basin which is maintained by tidal currents

Ebb shield: most elevated outer edge of flood-tidal delta (flood tidal deltas equivalent of terminal lobe; helps to divert ebb-currents along margins of flood-tidal delta

Feedback mechanism: *morphology of tidal basin* is determined *by hydraulic boundary conditions* (relative dominance of waves vs. tide etc), but *morphology of basin* also influences *hydraulic boundary condition*. Resulting geometric/hydraulic controls:

- **Tidal prism:** determined by combination of surface area of basin and tidal range
- **Tidal distortion (difference in flow velocities/transport at high vs. low water):** determined by combination of tidal range, channel depth and intertidal storage areas/flats
- **Wave propagation:** might be progressive or standing dependent on the length of the basin.
- **Difference in HW- and LW slack:** for very short basins (of great importance for net transport of fine sediments)

Tidal delta: extensive sand deposits at either side of tidal entrance due to strong sediment exchange between basin and outside area.

- **flood delta:** at 'inner' side.
    1. flood dominant channels shoal (less deep)
- **Ebb delta:** at outer side; reworked by waves
    1. Ebb dominant channels meander (deeper)
- A lot of wave action increases the net onshore sediment flux and decreases the net offshore sediment flux -> hence the flood delta grows for a situation with a lot of waves whereas the ebb delta decreases

when large river discharge in basin: tidal basin is often funnel shaped and not as branched (but potentially braided)

When no width restriction: flood and ebb current might follow different channels. When width restriction in general the same path.

Relatively small basin: if abundant sediment supply; flood-tidal delta spans entire basin area (like Wadden sea)

- If this is the case; focus on ebb-tidal delta

Intertidal flats: serve to accommodate the tidal prism

- Highest one which stay dry are called: **Supra-tidal flats/Salt marshes**

High energy waves: help bars to **bypass** towards downdrift side

- **Bypassing** also possible due to tides and waves together

Currents near tidal inlet:

- Partly tidal
    1. Concentrated in main channels
    2. **Secondary flow components:** might be curvature induced (curvature of tidal current)
        - Does not change sign as the tide turns
        - Therefore in upper part of water column always directed away from centre of curvature of flow
        - Lower part always towards it
        - Contributes to maintenance of shoals.
- Partly wave driven
    1. In areas where waves are breaking
    2. **Waves;** break in generall mostly on outer delta. Therefore not that much penetration. Wind might create new waves inside the basin
    3. Problem is complex topography in outer delta. Therefore usual approach is difficult to use (split longshore and cross shore balances)
- Partly wind driven
    1. Occur mainly during storm events (episodic)
    2. Due to **direct wind input** or via **wind set-up**
        - wind shear stress components should be added to depth averaged momentum equations
        - More effective on shallower water
        - Set-up causes more water to enter basin. Because of this sometimes flood current suppresses ebb current. This might change inlet morphology drastically

Sediment transport patterns:

- Flood channels on outer delta carry in general sediment from adjacent coasts to inlet (often during episodic events)
- Depending on sand demand of basin sand is transported into basin or into main ebb channel
    1. Part of Ebb sand output is picked up by long shore current and transported along delta edge
    2. Other part of ebb sand (+part of sand brought in by longshore drift) ends up in shoal system on outer delta
    3. Eventually due to hydrodynamic & sediment transport processes there is long-term residual transport and slow migration of shoals in direction of longshore drift

Tidal prism: volume of water entering or leaving the basin per half tidal cycle

- Is much larger as wave induced littoral drift -> tide dominated inlet
- In opposite situation -> wave dominance
- Relates to **sand volume stored in outer delta** (changes in prism will thus induce changes in outer delta, sources of sand might be: adjacent barrier coast, back-barrier system (i.e. the basin) or from offshore, most probably a combination
- Small basin for <<1/4L and little intertidal storage. Then: $P=A*h$

Coarse sediment: is tough to react immediately to flow velocity (/or bed shear stress)

- Long-term mean bed load transport determined by:
    1. Residual flow velocity
    2. Amplitude of M2 tidal current
    3. Amplitudes & phase (relative to M2) of M4 and M6 tidal currents
- Interaction between M2 & M6 does not lead to net sediment transport regardless of phase angle (leads only to sawtooth asymmetry)
    1. But combination of M2, M4 and M6 has a contribution
- Reacts instantaneously
- Timescales of erosion and sedimentation: order smaller as tidal period

Fine sediment transport

- **Memory effect of importance** (so suspended sediment transport not only depends on local instantaneous flow velocity)
- Does not react instantaneously
- Timescales of erosion and sedimentation: same order as tidal period
- Settle around flow reversal
    1. Controlled by duration of slack water

Large storage offering flat, 2 opposing effects:

- Large storage prism causes short slack duration in flow channel at HWS
- Other hand in this short period a strong settling can occur due to small water depth

Chapter 10

Strategies on coastal protection:

- Retreat
- Accommodate
- Protect

Permeable low crested groynes: used for beaches with small sediment deficit, result in more regular beach (no saw tooth as for impermeable ones)

Shore face nourishment; often half as expensive as beach nourishment