



CHINA ROCK 2025

第二十二次中国岩石力学与工程学术年会

THE 22ND CHINA ROCK MECHANICS AND ENGINEERING ANNUAL ACADEMIC CONFERENCE

Portuguese Coastline Cliffs: Risk Management and Stabilization Solutions

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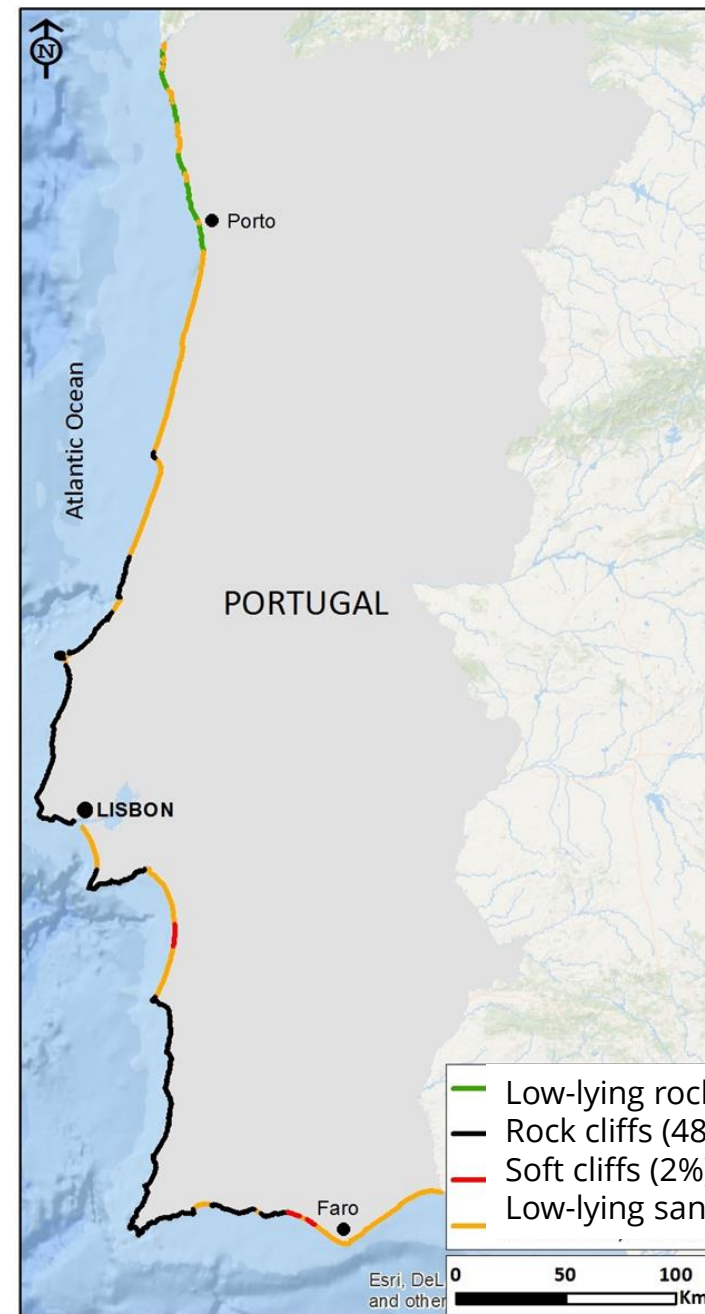
- **INTRODUCTION**
- ROCK CLIFF MAIN DYNAMICS
- RISK MANAGEMENT
- CLIFF STABILIZATION MAIN SOLUTIONS
- CASE STUDY: ALBUFEIRA BEACH
- FINAL REMARKS

Introduction

□ Portugal mainland coastline

- ❖ Low height rocky materials 
- ❖ Rocky cliffs 
- ❖ Small rocky cliffs 
- ❖ Low height sandy materials (dunes) 

Source: APA



Introduction: Portuguese Mainland Coastline



Source: APA

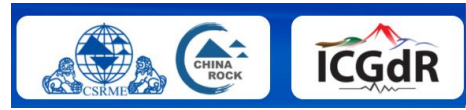
Introduction: Portuguese Atlantic Islands



Volcanic materials



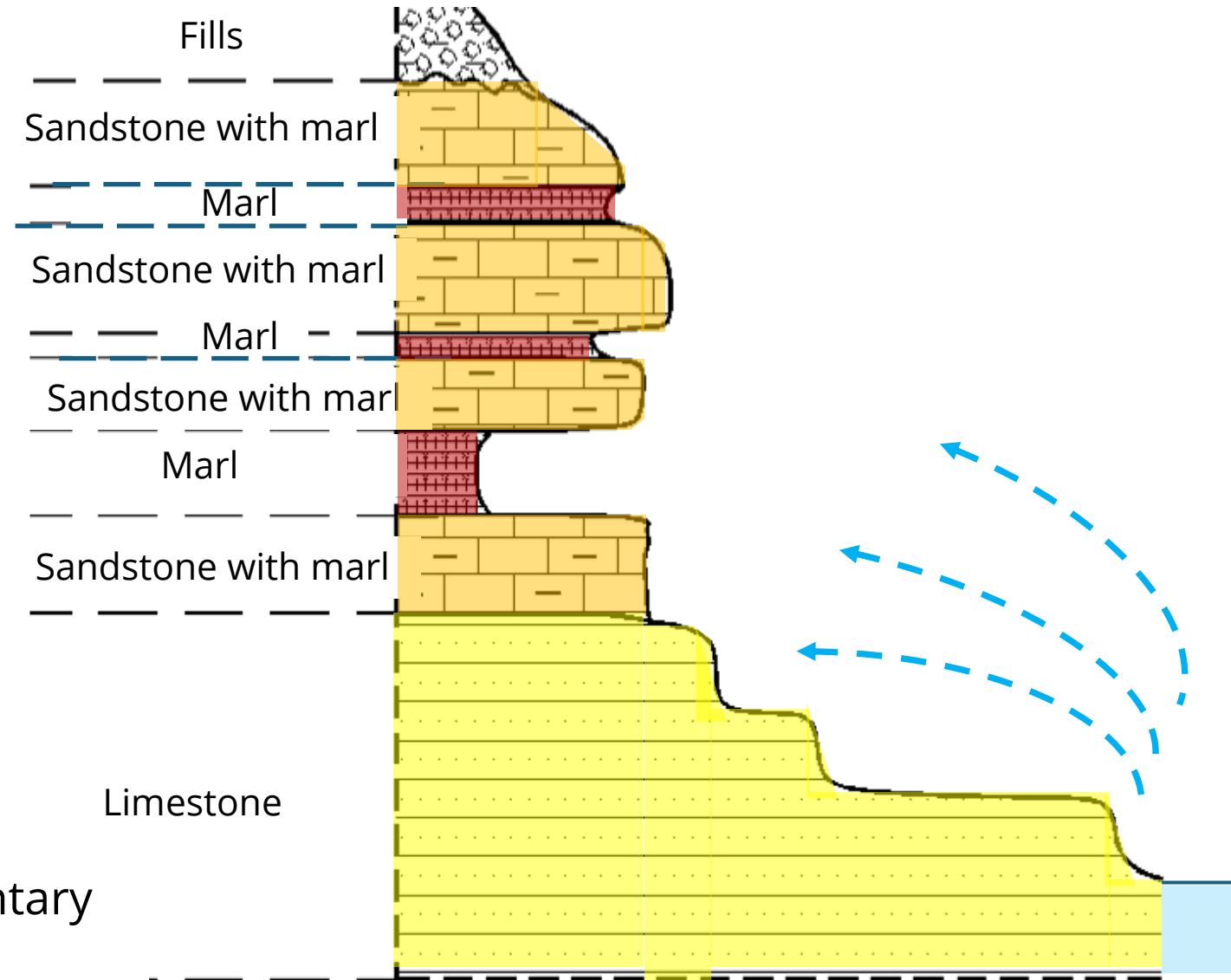
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Rock Cliff Main Geological Conditions

Geology and geotechnics



Typical geological cross section of sedimentary rocky cliffs

□ Geology and geotechnics



Nazaré
cliff

□ Geology and geotechnics

Soft cliffs

- ❖ Cut in **low resistance** materials
- ❖ **Rapid** evolution
- ❖ **Linear and parallel** retreat



Soft rock mass



Source: APA

Rock mass



Rocky cliffs

- ❖ Cut in **high resistance** materials
- ❖ **Slower** evolution
- ❖ **Discontinuous and irregular** retreat in space and time



Rock mass



Rock Cliff Main Dynamics

☐ Movements: main factors and mechanisms

Internal Conditioning Factors

- ❖ **Progressive degradation** of the rock mass resistance and characteristics
- ❖ **Materials characteristics** (composition, degree of weathering and structure of the rock mass)

External Conditioning Factors

- ❖ **Erosive action of sea waves** (abrasion, vibration)
- ❖ **Surface runoff**
- ❖ **Groundwater** infiltration and circulation
- ❖ **Imposition of vibrations and overloads** (anthropogenic activity)

TIME

Decrease of stability conditions

FAILURE

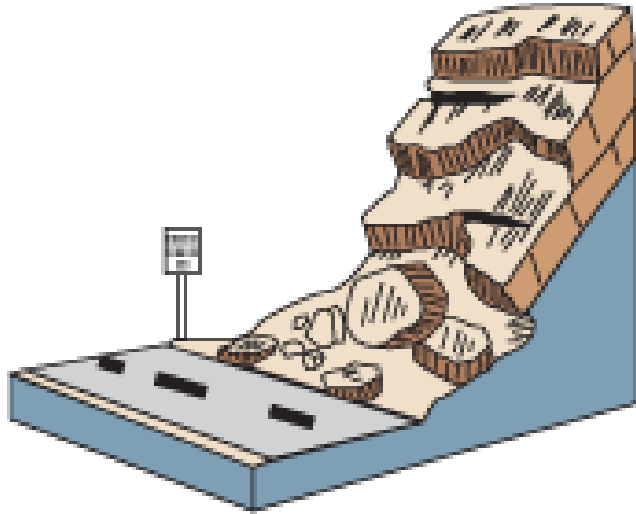


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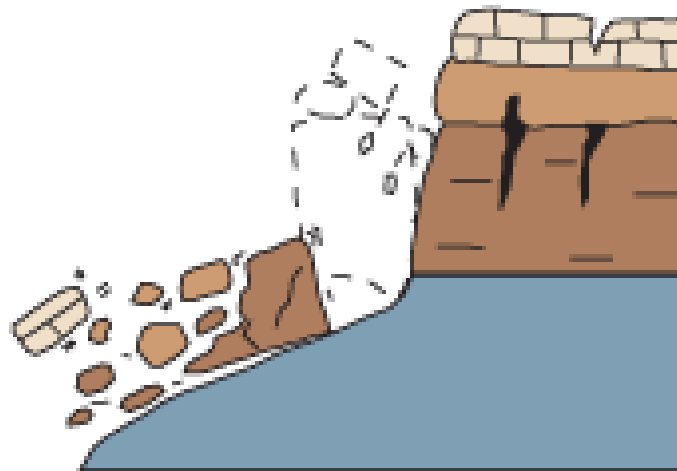
Rock Cliff Main Dynamics

□ Main dynamics

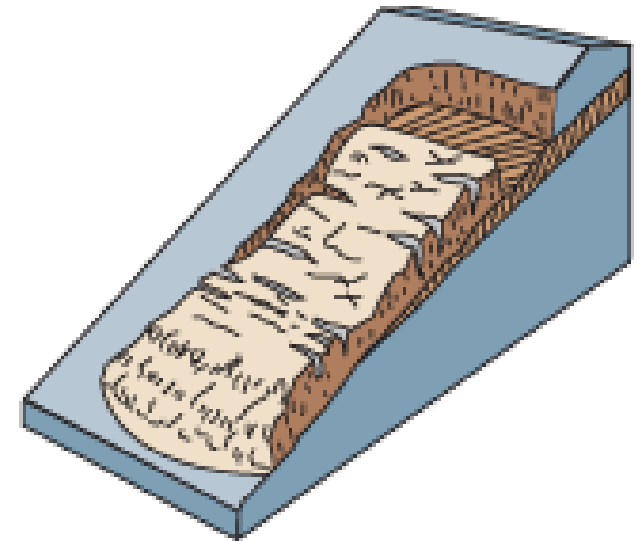
Rockfall



Toppling



Planar slide

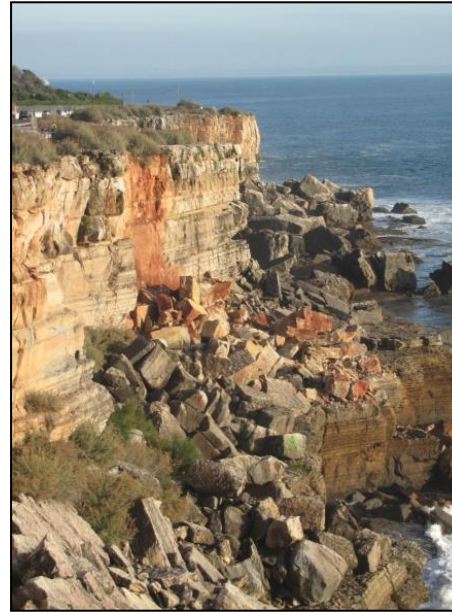


Rock Cliff Main Dynamics

□ Hazard / Risk

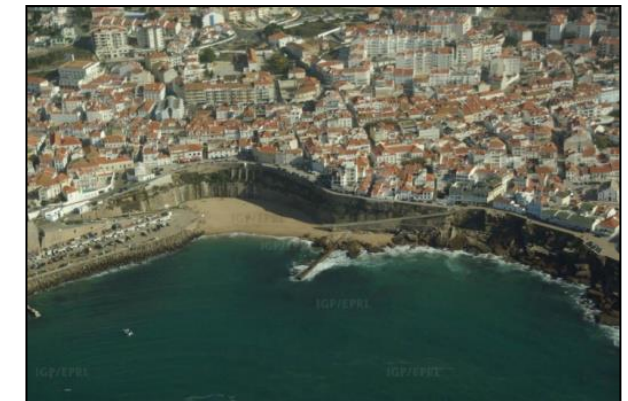
➤ Hazard

- ❖ **Probability** of a potentially hazardous event occur in some location



➤ Risk

- ❖ **Product of the hazardousness due to the degree of loss produced by the occurrence of the phenomenon (depends on the type and density of human occupation)**



Source: APA

Rock Cliff Main Dynamics

- Slope mass movements: need for risk management



Photos: APA



Rock Cliff Main Dynamics

- Base occupation: beach user's risk



Photo: APA

Rock Cliff Main Dynamics

- Base occupation: beach user's risk



Rock Cliff Main Dynamics

- Crest occupation: existent constructions risk



Azenhas do Mar

Rock Cliff Main Dynamics

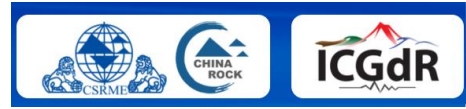
- Crest occupation: existent constructions risk

Facho (Alcobaça) – December 2018



Photos: APA

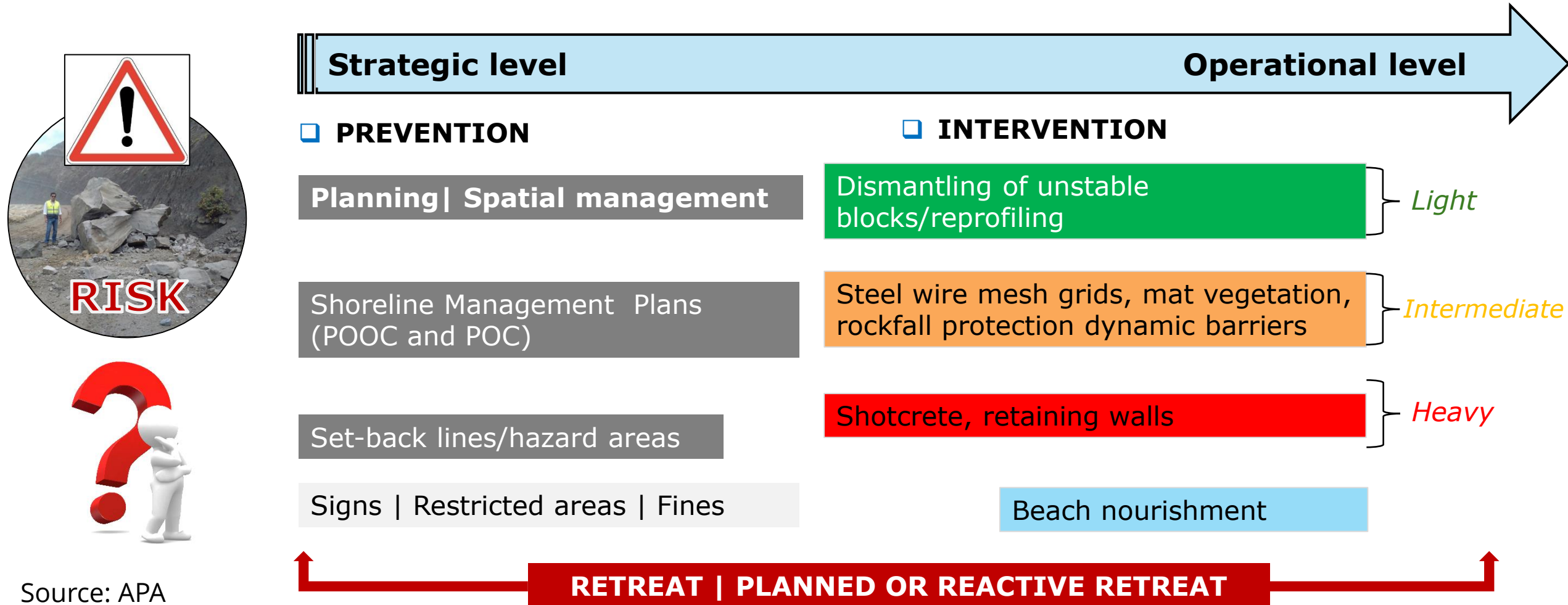
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Risk Management

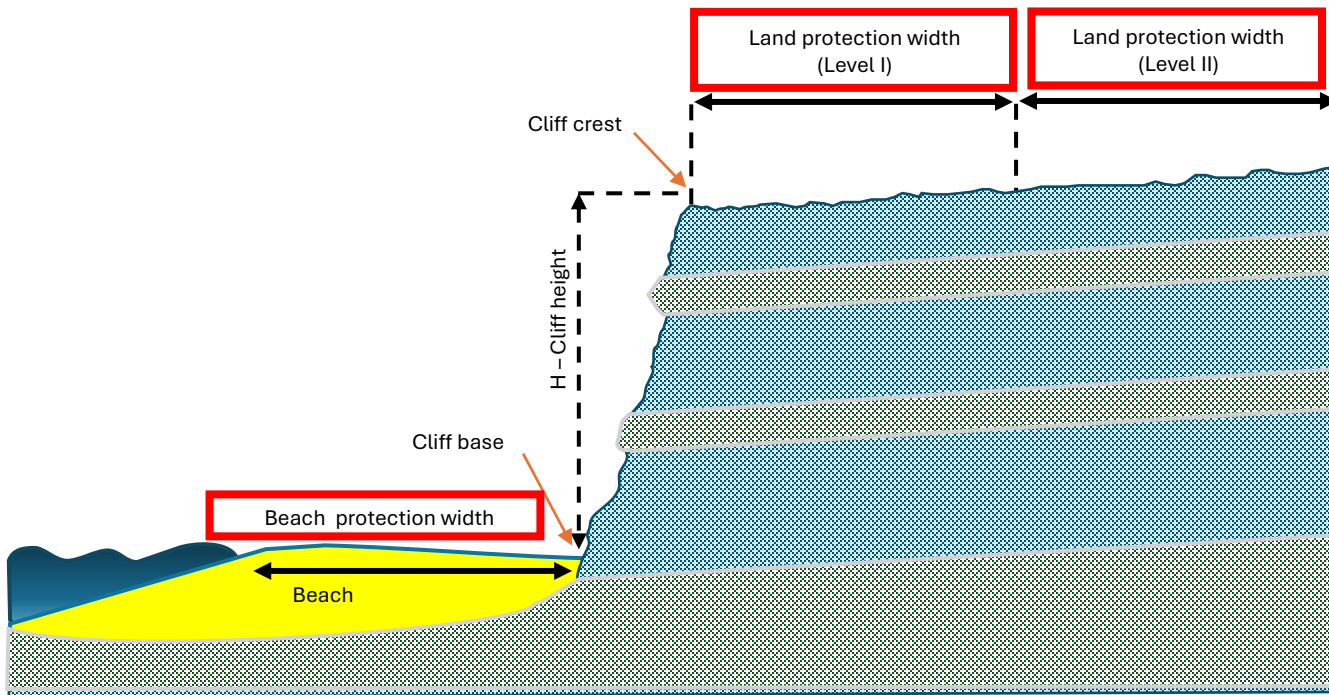
□ Strategic and operational level



Source: APA

Risk Management

□ Planning: Shoreline Management Plans /POOC/POC (Set-back lines / hazard areas)



Cross section



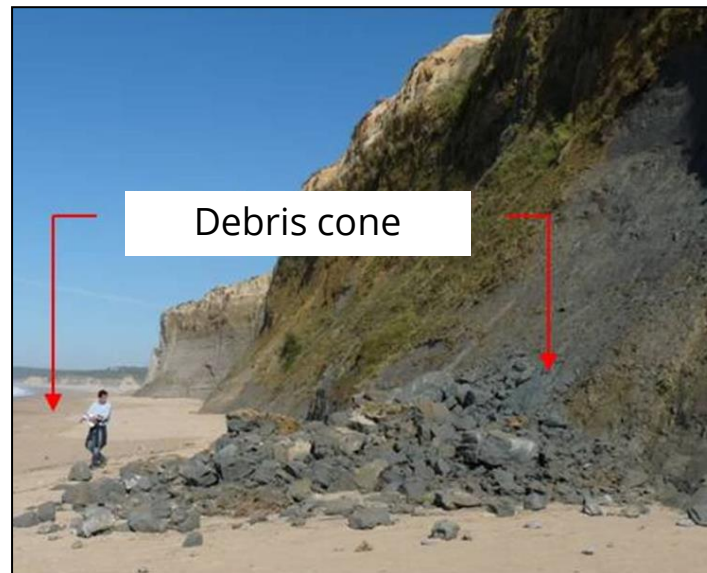
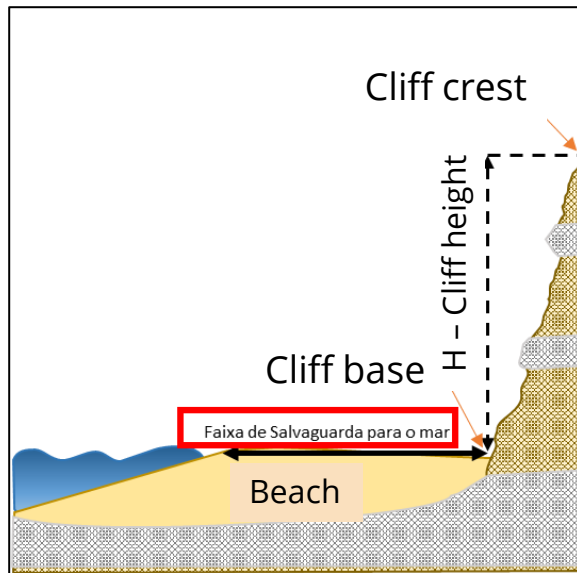
Plan

Source: APA

□ Planning: Shoreline Management Plans /POOC/POC (Set-back lines / hazard areas)

➤ Setting the dimension (width)

- ❖ Analysis of the geological and geomorphological characteristics of the cliffs (in different sectors)
- ❖ **Type of mass movements characterization** (MM) in specific sector
- ❖ **Analysis of the debris widths** (maximum) of MM recorded in a specific coastal stretch (geologically uniform)



❑ Planning: RESTRICTIONS 1/2)

Forbidden/Restricted occupation, except:

- ❖ Study on the geological/geotechnical and evolutionary characteristics of the cliffs → **safety conditions**
- ❖ **Probability of occurrence and size of MM** that may affect the cliff
- ❖ **Cliff stability analysis**
- ❖ Fracturing and resistance conditions of the rock mass
- ❖ Conditions of resistance of the rock mass to the overloads resulting from the construction of the building (if occupancy at the top of the cliff)

Source: APA



□ Planning: RESTRICTIONS (2/2)

Forbidden/Restricted occupation, except:

- ❖ **Foundation conditions** (if occupation occurs at the top of the cliff)
- ❖ **Length of beach that may be affected by debris** (if occupation occurs on the beach – near the base of the cliff)
- ❖ Development of **engineering interventions** (in specific situations)

Source: APA



Risk Management

Planning: CREST SIGNALING

- ❖ ≈ 500 signs/year
- ❖ ≈ 200 replaced
(vandalized/destroyed by the sea)
- ❖ $\approx 35\,000$ €/year

Source: APA

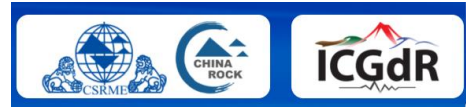


Risk Management

- Planning: BASE SIGNALING



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Cliff Stabilization Main Solutions

- Light: dismantling of unstable cliffs / reprofiling



Photos: APA



Cliff Stabilization Main Solutions

- Light: dismantling of unstable cliffs / reprofiling



Photos: APA



São Julião Beach (Sintra)

Cliff Stabilization Main Solutions

- Light: dismantling of unstable cliffs / reprofiling



São Bernardino Beach
(Peniche)

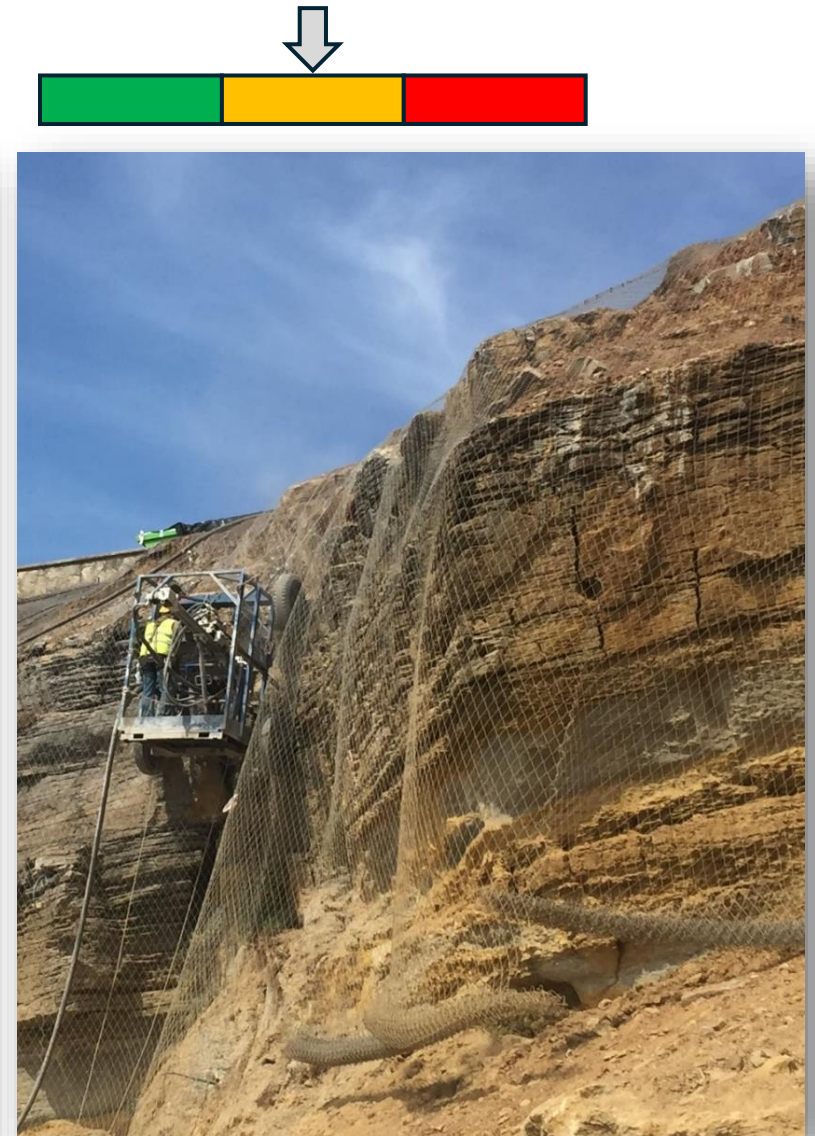
Photos: APA

Cliff Stabilization Main Solutions

- Intermediate: lining and reinforcement with steel meshes, and ground nails



Magoito Beach



Cliff Stabilization Main Solutions



- Intermediate: lining and reinforcement with steel meshes, and ground nails



Zambujeira do Mar Beach

Cliff Stabilization Main Solutions



- Intermediate: lining and reinforcement with mat vegetation and ground nails



Blue Beach (Torres Vedras)

Cliff Stabilization Main Solutions

- Intermediate: lining and reinforcement with steel wire mesh grids and ground nails



South Beach (Mafra)

Cliff Stabilization Main Solutions

- Intermediate: lining and reinforcement with steel wire mesh grids and soil nails



South Beach (Mafra)

Cliff Stabilization Main Solutions



Intermediate: rock fall dynamic barriers

- ❖ High degree of risk reduction
- ❖ Maintenance of the public leisure and safety in the sidewalk
- ❖ Intervention with greater **environmental acceptability** and less impact from a landscape point of view
- ❖ **Cost-effective** solution (15% of the cost of a heavy intervention)



Photos: APA

South Beach (Ericeira)

Cliff Stabilization Main Solutions



- High: retaining walls



Algodio Beach (Ericeira)

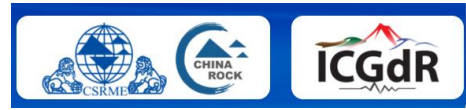
Cliff Stabilization Main Solutions

- High: nails and lining with shotcrete



Albufeira Beach

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Case Study: Albufeira Beach

Location



Case Study: Albufeira Beach

□ Initial scenario

❖ Coastal Cliff:

- Erosion and local mass movements
- Natural geological hazard
- High exposure to atmospheric actions
- Risk increase by high exposure of people accessing and using beach public space



Case Study: Albufeira Beach

□ Initial scenario

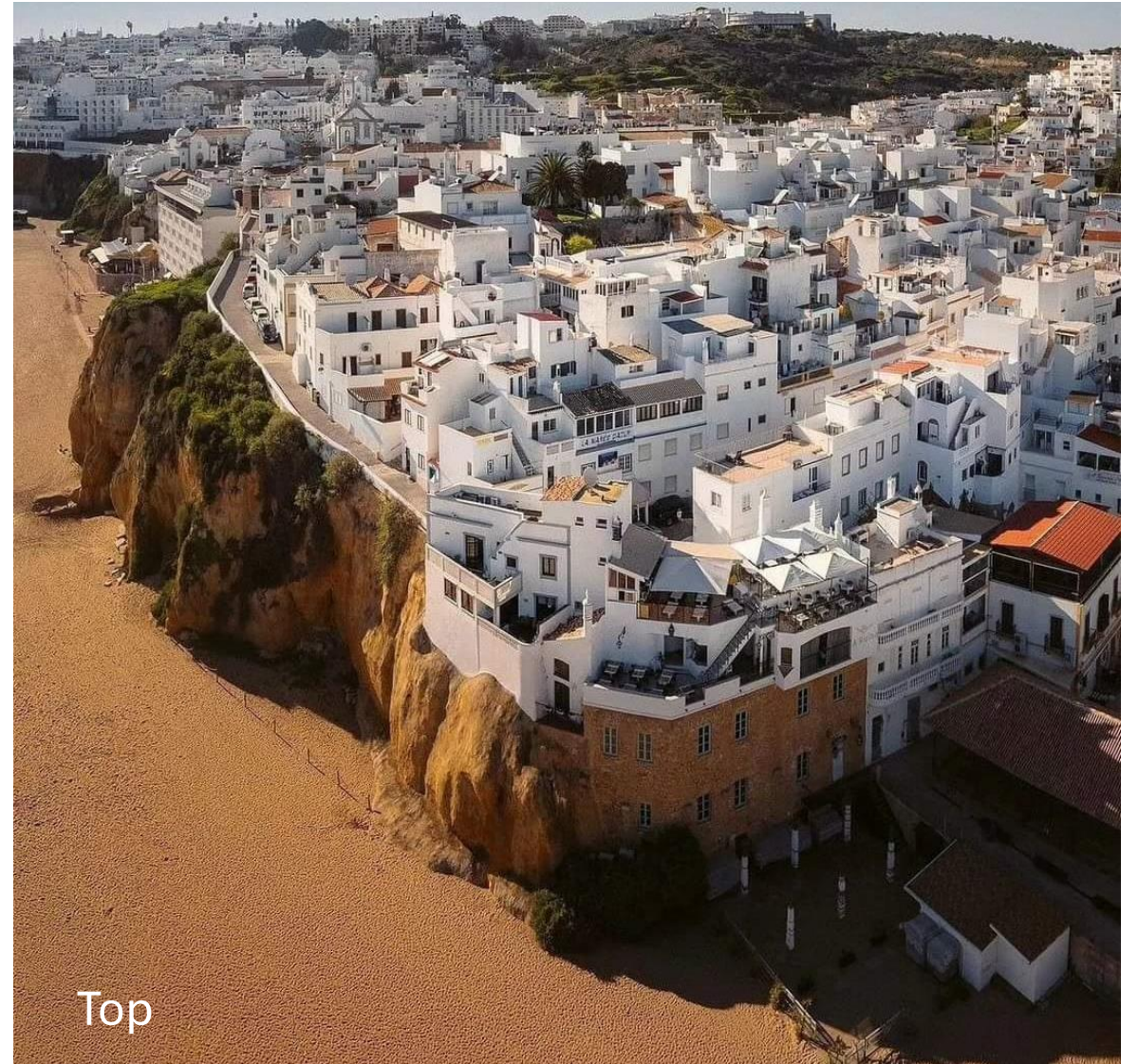
❖ Access Stairs:

- Structural pathologies
- Poor foundation conditions
- Pavement and walls cracks



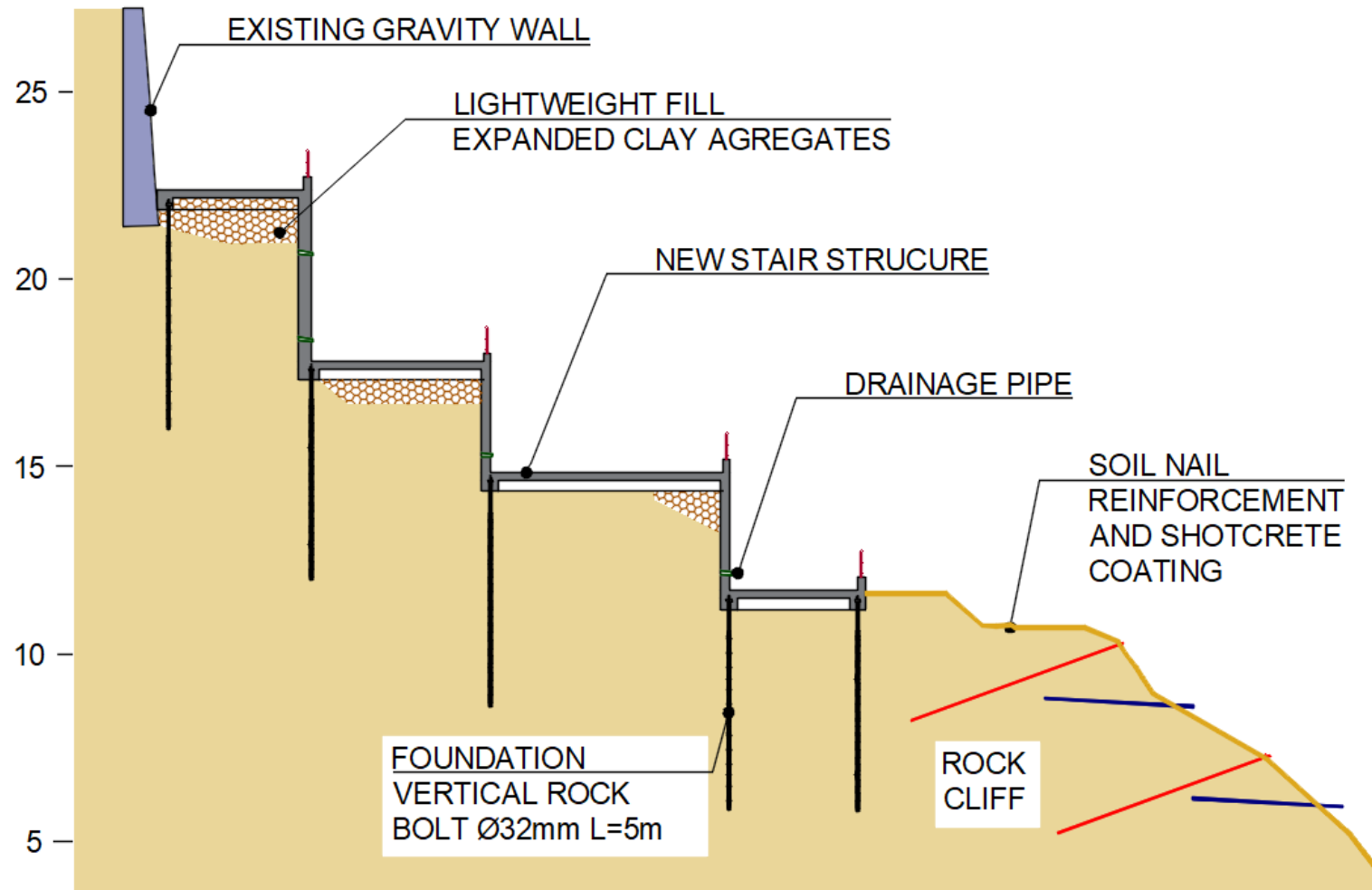
Case Study: Albufeira Beach

□ Main restraints



Case Study: Albufeira Beach

Adopted solutions: access stairs reconstruction cross section

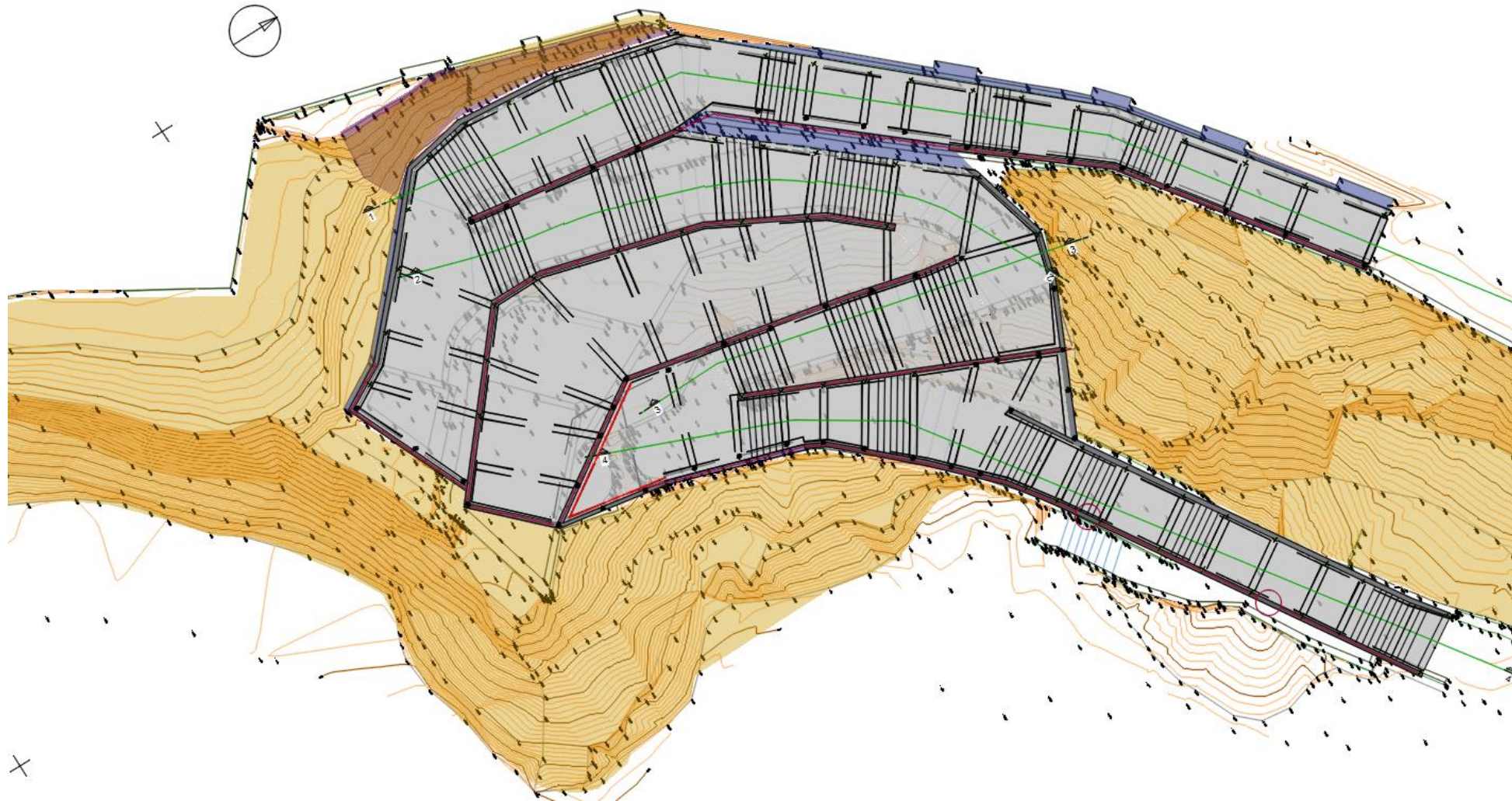


❖ Access Stairs:

- Structure reconstruction
- **Vertical rock bolts** as foundation elements

Case Study: Albufeira Beach

- Adopted solutions: access stairs reconstruction plan view



Case Study: Albufeira Beach

❑ Adopted solutions: cliff stabilization

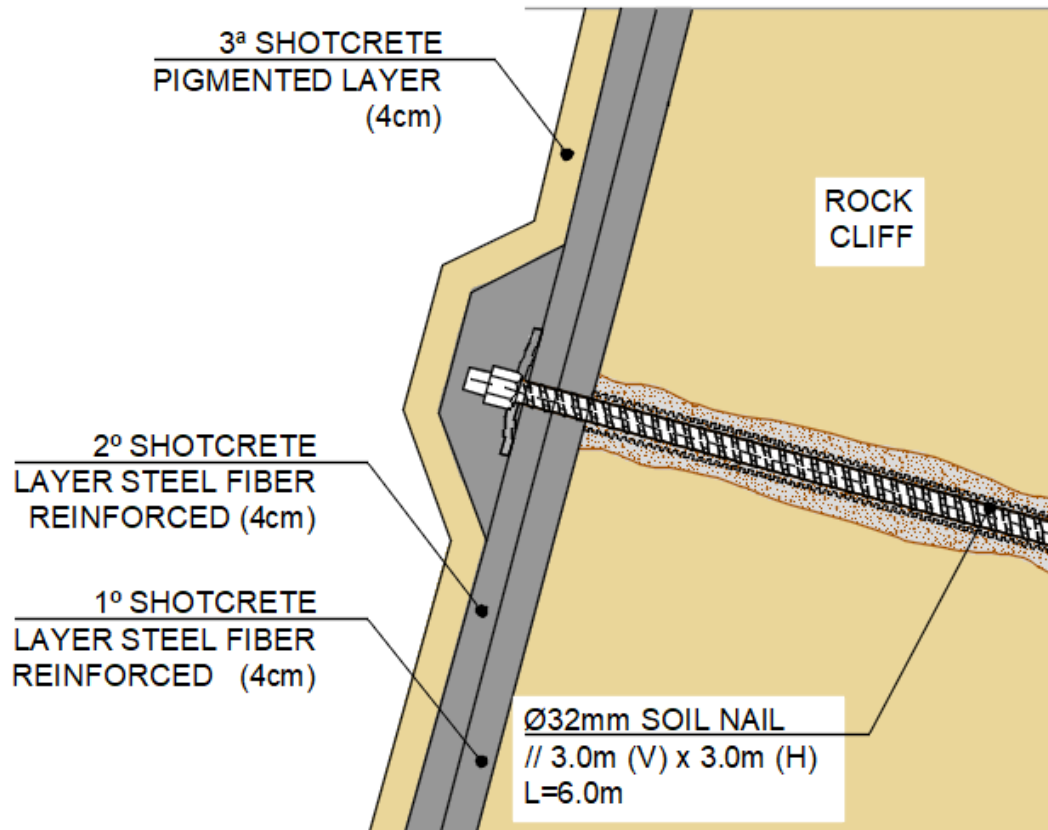
❖ **Cliff stabilization:**

- Ground **nail** stabilization
- **Shotcrete lining** for erosion control with steel fibre reinforcement
- Pigmented (yellow) shotcrete for **environment** integration
- Shotcrete **drainage** using geodrains

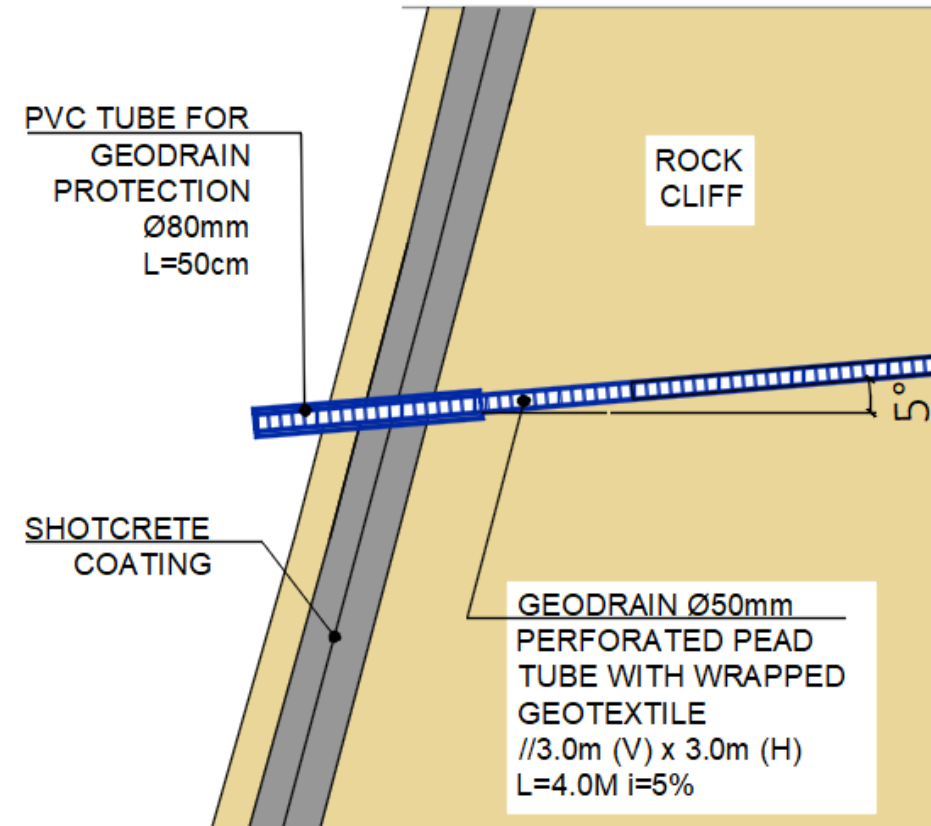


Case Study: Albufeira Beach

Adopted solutions: cliff stabilization



Shotcrete and ground nail detail



Geodrain detail

Case Study: Albufeira Beach

Executed works

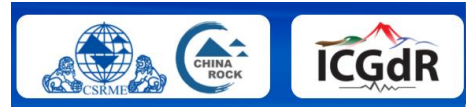


Case Study: Albufeira Beach

Executed works



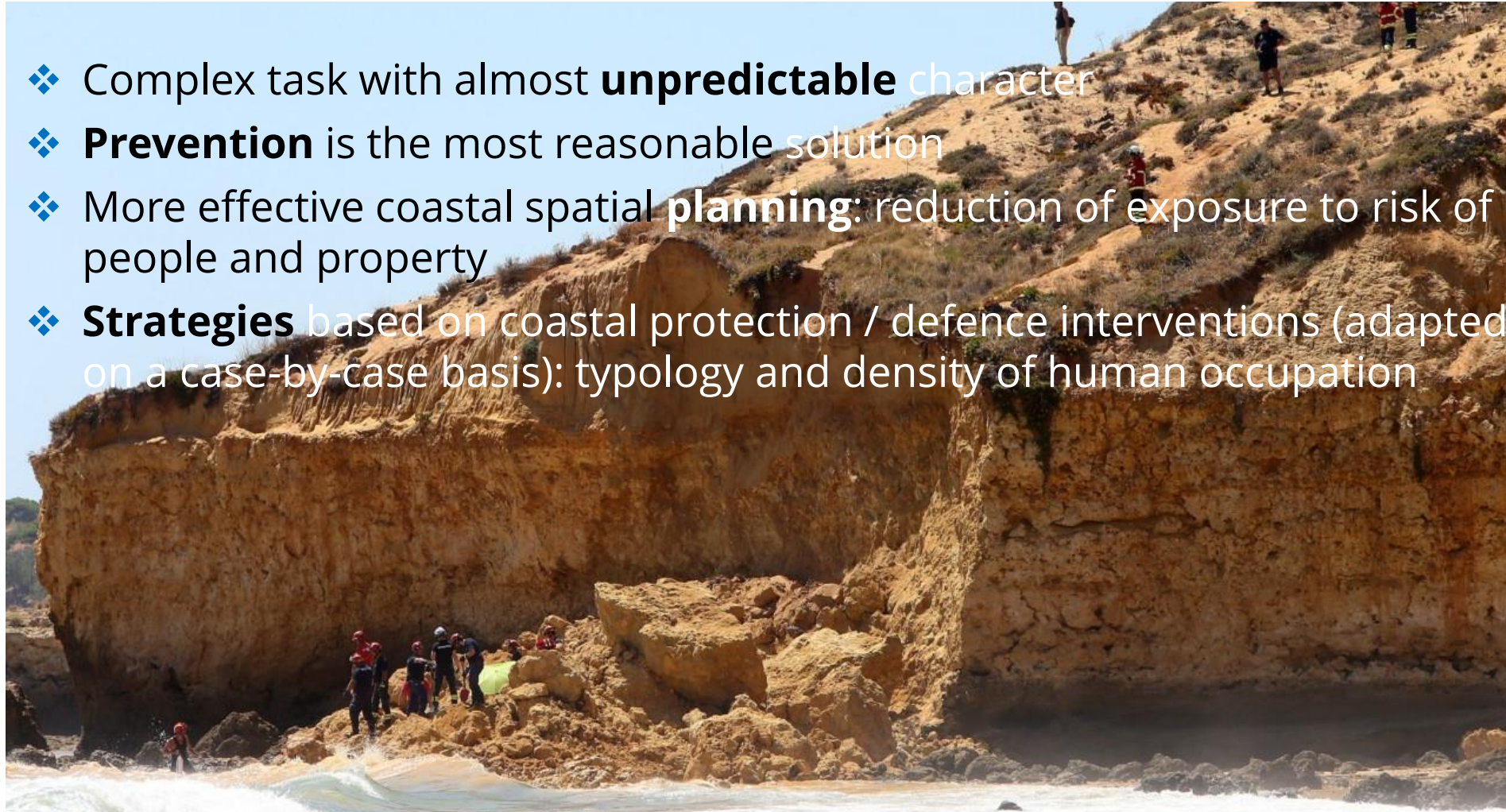
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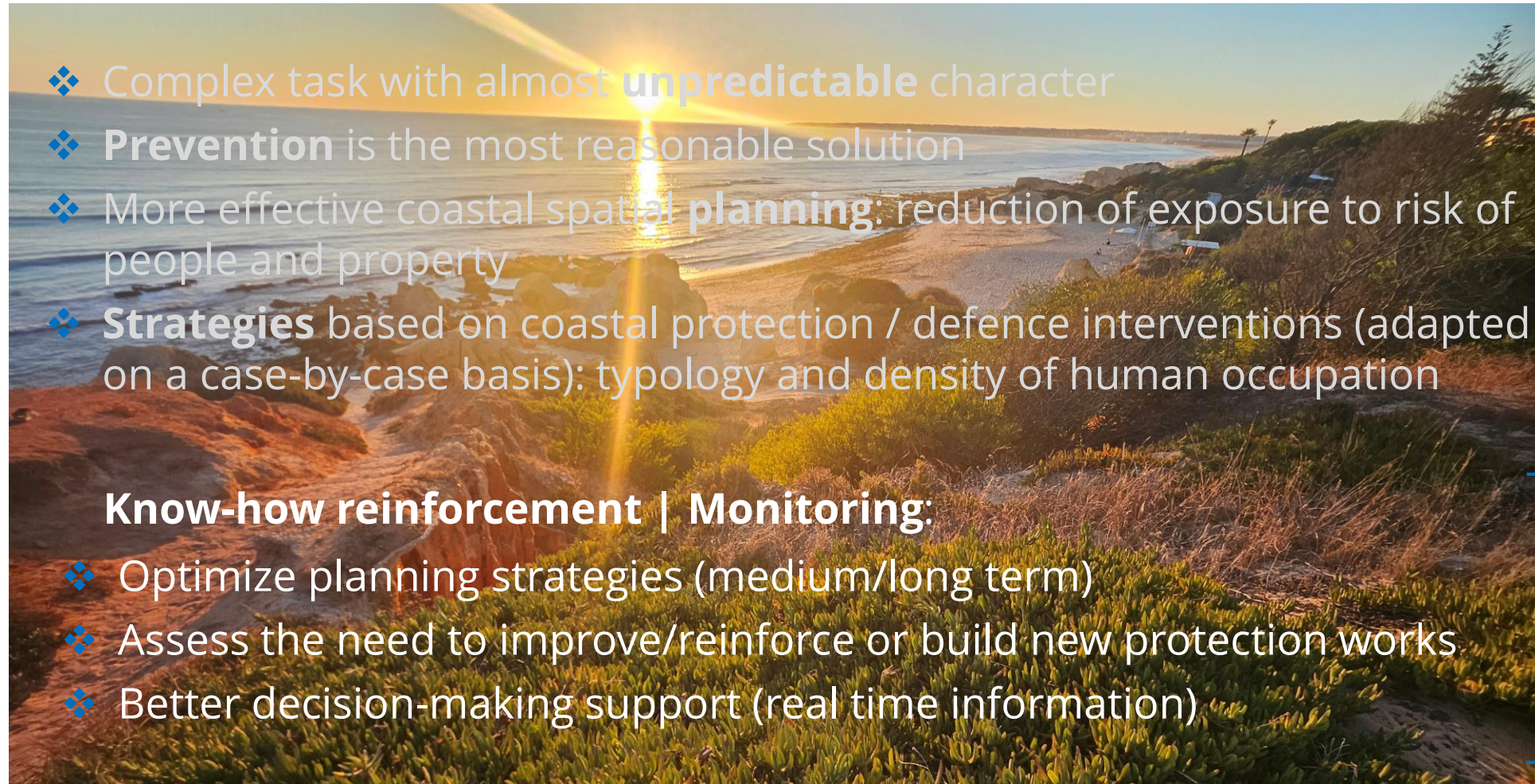
❑ Risk management in rocky coastal cliffs

- ❖ Complex task with almost **unpredictable** character
- ❖ **Prevention** is the most reasonable solution
- ❖ More effective coastal spatial **planning**: reduction of exposure to risk of people and property
- ❖ **Strategies** based on coastal protection / defence interventions (adapted on a case-by-case basis): typology and density of human occupation



Source: APA

❑ Risk management in rocky coastal cliffs

- 
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 - ❖ **Strategies** based on coastal protection / defence interventions (adapted on a case-by-case basis): typology and density of human occupation

Know-how reinforcement | Monitoring:

- ❖ Optimize planning strategies (medium/long term)
- ❖ Assess the need to improve/reinforce or build new protection works
- ❖ Better decision-making support (real time information)

**OPTIMIZATION
OF
COASTAL RISK
MANAGEMENT**

Source: APA

Acknowledgements



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portuguese
environment
agency



**Thank you for the kind
attention!**

Benagil
cave,
Algarve,
Portugal



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