

Practice Exam

Long Waves and Tidal Morphodynamics

(201800024)

CIVIL ENGINEERING & MANAGEMENT, UNIVERSITY OF TWENTE

Location: –, date: dd-mm-yyyy, time: .

Abstract

Important remarks:

- Please write your name and student number on each sheet of paper.
- It is *not* allowed to use lecture notes, or any other course material or textbook during this exam.
- The use of a (graphical) pocket calculator is allowed.
- Hand in every sheet of paper you used after the exam (including this exam)!

Good luck!

Part I - Open Questions

Kelvin wave: M2 vs S2 (30p)

Consider the idealized situation of an infinitely long rectilinear coast in a sea of uniform depth (15 m) at a latitude of 30°N. Here we compare the properties of two Kelvin waves of different period: a semidiurnal lunar wave ('M2', period 12h25min) and a semidiurnal solar wave ('S2', period 12h00min). The amplitudes of the surface elevations at the coast for these two waves are given by $\zeta_{M2} = 1.0$ m and $\zeta_{S2} = 0.5$ m, respectively.

Let us introduce the usual coordinate system, with horizontal coordinates x (coast-parallel) and y (coast-normal), such that $y = 0$ is the coastline and $y > 0$ the water domain. From Kelvin wave theory, we know that the unknowns of this system (u , v and ζ) satisfy the following model equations:

$$\frac{\partial \zeta}{\partial t} + h \frac{\partial u}{\partial x} = 0, \quad \frac{\partial u}{\partial t} = -g \frac{\partial \zeta}{\partial x}, \quad f u = -g \frac{\partial \zeta}{\partial y}, \quad (1)$$

supplemented with appropriate boundary conditions (not specified here). All parameters have their usual meanings. Further, you may want to use $\Omega = 7.292 \times 10^{-5} \text{ rad s}^{-1}$.

(5p) 1. Which important Kelvin wave property regarding one of the unknowns has already been applied to arrive at Eq.(1)?

(16p) 2. Calculate the following properties for both Kelvin waves:

- angular frequency (i.e., σ_{M2} and σ_{S2})
- wavelength (λ_{M2} and λ_{S2})
- maximum value of the flow velocity in the domain (U_{M2} and U_{S2})
- Rossby deformation radius (R_{M2} and R_{S2}).

(9p) 3. *Describe and sketch* the spatiotemporal pattern resulting from the superposition of these two Kelvin waves (M2 and S2). What is the name of this tidal phenomenon?

N.B.: No calculations required, only a *qualitative* description and a sketch.

Answer:

1) Velocity in the cross-shore direction is zero ($v = 0$), everywhere in the domain.

2) for both M2 and S2:

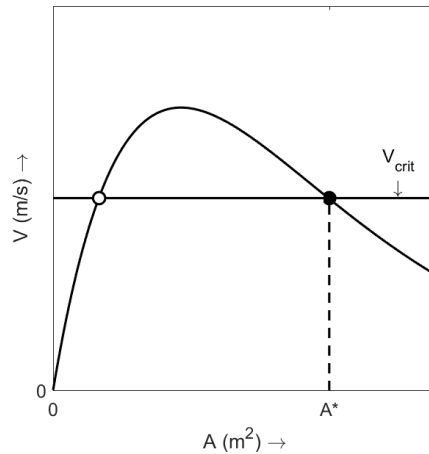
- $\sigma = \frac{2\pi}{T}$ $\sigma_{M2} = 1.405 \cdot 10^{-4} [\text{rad s}^{-1}]$ $\sigma_{S2} = 1.454 \cdot 10^{-4} [\text{rad s}^{-1}]$
- $\lambda = T\sqrt{gh}$ $\lambda_{M2} = 542 \cdot 10^3 [m]$ $\lambda_{S2} = 524 \cdot 10^3 [m]$
- $U = \frac{gk}{\sigma}\zeta$ $U_{M2} = 0.81 [m s^{-1}]$ $U_{S2} = 0.40 [m s^{-1}]$
 $k = \frac{2\pi}{\lambda}$
- $R = \frac{\sqrt{gh}}{f}$ $R_{M2} = R_{S2} = 1.66 \cdot 10^5 [s^{-1}]$
 $f = 2\Omega \sin(\varphi) = 7.29 \cdot 10^{-5} [s^{-1}]$

3) A sketch of two sinusoidal signals of slightly different frequency and wavelength, these signals modulate, in the sense that they sometimes add together forming the spring tide, and sometimes cancel each other resulting in neap tide. This phenomenon is referred to as the spring neap cycle.

Single inlet systems and external changes (16p)

Escoffier's concept helps analyse and interpret the cross-sectional evolution and stability of tidal inlet systems. It is based on a competition between wave-driven sediment import and tide-driven export of sand in the inlet. The resulting *closure curve*, showing how inlet velocity amplitude V depends on cross-sectional area A , relative to a critical value V_{crit} , is shown in the figure.

We consider a single inlet system initially in stable equilibrium, as denoted by the filled black dot, with associated cross-sectional area A^* . However, the system is subject to external changes, to which it will respond. Here we apply Escoffier's concept to investigate the evolution of the inlet's cross-sectional area triggered by two examples of these changes.



- (8p) 4. Describe inlet evolution if, due to climate change, the *wave-driven sediment import* would *increase* (tidal conditions unchanged).
N.B.: Apply Escoffier's concept and the figure above.
- (8p) 5. Describe inlet evolution if, due to *basin reduction*, the basin is brought *closer to tidal resonance* (wave conditions unchanged).
N.B.: Apply Escoffier's concept and the figure above.

Answer:

4) If wave-driven sediment import increases, it means that sediment export due to tidal flow needs to increase to reach a balance between import and export. Thus the horizontal line indicating the critical velocity moves upward in the graph. Thus the stable equilibrium (filled black dot) moves along the curve to the left, and thus the cross-sectional area of the inlet would decrease. If the wave-driven import of sediment would increase to above the line above the tidal velocity curve, then there are no equilibria left and the inlet will close entirely.

5) If the basin size is reduced such that it is closer to resonance, tidal velocities become further amplified. This means that the response curve of velocities versus cross-sectional area is amplified, and thus moves upward. With unchanged wave conditions, the horizontal line remains in place. The cross-section of the velocity response and the critical velocity of the stable (filled black dot) then moves to the right, meaning the cross-sectional area would increase as it evolves towards the new stable equilibrium.

Ekman spiral and Ekman transport (24p)

Wind-driven flow in an ocean may display a so-called Ekman spiral. Apart from horizontal uniformity and the absence of vertical flow, i.e. $w(z) = 0$ for all z , Ekman flow satisfies the following relationships:

$$-fv = K \frac{d^2 u}{dz^2}, \quad fu = K \frac{d^2 v}{dz^2}, \quad (2)$$

with Coriolis parameter f and eddy viscosity K . Boundary conditions read

$$K \left(\frac{du}{dz}, \frac{dv}{dz} \right) \Big|_{z=0} = (0, \tau_w/\rho), \quad \lim_{z \rightarrow -\infty} |(u, v)| = 0, \quad (3)$$

where τ_w is the wind stress and ρ the density of water.

The so-called *Ekman transport*, defined as the vertical integral of the flow profile (multiplied with ρ), turns out to be given by

$$M_x = \rho \int_{-\infty}^0 u(z) dz = \frac{\tau_w}{f}, \quad M_y = \rho \int_{-\infty}^0 v(z) dz = 0. \quad (4)$$

(15p) **6.** Without actually knowing the solution $u(z)$ and $v(z)$, use Eqs.(2)-(3) to directly derive the results in Eq.(4).

(9p) **7.** From a *physical* perspective, qualitatively explain the result in Eq.(4).

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Answer:

$$6) M_x = \rho \int_{-\infty}^0 u(z) dz = \rho \int_{-\infty}^0 \frac{K}{f} \frac{d^2 v}{dz^2} dz = \rho \left[\frac{K}{f} \frac{\tau_w}{K\rho} - 0 \right] = \frac{\tau_w}{f}$$

similarly for M_y , use both boundary conditions (both zero) to obtain the result of zero.

7) To close the force balance of a shear stress in the positive y-direction a net Coriolis force is needed in the negative y-direction. To facilitate a Coriolis force in the negative y-direction a net mass flux in the positive x-direction is required. This thus means that shear stress in one direction causes a net mass flow of water in a direction 90 degrees to the right with respect to the wind shear, that is after the initial transient effects have dissipated.

Part II – Multiple Choice Questions

(3p) **8.** Consider the following statements about the **Coriolis force** and tides. What can you say about the following two statements?

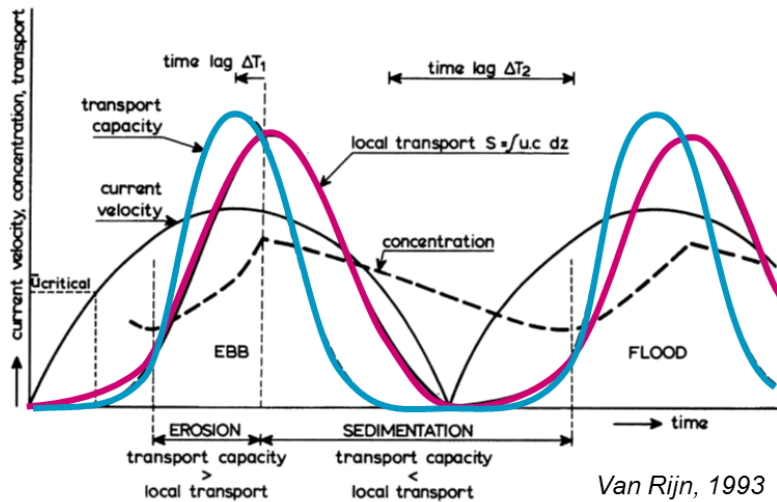
I The Coriolis force deflects winds and currents to the right in the Northern Hemisphere.

II The tidal waves of amphidromic systems tend to rotate anti-clockwise in the Northern Hemisphere.

a) Both I and II are true.

- b) I is true, II is false.
- c) I is false, II is true.
- d) Both I and II are false.

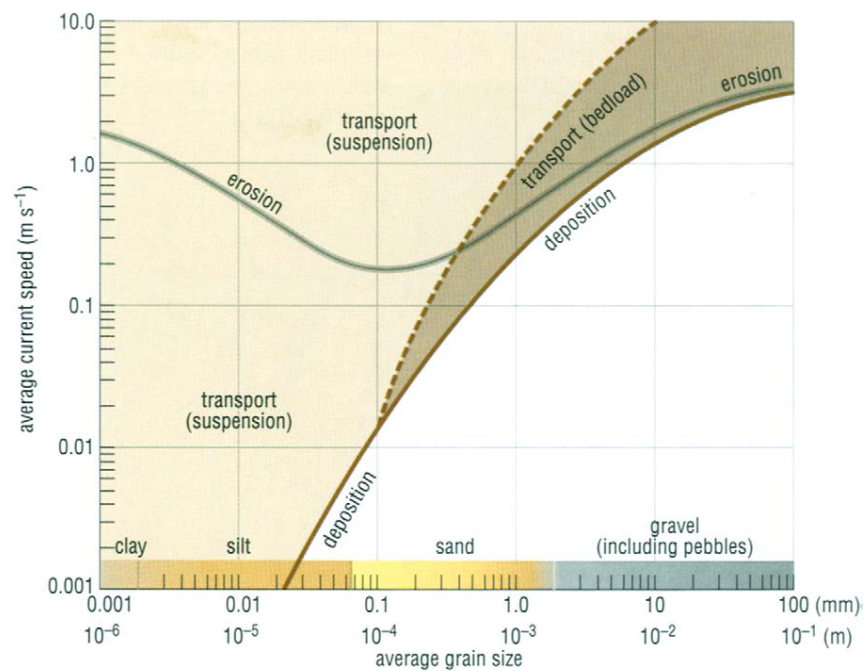
Answer: a



- (3p) 9. Consider the local **sediment transport** depicted in the figure above. The *time lag* ΔT_1 indicates the lag between the time of maximum current velocity and the time of the maximum local sediment transport rate. If the local sediment grain size would increase but the current velocity were to remain the same, what changes would occur to this local transport curve?
- a) The peaks of the local transport curve would increase and the time lag ΔT_1 would increase.
 - b) The peaks of the local transport curve would increase and the time lag ΔT_1 would decrease.
 - c) The peaks of the local transport curve would decrease and the time lag ΔT_1 would decrease.
 - d) The peaks of the local transport curve would decrease and the time lag ΔT_1 would increase.

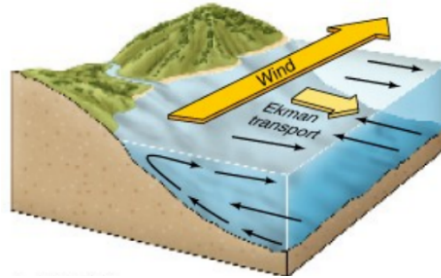
Answer: d

- (3p) 10. Consider the **sediment transport diagram** in the figure below. At a current speed of 30 cm/s, what can we say about the sediment transport?



- a) Clay, silts and fine sands can be picked-up from the bed and transported in suspension.
- b) Coarse silts and fine sands can be picked-up from the bed and transported in suspension.
- c) Sands can be picked-up from the bed and will be transported mostly as bed-load.
- d) Coarse silts and fine sands that are in transport can be deposited on the bed.

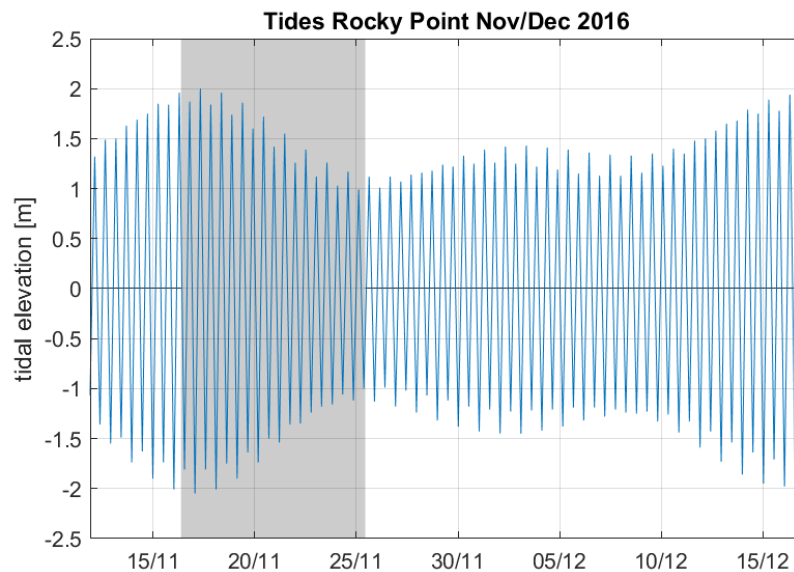
Answer: b



(3p) 11. Considering the characteristics of **Ekman transport**, what process is depicted in the figure above?

- a) Upwelling in the Northern Hemisphere.
- b) Downwelling in the Northern Hemisphere.
- c) Upwelling in the Southern Hemisphere.
- d) Downwelling in the Southern Hemisphere.

Answer: a



(3p) **12.** The tidal signal in the **tide chart** above shows a number of variations in the tides at Rocky Point, New Zealand. Which statement is correct?

- a) This tide chart shows the daily inequality due to an inclination of the Moon.
- b) This tide chart shows a tidal signal according to the equilibrium tides described by Newton.
- c) The shaded area in the tide chart covers a full spring-neap tidal cycle.
- d) The change in high tidal elevations in the chart is due to the elliptical orbit of the Earth around the Sun.

Answer: a

(3p) **13.** What **positions of the Moon and Sun** give rise to the variation of the tides in the shaded area on the tide chart for Rocky Point between Nov 16th and Nov 25th?

- a) Just before Nov 16th the Moon is in *syzygy* and the Sun and the Moon are in *conjunction*; Just before Nov 25th the Moon is in *syzygy* and the Sun and the Moon are in *opposition*.
- b) Just before Nov 16th the Moon is in *syzygy* and the Sun and the Moon are in *conjunction*; Just before Nov 25th the Sun and the Moon are in *quadrature*.
- c) Just before Nov 16th the Moon is in *syzygy* and the Sun and the Moon are in *opposition*; Just before Nov 25th the Moon is in *syzygy* and the Sun and the Moon are in *conjunction*.

- d) Just before Nov 16th the Sun and the Moon are in *quadrature*; Just before Nov 25th the Moon is in *syzygy* and the Sun and the Moon are in *opposition*.

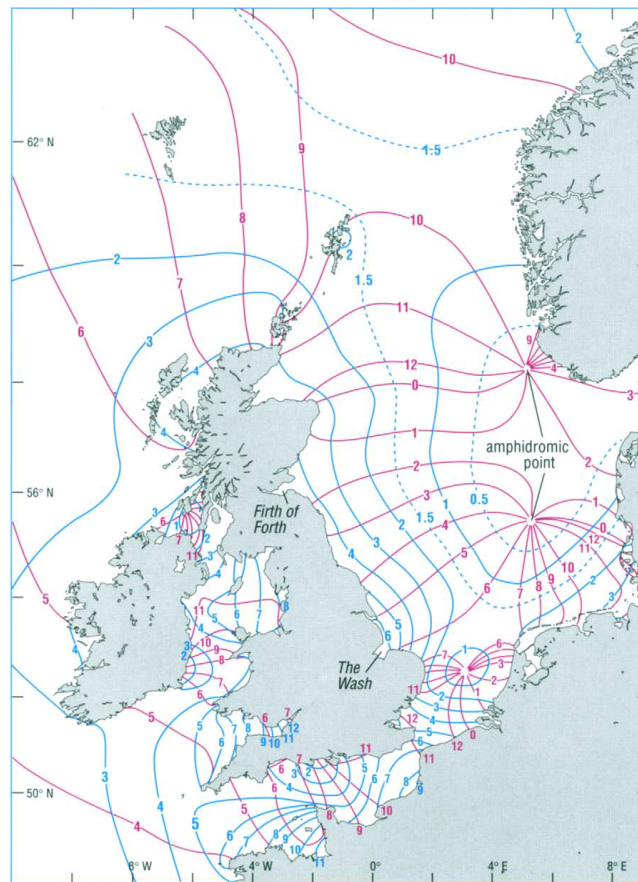
Answer: b

(3p) **14.** Consider the equilibrium tide and the following statements about the **tide producing forces**. What can you say about the following two statements?

- I The gravitational force of the Earth-Moon system has the same direction all around the Earth.
- II The centrifugal force at any location on Earth is different based on the different distance of that specific location to the Moon.

- a) Both I and II are true.
- b) I is true, II is false.
- c) I is false, II is true.
- d) Both I and II are false.

Answer: d



- (3p) **15.** Consider the amphidromic systems as shown. One morning, a boat departs one hour before high water in The Wash and sails north. The same day, it arrives in Firth of Forth at high tide there. How long did this boat trip take?
- a) Between 4 and 6 hours.
 - b) Between 6 and 8 hours.
 - c) Between 8 and 10 hours.
 - d) Between 10 and 12 hours.

Answer: c

(3p) **16.** Consider the following statements about the **amphidromic systems in the North Sea**. What can you say about the following two statements?

I The tidal wave along the Irish west coast propagates faster than the tidal wave along the British east coast.

II At an amphidromic point, the tidal range is minimal.

- a) Both I and II are true.
- b) I is true, II is false.
- c) I is false, II is true.
- d) Both I and II are false.

Answer: a

(3p) **17.** Which of the sequences of **bedforms** has been put in order of increasing wavelength? (shortest first, longest last)

- a) Megaripples, sand waves, sand banks.
- b) Ripples, sand banks, sand waves.
- c) Sand waves, sand banks, ripples.
- d) Megaripples, sand banks, sand waves.

Answer: a