Structure Failure Modes

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Structure Failure Modes

Contents

• Introduction
• Sloping-Front Structure Failure Modes
  • Breakwaters and Jetties
  • Revetments
• Vertical-Front Structure Failure Modes
  • Caissons
  • Gravity Walls
  • Tied Walls

Based on: CEM Chapter VI-2 (Author: Hans F. Burcharth)
Key Point of This Presentation

Competent design requires an understanding of all the possible ways in which a structure may fail.
Structure Failure Modes

Failure Definition

• In general usage:
  The term "failure" implies total or partial collapse of a structure

• In the context of design reliability:

  "Failure" is damage that results in structure performance and functionality below the minimum anticipated by design.
Structure Failure Modes

Reasons for Project Failure

• **Design Failure** occurs when:
  (1) Whole structure or some components cannot withstand loads beneath the design loads, or
  (2) Structure does not perform as intended.

• **Load Exceedance Failure** occurs because design loads are exceeded.

• **Construction Failure** arises due to incorrect or faulty construction practices or materials.

• **Deterioration Failure** is caused by structure deterioration and lack of proper maintenance.
Structure Failure Modes

Project Failure Footnotes

• New or innovative designs are more susceptible to design failure due to lack of previous experience
• All projects have some level of load exceedance failure probability
• Load exceedance probability increases where little prototype data exist
• Safety factors should be increased to compensate for uncertainties in design
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Based on: CEM Chapter VI-2 (Author: Hans F. Burcharth)
Overview of Rubble-Mound Breakwater Failure Modes
Sloping-Front Structures

Armor Layer Instability

Hydraulic instability of main armor for a conventional multilayer structure

- Displacement of main armor around SWL.
- Subsequent erosion of under layer and core resulting in development of S-profile.
- Eventually wash-down of crest structure.

Usually a rather slow development of failure.
Sloping-Front Structures

Armor Layer Instability

Erosion of rear side of crest of conventional structure due to overtopping

- Displacement of crest and rear side armor.
- Subsequent wash - down of crest armor and underlayers.
- Flattening of top part of the structure.
Armor Layer Instability

Hydraulic instability of single layer randomly placed armor units on rather steep slopes

- Sudden displacement of a large proportion of the main armor layer.
- Subsequent erosion of the exposed underlayer and core.
Sloping-Front Structures

Armor Layer Instability
Sloping-Front Structures

Failure Due to Armor Unit Breakage

Hydraulic instability and/or breakage of complex types of armor units leading to failure of wave wall superstructure

- Displacement of intact or broken units.
- Subsequent exposure of the wave wall to large wave impacts and uplift pressures.
- Eventual breakage and wash down of superstructure.

The failure can proceed rather fast if the armor unit breakage is extensive.
Sloping-Front Structures

Failure Due to Armor Unit Breakage
Sloping-Front Structures

Failure Related to Superstructures

Sliding of wave wall superstructure

Backwards sliding of the superstructure occurs when the horizontal wave force exceeds the friction forces underneath the base plate.

Large displacements lead to tilting and wash-down of the superstructure.
Failure Related to Superstructures

Erosion of reclaimed area due to venting underneath superstructure

- Wave induced water and air pressure pushes the infill material in the air.
- Further erosion of bedding material underneath the base plate might cause displacement and tilting of the superstructure.
Forward tilt of superstructure due to undermining

- Displacement of main armor and erosion of filter layers and core material in front of a superstructure might lead to a forward tilt of the superstructure.
Backside Slope Failure Due to Overtopping

Erosion of rear side armor due to overtopping of a structure with capping

- Displacement of rear side armor.
- Subsequent push - out of bedding material under superstructure due to increased venting.
- Possible slip failure in bedding material causing displacement of superstructure.
Sloping-Front Structures

Failure Due to Toe Berm Erosion and Scour

Failure of main armor due to erosion of toe berm

- Erosion starts at the “shoulder” of the toe and progresses towards the foot of the main armor. The toe is functioning as support for the main armor as long as the toe erosion do not cause undermining of the armor.
- Undermining of the armor layer causes sliding of armor units which eventually are armoring the remaining part of the toe.
Failure Due to Toe Berm Erosion and Scour

Sliding of main armour due to seabed scour

- Formation of scour hole close to the foot of the structure due to wave and current action. The toe is functioning as support for the main armour as long as the toe erosion does not cause undermining of the armour.
- Reduced stabilizing forces causes slip failure to occur which results in sliding of armour.
Sloping-Front Structures

Failure Due to Toe Berm Erosion and Scour
Sloping-Front Structures

Failure Due to Other Toe Problems

Subsidence of blocks into fine material seabeds due to wave induced liquefaction

- Wave induced pore pressure built-up in sandy seabeds reduces the bearing capacity of the seabed material.
- Underlayer stones and armor units sink into the seabed eventually causing an armoring which stops further subsidence.
Instability of toe and foot of armor in shallow water when placed on hard seabeds and exposed to wave breaking

- The forces from breaking waves cause displacement of the blocks unless they are several times heavier than conventional toe blocks and heavier than the main armor blocks. On smooth rock surfaces it is necessary to bolt or anchor the toe block if a trench is not made.
Geotechnical Failures

Wash - out of fine material

- The wave induced pressure gradients causes wash out of finer material through coarser material if the criteria for stable filters are not met.
- Wash - out causes cavites and local collapse of the structure.
Geotechnical Failures

Settlement of the sea bed and the core material

- The weight of the structure causes settlements which, in case of soft sea bed soils and high structures, might reduce the crest design level, thus causing increased overtopping.
- Moreover, differential settlement might cause breakage of in-situ cast concrete caps, road pavements and pipeline installations placed on the superstructure.
Geotechnical Failures

**Slip surface failures (soil mechanics failures)**

- Wave loads on wave wall and related pressure gradients can cause a failure surface to develop underneath the superstructure.
- Under a wave trough there are large antistabilizing pressure gradients generated in the front of the structure. This might, in case of weak sea bed soils, cause the generation of a slip failure surface which penetrates into the sea bed.
Sloping-Front Revetments

Failure Due to Overtopping and Toe Erosion

Back scour failure due to overtopping

- Excess overtopping causes erosion of hinterland.
- Subsequent collapse of top of sea wall structure.
Failure Due to Overtopping and Toe Erosion

- Lowering of beach level below design level in front of the structure.
- Subsequent undermining and sinking of the stone material into the beach.

Toe erosion failure of rubble slope
Sloping-Front Revetments

Failure of Laid-Up Structures

Toe erosion failure of concrete slab armored slope with sheetpile toe wall

- Lowering of beach level below design level in front of toe wall.
- Subsequent tilting of sheetpile and failure of the structure and exposure of the slope to further erosion.
Sloping-Front Revetments

Failure of Laid-Up Structures

Push-out of slab elements due to uplift pressure

- Maximum uplift pressures on the slope elements occur at wave trough conditions.
- Slab elements are pushed out when the resultant pressure forces exceed the resultant gravity and friction forces.
Sloping-Front Revetments

Failure of Laid-Up Structures
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Based on: CEM Chapter VI-2 (Author: Hans F. Burcharath)
Vertical-Front Caissons

Summary of Failure Modes

• Global (Overall) Instability
  • Foundation failure: Slip surface failure
  • Foundation failure: Excessive settlement
  • Overturning
  • Lateral displacement or sliding on foundation

• Local Instability
  • Hydraulic instability of rubble foundation
  • Hydraulic instability of fronting rubble protection
  • Seabed scour in front of structure
  • Breakage and displacement of structural elements
Global Failure Modes

Shoreward sliding of caisson

- Resulting horizontal wave force in seaward direction exceeds the friction force between the caisson base plate and the bedding layer. Large resulting shoreward wave force occurs when wave crests hit the caisson front simultaneously with wave troughs at the rear side of the caisson.
Global Failure Modes

Overturning of caisson around heel

- Tilting of the caisson takes place when the wave induced resulting moment exceeds the gravity based stabilizing moments. The failure mode is relevant only to cases where ground failure does not occur, i.e., in case of rocky sea beds and very strong subsoils. Tilting of a caisson will in most cases cause local crushing of the caisson heel and cracking in the caisson walls.
Global Failure Modes

Settlement

- Vertical settlements occur when soil consolidation takes place.
Vertical-Front Caissons

Global Failure Modes

Slip failure in subsoil

- The caisson base plate load on the subsoil creates stresses which exceed the strength of the soil. The strength of the soil is influenced by possible pore pressure built up due to the cyclic wave induced pressure variations in the soil.
- The slip surface failure causes the caisson to rotate and settle.
Vertical-Front Caissons

Global Failure Modes

Slip failures in rubble foundation and subsoil

- The caisson base plate load on the rubble foundation creates stresses which exceed the strength of the rubble material and possibly also that of the subsoil. The subsoil strength might be influenced by wave induced pore pressure build up.
Local Failure Modes

Erosion of rubble foundation, seaward tilt and settlement

- Wave induced erosion of the seaward rubble foundation might cause seaward tilt and subsequent settlement of the caisson.
- The critical wave load situations are when deep wave troughs occur at the caisson front.
Local Failure Modes

Scour in seabed, seaward tilt and settlement

- Scour in front of a caisson due to waves and currents might cause seaward tilt and settlement of the caisson.
- The critical wave load situations are when deep wave troughs occur at the caisson front.
Vertical-Front Caissons

Local Failure Modes

Push-out of base material due to rocking motion of the caisson

- Wave induced rocking motion of a caisson causes oscillatory porous flow in the bedding layer and the subsoil.
- In case of relatively fine materials a push-out of material might take place resulting in increased rocking motion and subsequent possible ground failure and tilt of the caisson.
Local Failure Modes

- Breakage and displacement of armour units in front of caisson
- The wave action might lead to breakage and/or displacement of the armour units.
- The subsequent increase in the wave forces on the caisson front wall might cause the caisson to slide.
- The damage to the armour protection might increase the overtopping.
Local Failure Modes

Failure of caisson front wall

- Failures might be caused by excess wave loads, deteriorated reinforced concrete and ship impact.
- If the caisson fill is leaking the caisson might slide and/or tilt due to decreased gravitational stability.
Local Failure Modes

Push-out of elements in blockwork structures and failure of shear keys between blocks and caissons

- Wave induced loads might cause elements in blockwork structures to be pushed out of position with subsequent failure of the wall.
- Failure of shear keys between blocks and caissons due to large differential wave loads or due to differential settlements in case of caisson will lead to displacements of blocks and caissons.
Vertical-Front Caissons

Local Failure Modes
Seaward Failure Modes

Sliding of gravity wall

- The sliding of the wall occurs when the resulting pressure on the rear side of the wall from active soil pressure and the groundwater exceeds the sum of the frictional resistance over the base of the wall and the passive resistance at the toe.
Seaward Failure Modes

Seaward overturning and settlement of gravity wall

- Scour in front of the wall reduces both the passive resistance and the bearing capacity of the foundation soil.
- The resulting load from the active backfill pressure, the high groundwater table and the weight of the wall cause a bearing capacity failure in the soil resulting in a forward overturning and some settlement of the wall.
Landward Failure Modes

Landward overturning of gravity wall due to overwash scour

- Heavy overtopping might cause rear side scour and thereby loss of passive resistance from the backfill.
- Wave loads on the front might cause a landward tilt of the wall.
Landward Failure Modes

Component dislodgement in blockwork wall

- Heavy overtopping might cause rear side scour and thereby loss of passive resistance from the backfill.
- Wave loads on the front might push the wall elements out of position.
Vertical-Front Gravity Walls

Foundation Failure Modes

Settlement of gravity wall

- Settlement might be caused by consolidation of the foundation soil or by soil mechanics failures when the foundation load exceeds the bearing capacity of the soil.
Foundation Failure Modes

Rotational slip failure

- Rotational slip failure occurs when the driving moment caused by the weight of soil, groundwater and surface loads exceeds the restoring moment given by the soil strength.
Vertical-Front Tied Walls

Geotechnical Failure Modes

**Toe scour undercut and rotation of sheet wall**

- Toe scour and undercut reduces/eliminates the passive pressure from the soil.
- Subsequent rotation of the wall when the loads from the active soil pressure and the pressure from the groundwater exceeds the passive pressure.
Geotechnical Failure Modes

Rotational slip failure

- Rotational slip failure occurs when the driving moments from the weight of the soil and the surface loads exceeds the restoring moment given by the soil strength.
Vertical-Front Tied Walls

Structural Failure Modes

Yielding in sheet wall

- Yielding in the sheet wall due to stress exceeding the strength
Vertical-Front Tied Walls

Structural Failure Modes

Anchor pullout and seaward tilt of sheet wall

* Excess loads from active soil pressure and high groundwater table or too small wall anchor slabs might lead to anchor pullout and subsequent collapse of the sheet wall.
Vertical-Front Tied Walls

Structural Failure Modes

Overwash scour and failure of sheet wall
Vertical-Front Tied Walls

Structural Failure Modes
Floating Structures

Structural Failure Modes

- Failure of floating sections
- Failure of floating section connectors
- Failure of anchor system or pile supports
- Flooding and sinking of structure or some sections
Beach Fills

Practical Realization

Beach fills are placed on problem shorelines where erosion of the fill is expected. Judgement of success or failure is subjective, and often political opinions override engineering assessments.

Recognized Failure Modes

- Failure to protect upland property or structures during storm events
- Movement of fill material to undesired locations
- Loss of fill material at a rate greater than anticipated for some reason other than design wave exceedance
Conclusions

- Important to identify potential failure mechanisms
- Most structures can fail in several different modes
- Don't confuse "failure" with "damage"