Natural stone as structural material

Relevance, Opportunities, and New Challenges in Construction

Clemente Pinto

Professor and Researcher in Structural Mechanics

UNIVERSIDADE da BEIRA INTERIOR / C-MADE

UNIVERSIDADE BEIRA INTERIOR

FACULDADE ENGENHARIA

Departamento de Engenharia Civil e Arquitetura

C MADE

CENTRE OF MATERIALS & BUILDING TECHNOLOGIES

Excellent structural material

Good mechanical strength

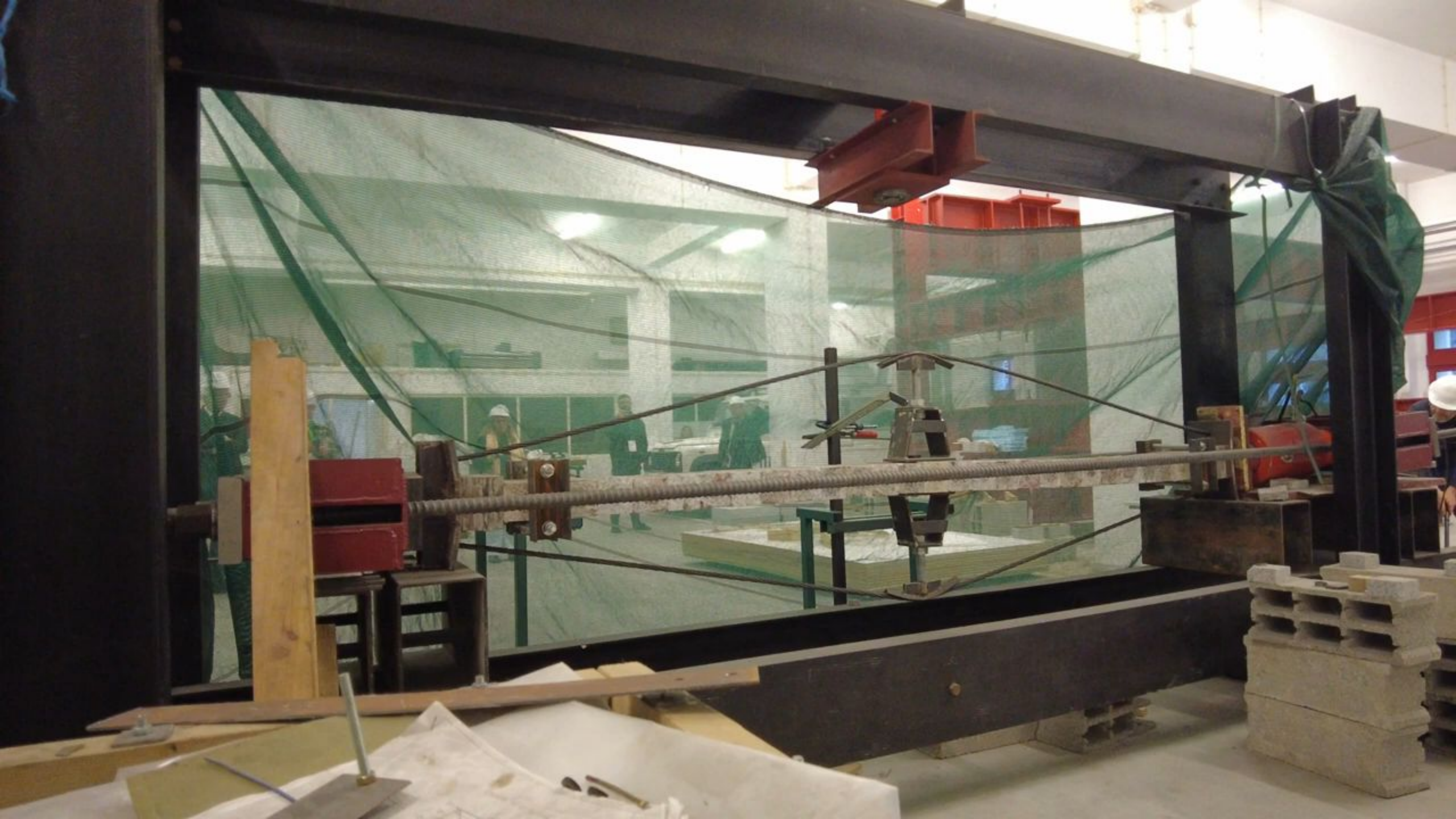
- High to ultra-high compressive strength: 140 MPa-230 MPa;

Excellent durability

- Appropriate use depending on design and structural planning;

Globally abundant

- Potential to contribute to solving sustainability challenges in construction.



Conditionings (same as concrete)

Limited tensile strength

•Construction with joints;

Lack of "moldability"

•Overcome by cutting technology;

•Appropriate use depending on design and structural planning;

Balance depends on shape

•Architectural forms with curvature, limiting applications.

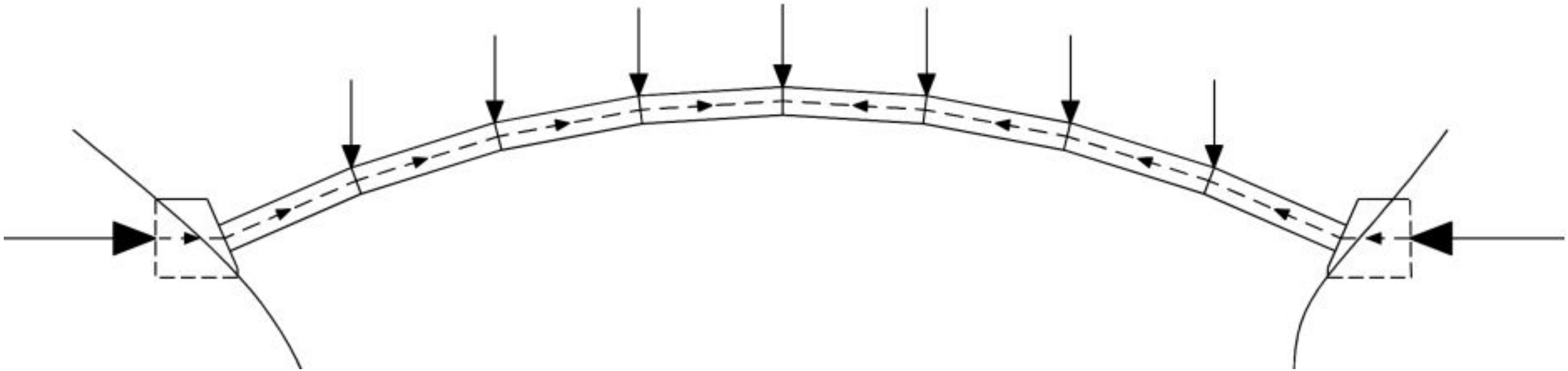
Interior da Sé da Guarda

Interior da Sé
da Guarda

Danhe Bridge
(World record for longest stone arch bridge)

Ponte Danhe
(Recorde mundial
de ponte em arco)

http://www.highestbridges.com/wiki/index.php?title=Danhe_Bridge



Reinforced concrete

Combination of concrete with steel

- Solved the mechanical limitations of concrete;
- Shape is no longer necessary for balance;
- Flexibility in architectural spaces.

Ponte de S. João (Engº Edgar Cardoso)

Prestressed concrete

Arch function without arch shape

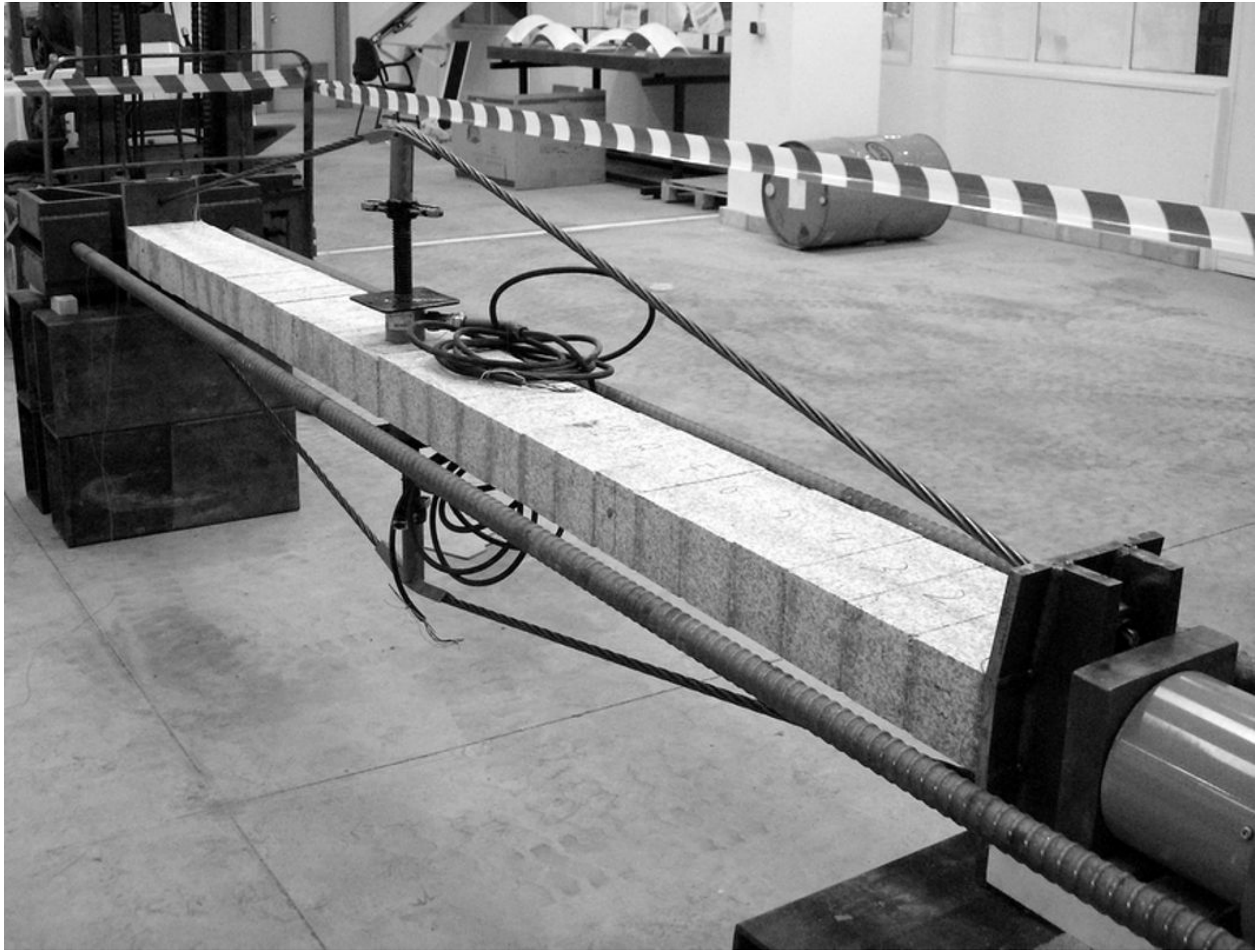
- Pre-compress the concrete with high-strength steel cables;
- Slender structures;
- Long-span elements.

Ponte de S. João (Engº Edgar Cardoso)

Prestressed stone

Pre-compress stone blocks with external or internal cables:

- Utilize the high compressive strength of natural stone;
- Well-developed technology in prestressed concrete construction.



High-strength granite beam-column prestressed with external cable

Prestressed limestone stairs

(The Stone Masonry Company, LTD)

“The New Stone Age” (Exposição em Londres)

Limestone prestressed beam

(The Stone Masonry Company; Webb Yates Engineers; Groupwork)

Opportunities

Reduction of carbon footprint in construction

WEBB YATES ENGINEERS

POLYCOR

THE STONEMASONRY COMPANY LIMITED

eight associates

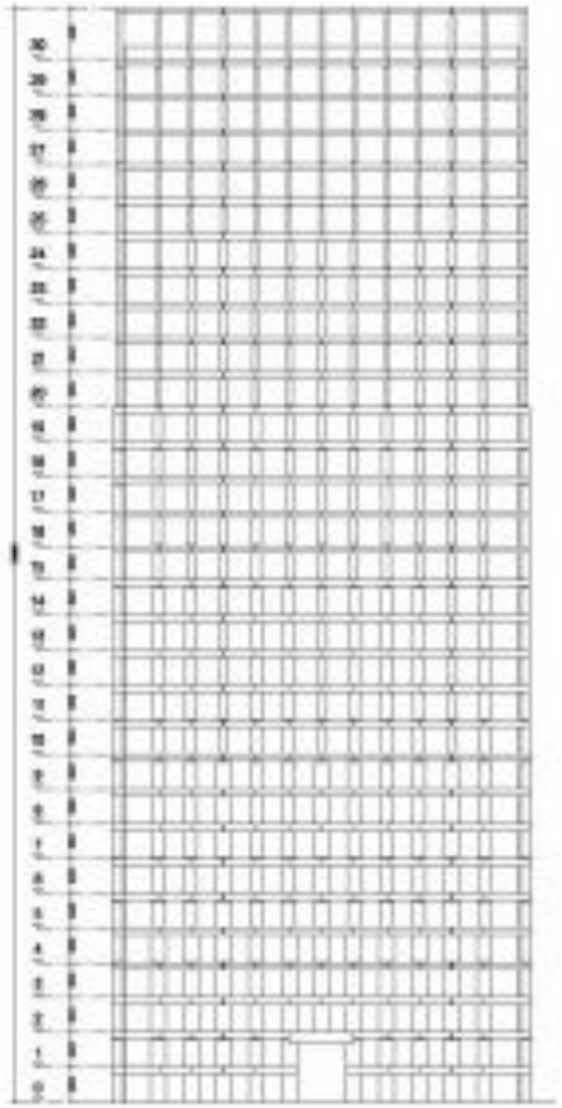
GROUPWORK

jackson|coles

Stone Tower Research Project

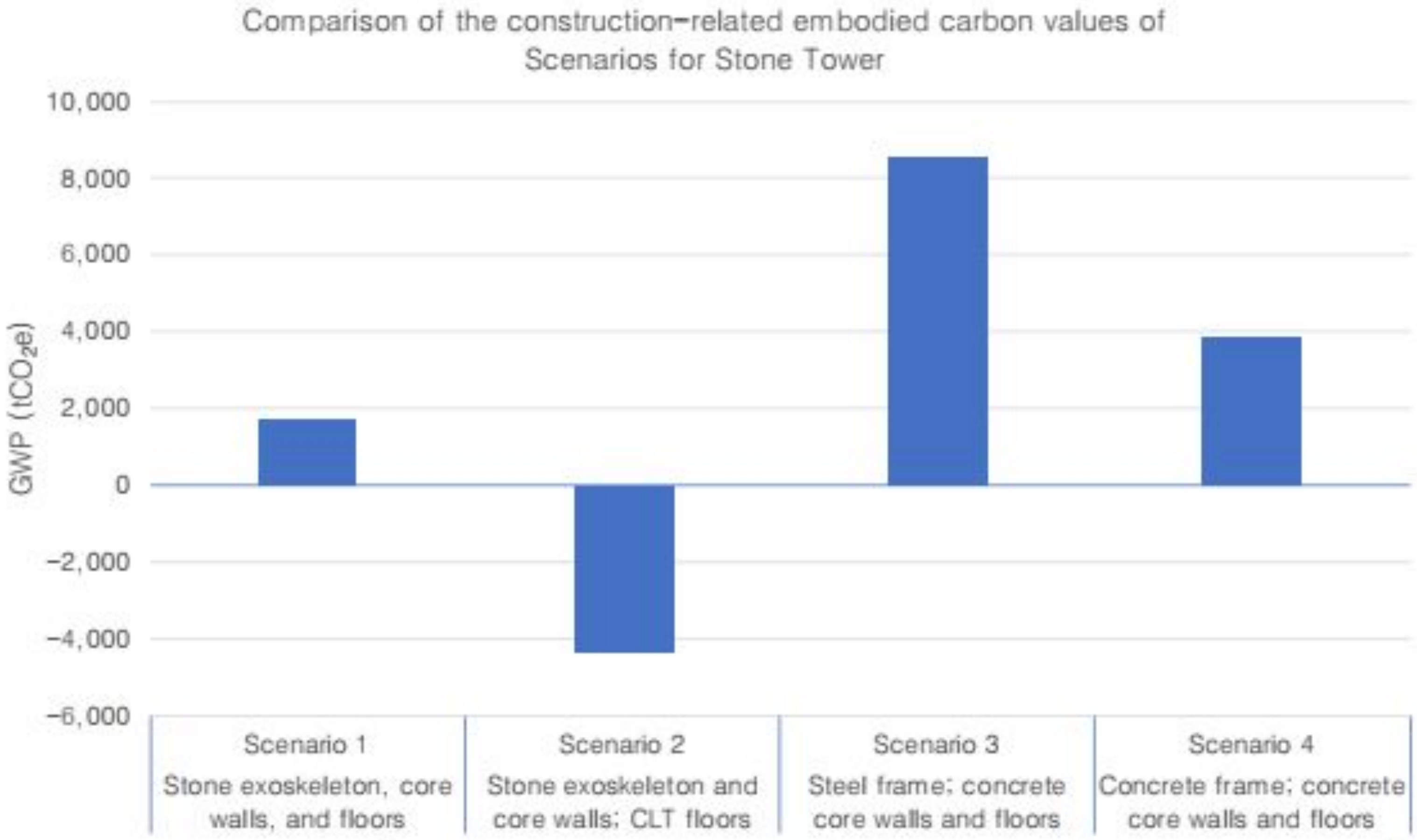
Opportunities

Reduction of carbon footprint in construction



Opportunities

Reduction of carbon footprint in construction



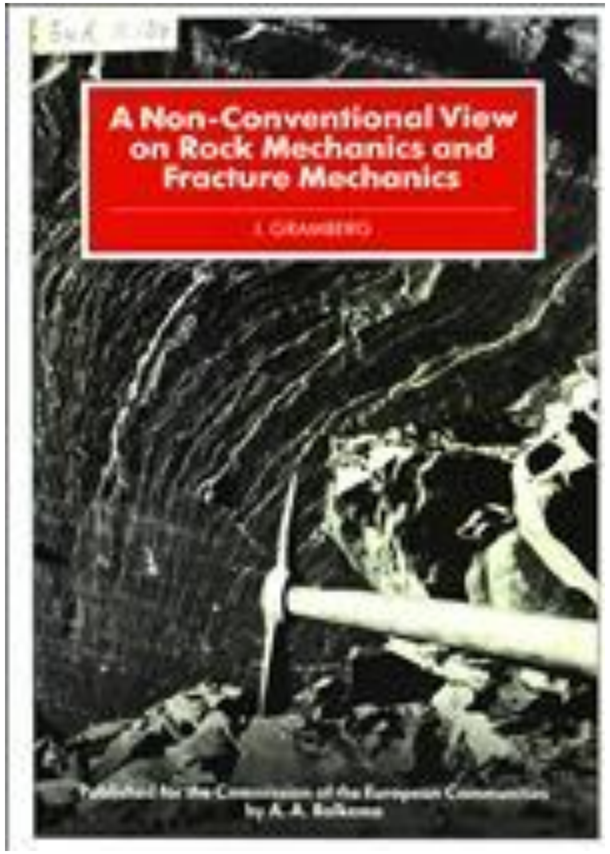
Opportunities

- **Use of lower-value quarry material in other applications;**
- **New complementary products to the current ranges;**
- **Approach with integrated solutions for the construction industry:**
    - **Concrete replaced by stone;**
    - **Reinforced concrete replaced by reinforced stone;**
    - **Prestressed concrete replaced by prestressed stone;**
    - **Stone-wood combinations.**
    - **The construction sector is moving towards prefabrication.**

Challenges

More than a century of residual use of stone in structural applications:

- **Lack of scientific and technical knowledge;**
- **Absence of specific regulations:**
  - **Eurocode (????????);**
  - **Limits widespread stone construction;**
  - **Does not limit the use of certified products.**
- **Lack of awareness among stakeholders in the construction sector:**
  - **Architects;**
  - **Engineers;**
  - **Academia;**
  - **Companies.**



https://op.europa.eu/en/publication-detail/-/publication/bfbf24ff-273b-4c31-b19a-566989fccb81#_publicationDetails_PublicationDetailsPortlet_relatedPublications

[Gramberg, J]

These forces were used and controlled by the miners, only based on practical experience. This changed after 1930, when science was about to be introduced into underground mining. This was due, namely, to the fact that in 1947 the first symposium in the world on the subject of Roch Mechanics, then called "Rock Pressure", had been organized in Heerlen, Holland. The effect of that symposium took a few years to penetrate mentally. At the mining department of the Delft University of Technology (Holland) the lessons in "Rock Pressure" (or Rock Mechanics) were started immediately after that symposium.

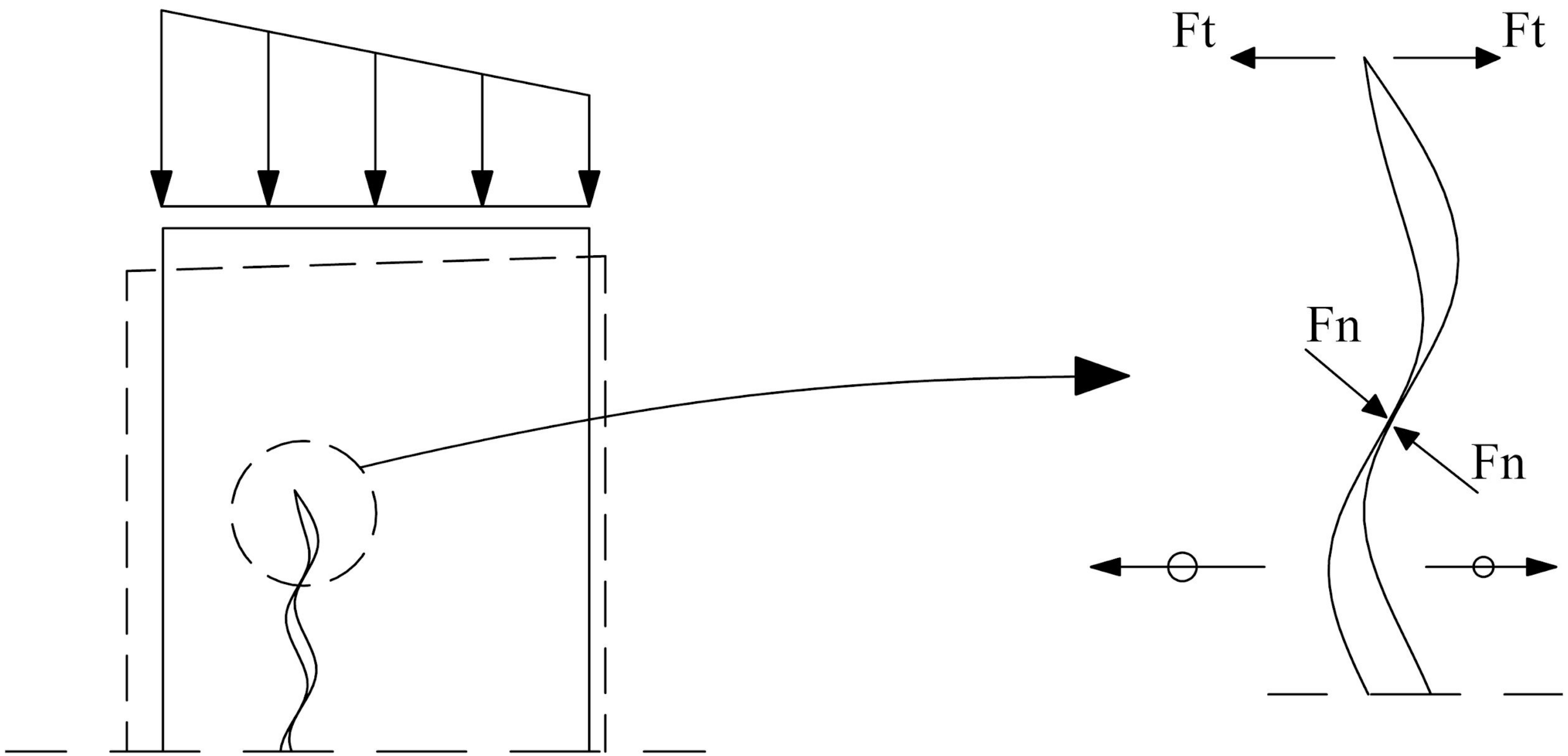
From the beginning we have asked ourselves what the exact meaning could be concerning the "compressive strength"; and what is "fracture"?

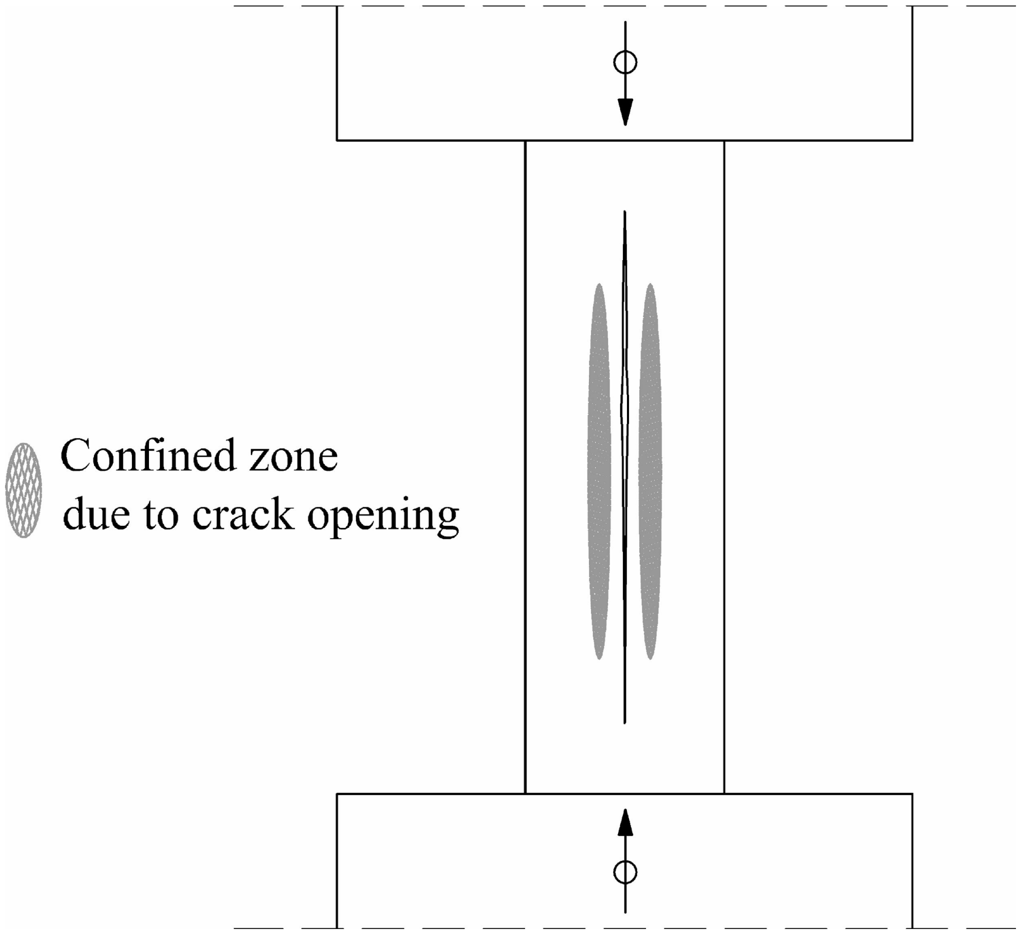
As a result of this extensive research it became clear that the phenomenon of the axial cleavage fracture was everywhere strongly dominant: in the mine, in the tunnel wall, and also in the form of a diaclase or joint system in the earth's crust, in fact, everywhere in hard rock

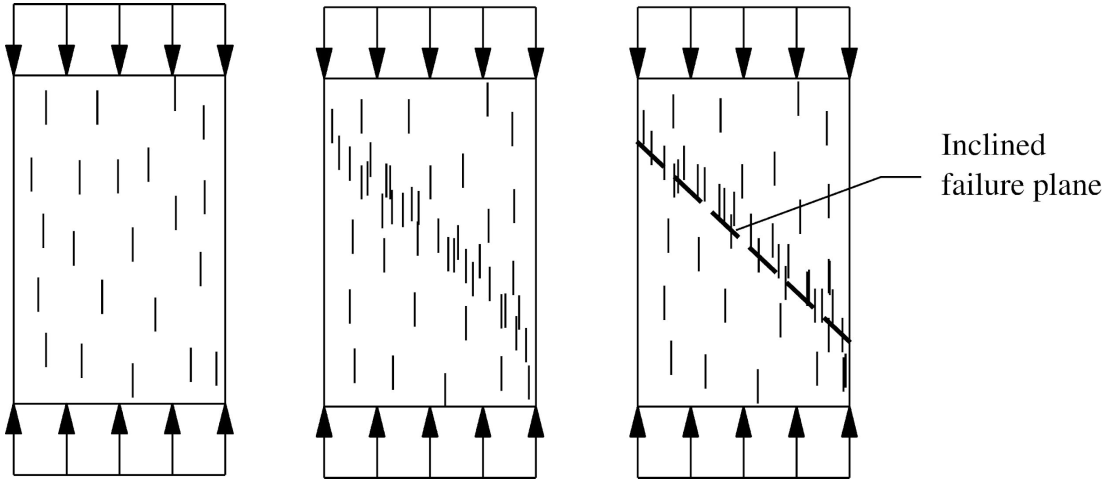
It should be kept in mind that the behaviour of fracturing in the various rock types shows a great variety of forms. It has to be understood as well that the theories of stress and elasticity are no other than products of very clever human intelligence, which are based on a strongly idealized picture of solid material.

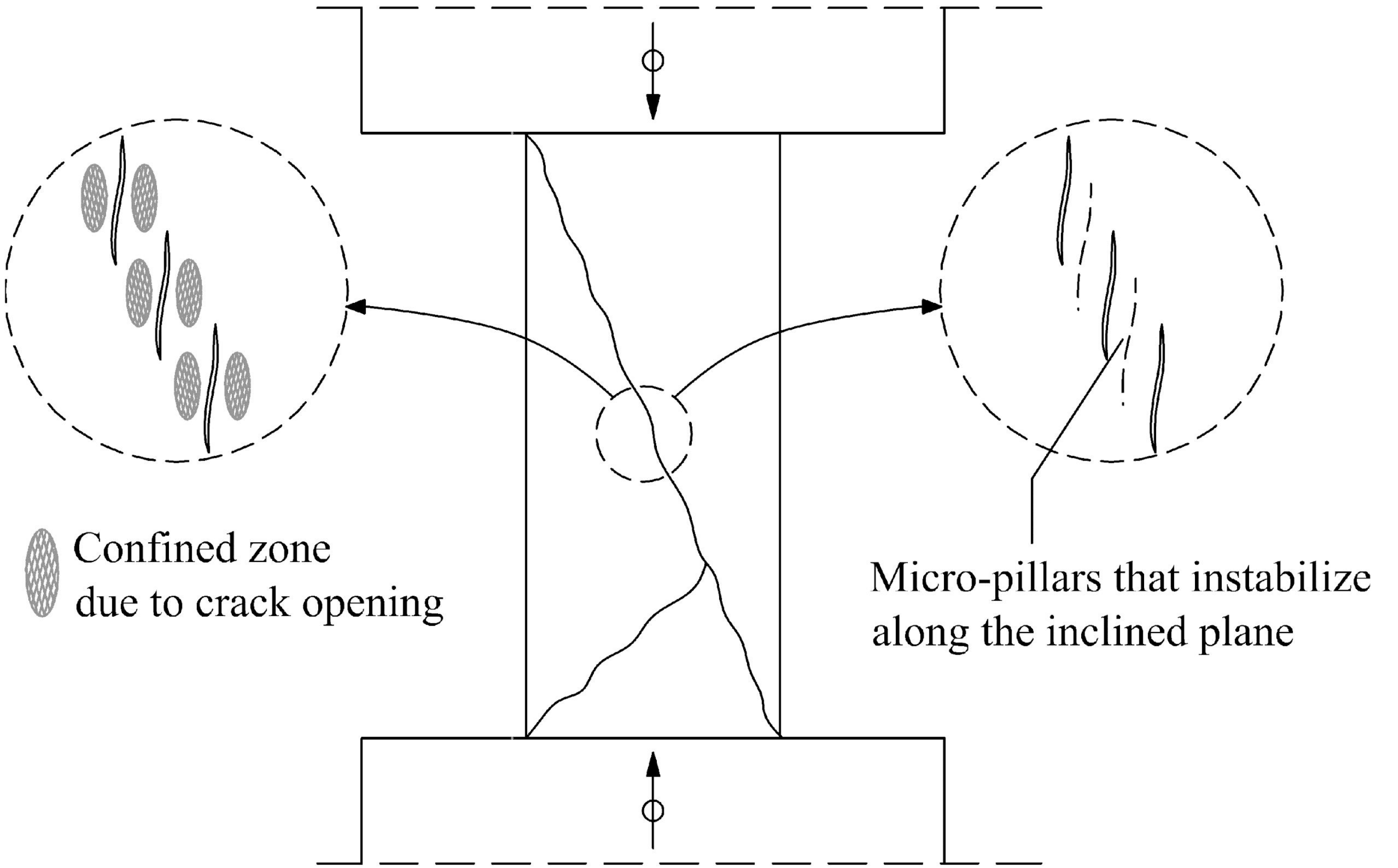
It took me more than 30 years to start, to gather and to complete the basic material which forms the contents of this publication. Within this period I received training, opportunity, support and encouragement from many institutes and persons from all over the world. Their number is much too large to mention all of them here separately. Now I am already pensioned for 10 years, but still I have the opportunity to work and to move about in the familiar environment of the Mining Institute of the Delft University of Technology. Because my knowledge of mining, geology, mineralogy and rock behaviour was initiated and developed mainly within this Institute, I consider the T.U.D. as my "Alma Mater". Therefore, although I may act as a private person, I consider my activities to be under the auspices of the T.U.D. However, this report, which contains the matured and completed contents of a basic subject of my research, would never have been written without the encouragement and the support of the Directorate-General for Science, Research and Development of the Commission of the European Communities. Therefore I express my special acknowledgement to the C.E.C.

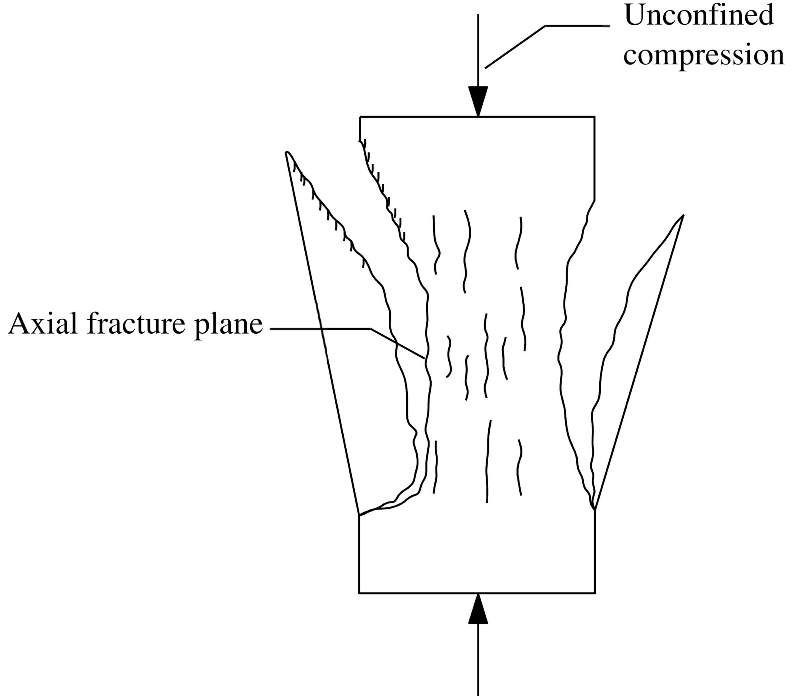
The Hague/Delft, December 1987 J. Gramberg Ph.D. Mining Engineer


Ft
Ft
Fn
Fn


Confined zone
due to crack opening

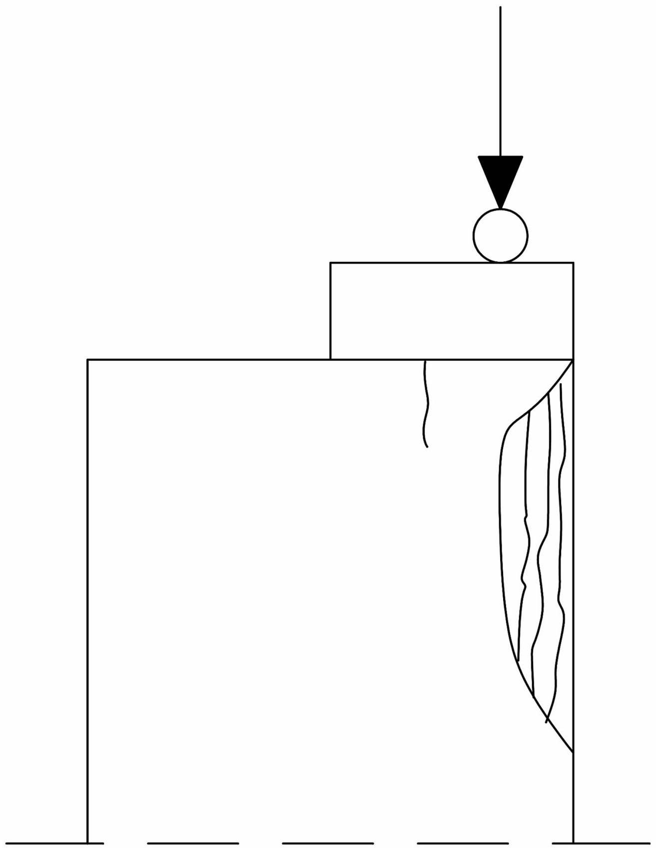

Inclined
failure plane

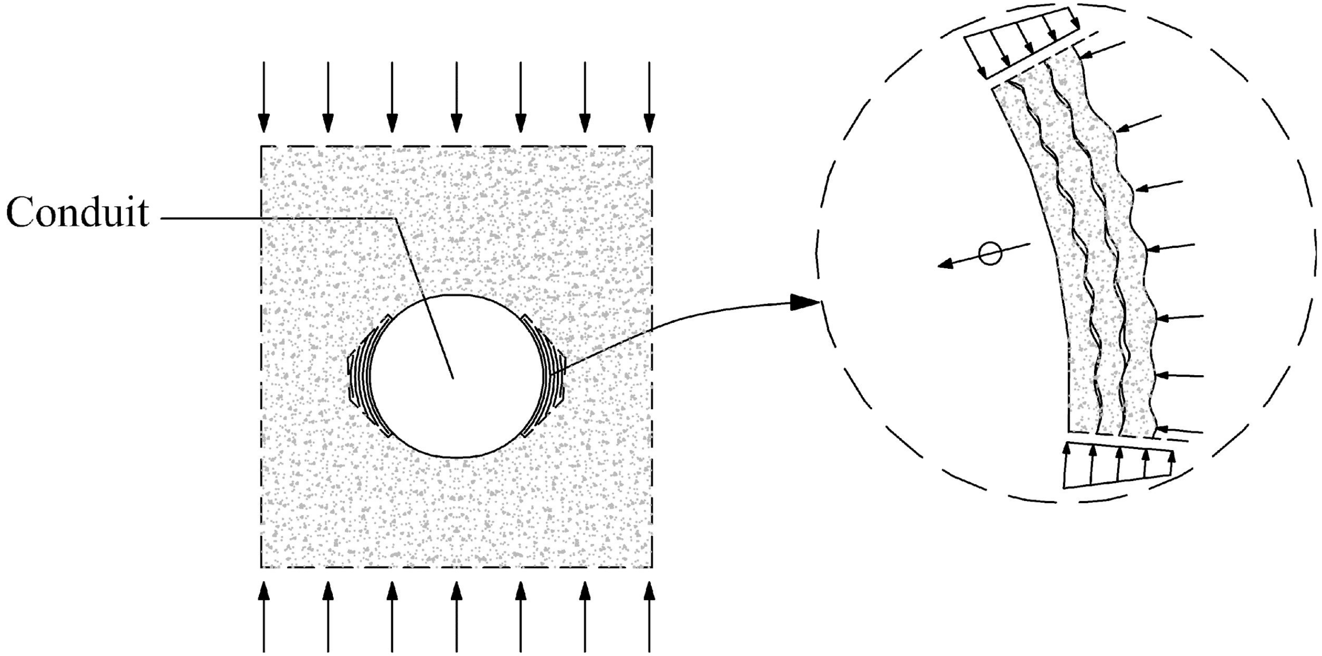

Confined zone
due to crack opening
Micro-pillars that instabilize
along the inclined plane

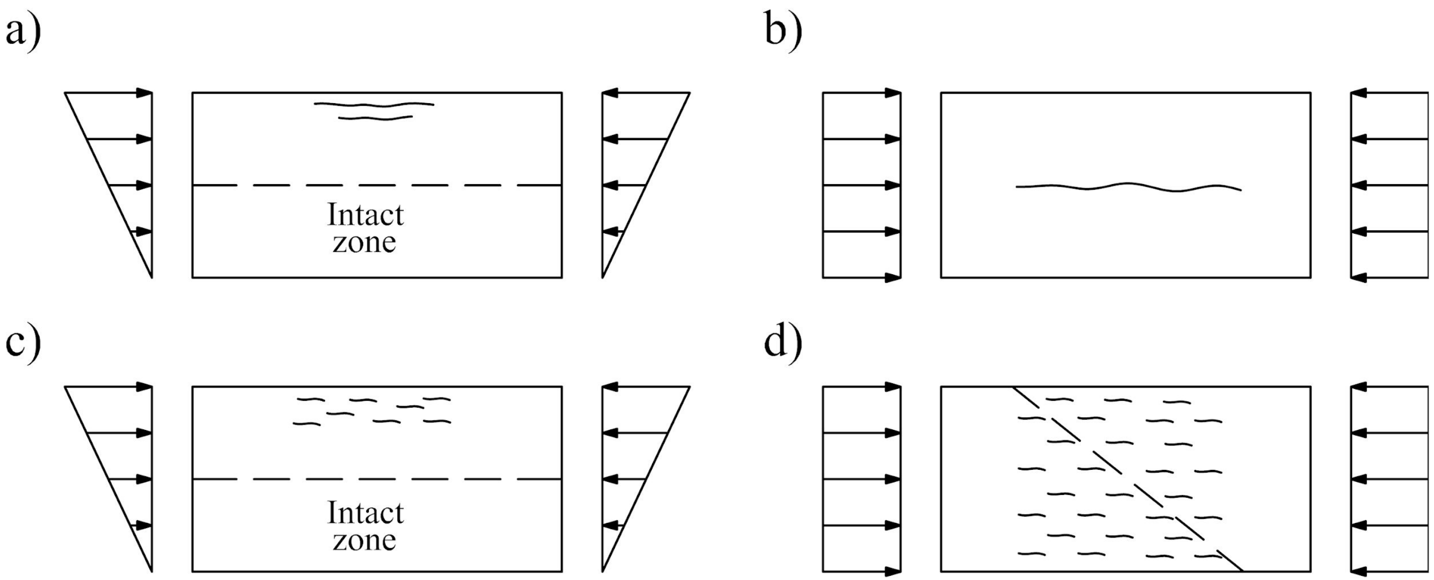


UNIVERSIDADE
BEIRA INTERIOR

C MADE
CENTRE OF MATERIALS
& BUILDING TECHNOLOGIES

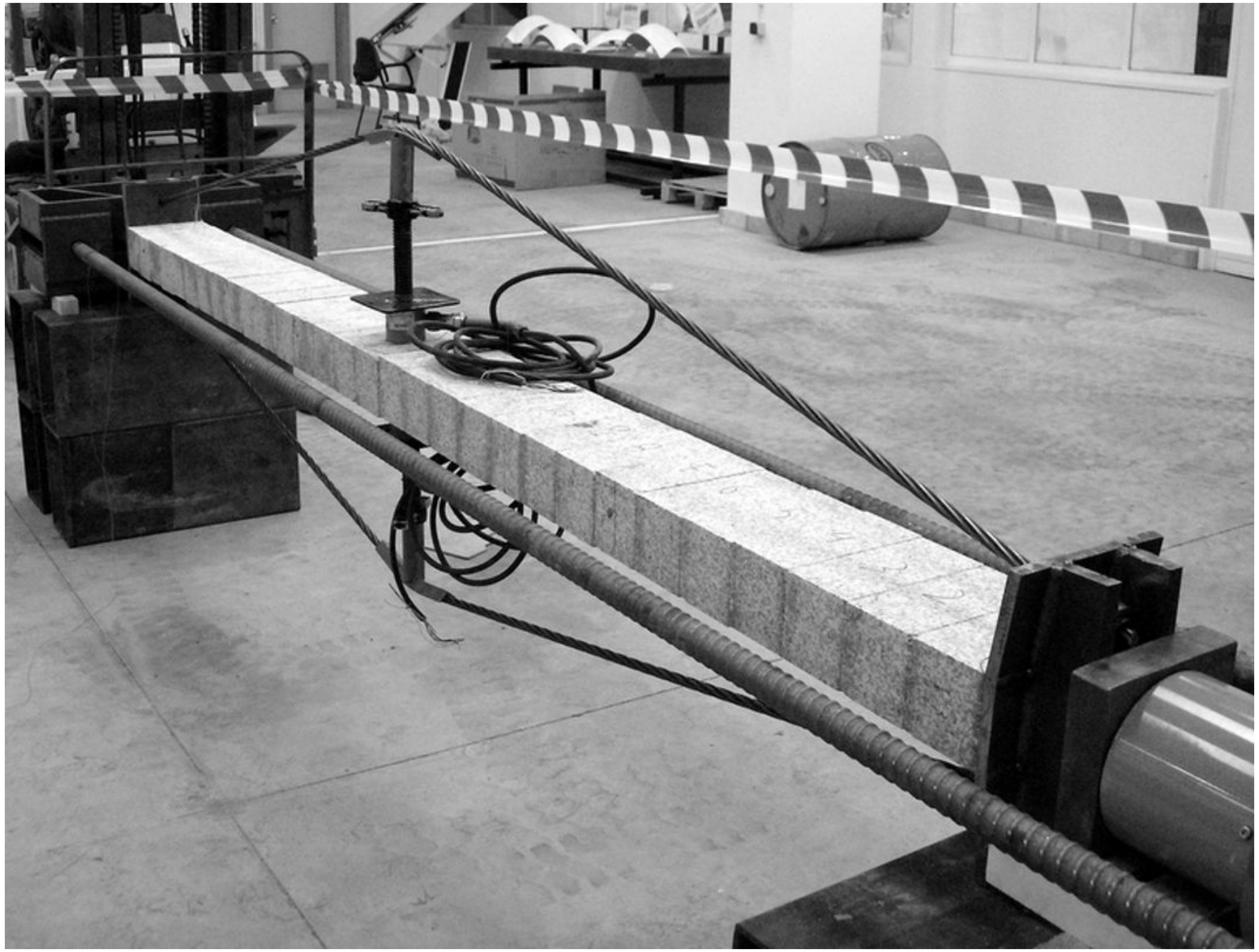



Conduit

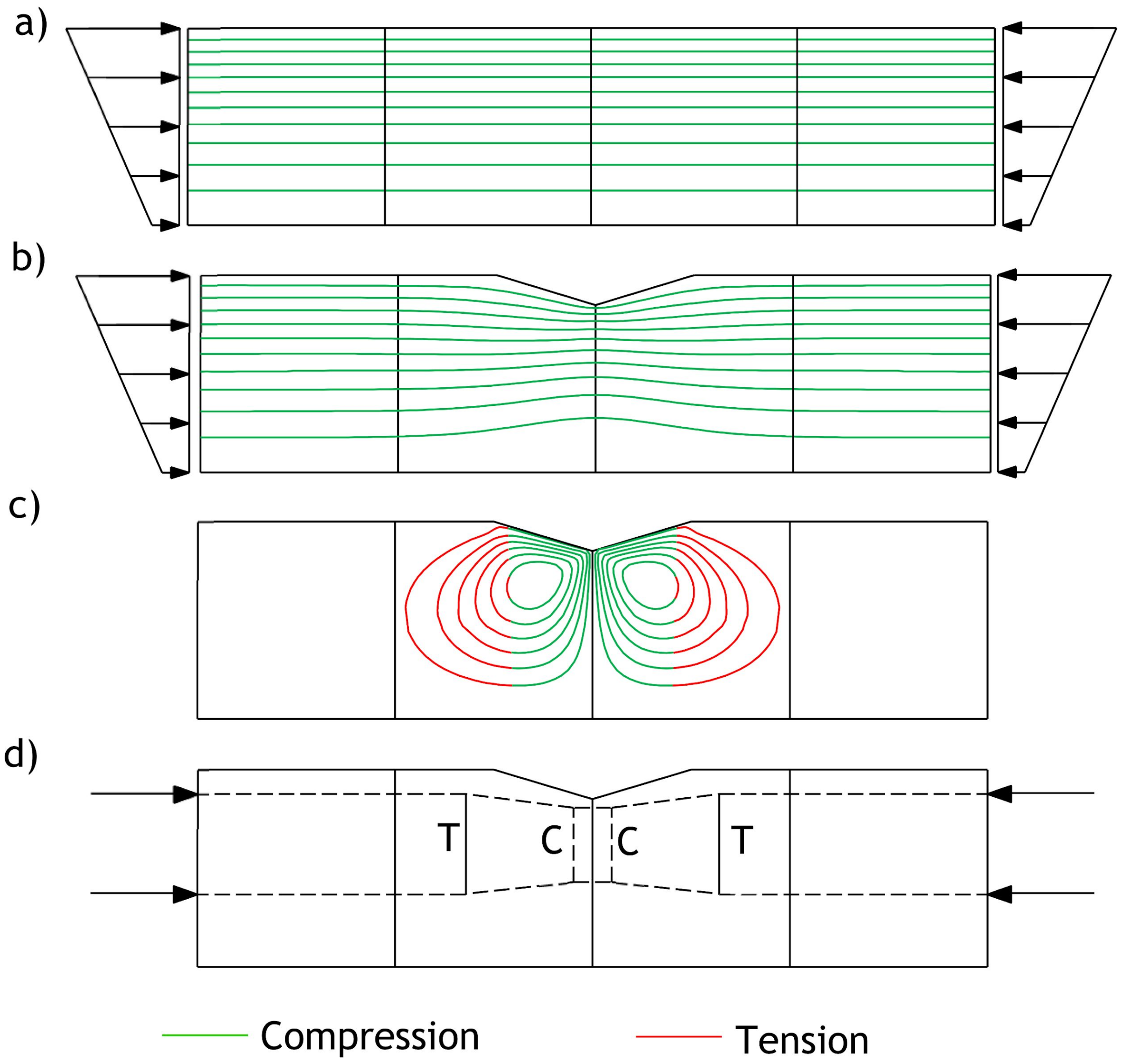


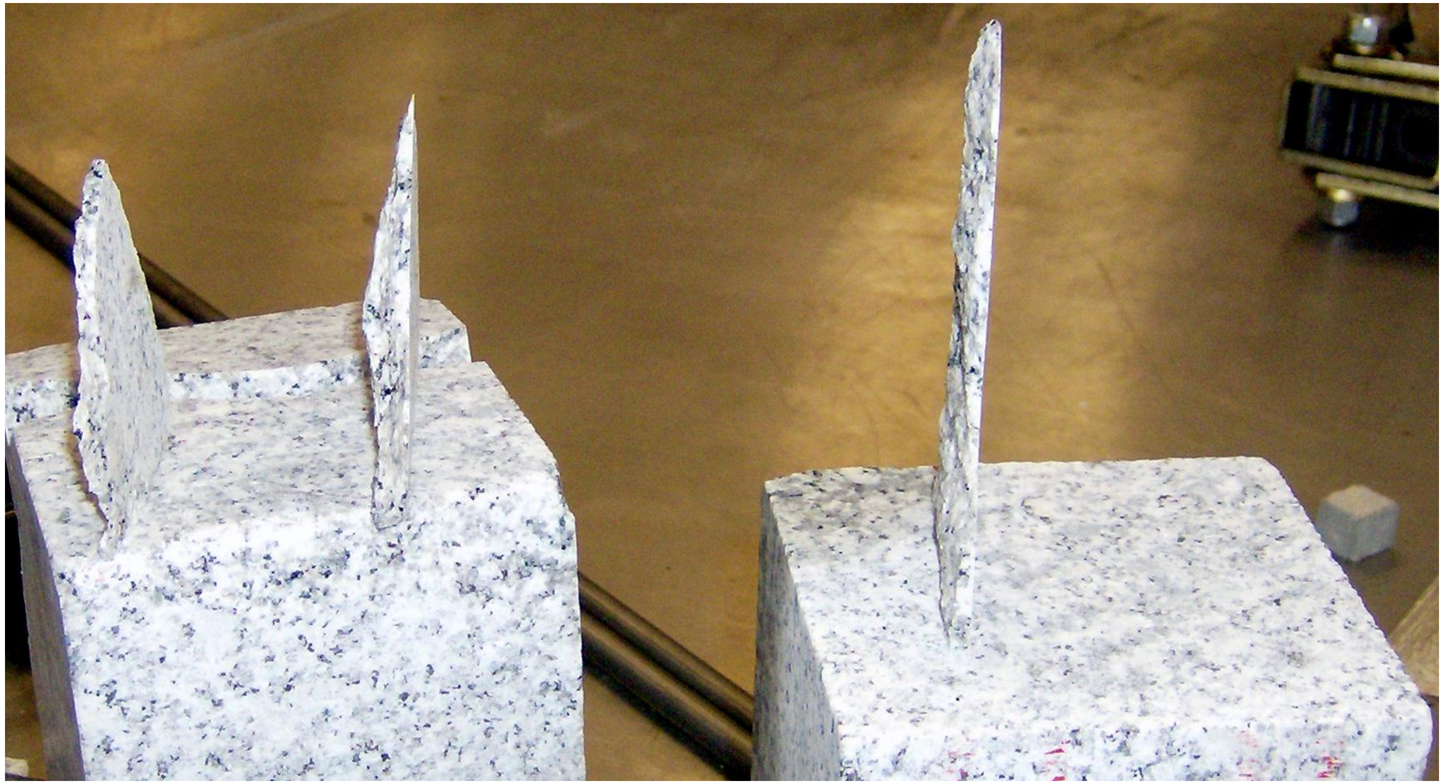
UNIVERSIDADE BEIRA INTERIOR

C MADE
CENTRE OF MATERIALS
& BUILDING TECHNOLOGIES



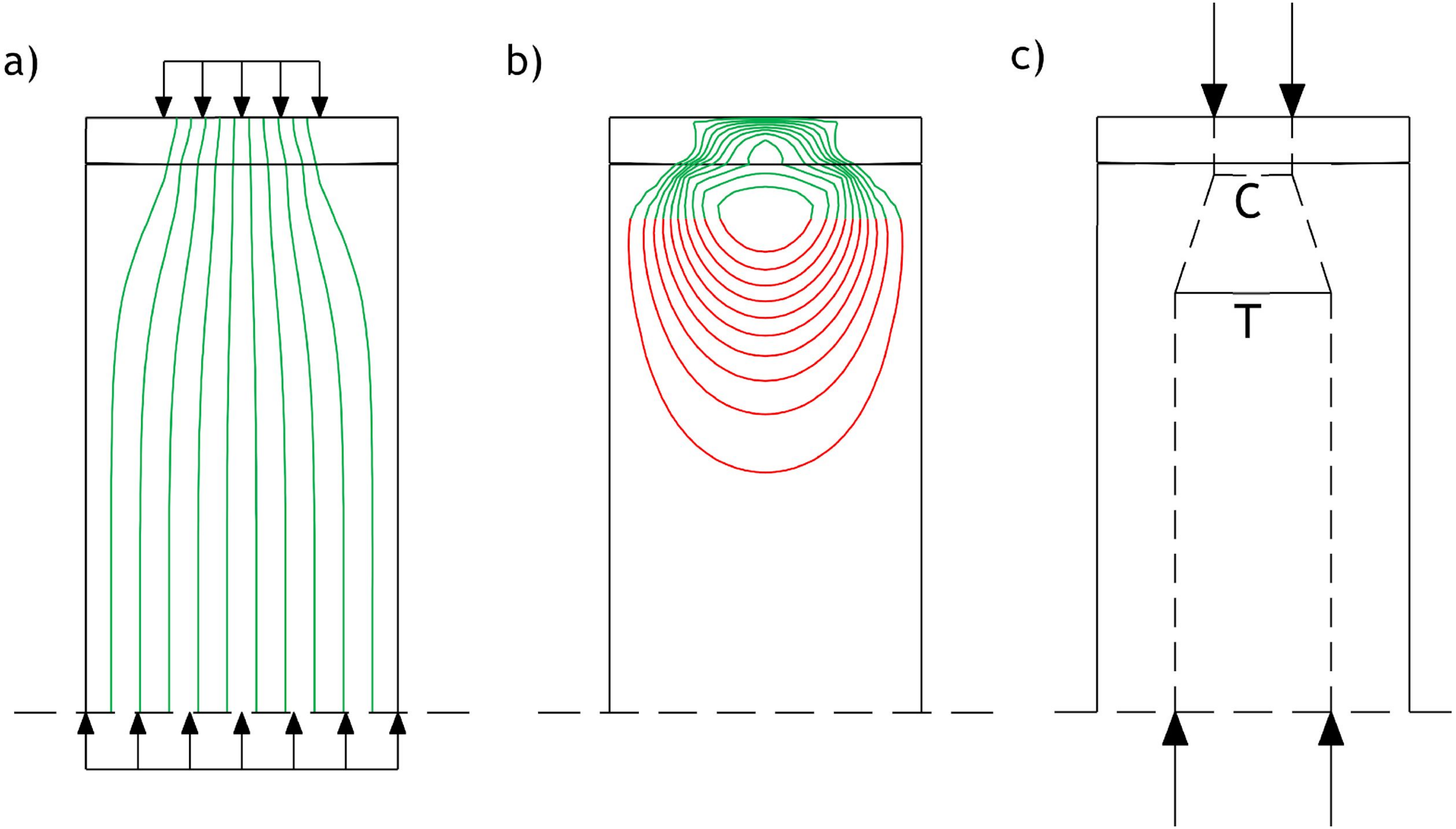

B


a)
b)
c)
d)
T
C
C
T
Compression
Tension



UNIVERSIDADE BEIRA INTERIOR

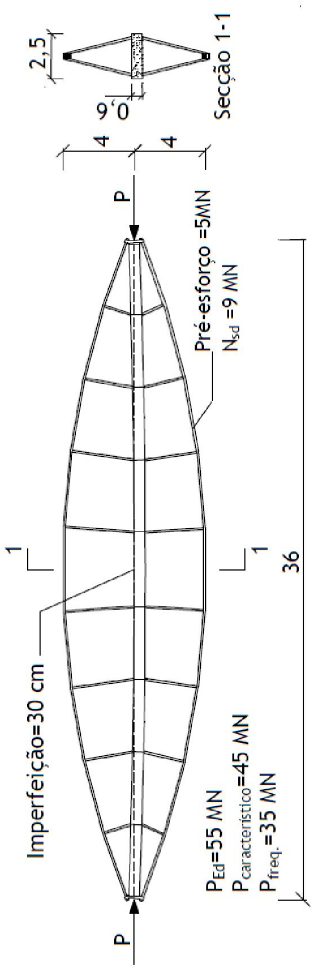
C MADE
CENTRE OF MATERIALS
& BUILDING TECHNOLOGIES


a)
b)
c)
C
T

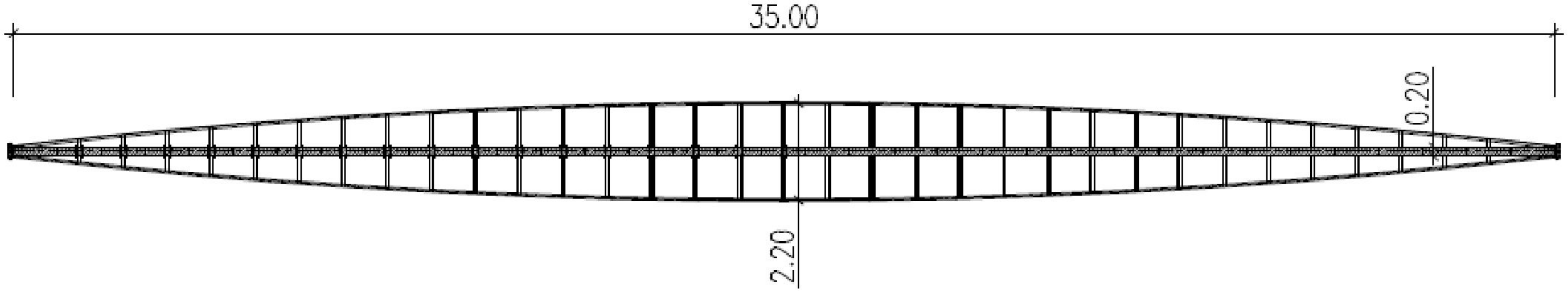
Modern applications

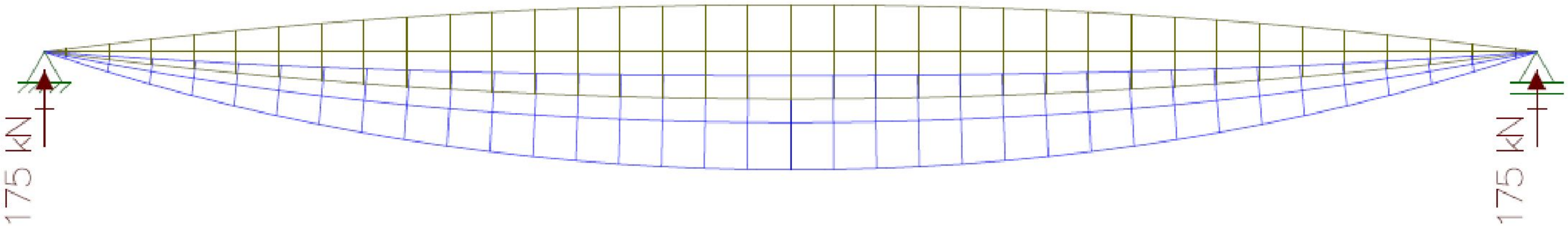
Joint_to_stone

Slender column

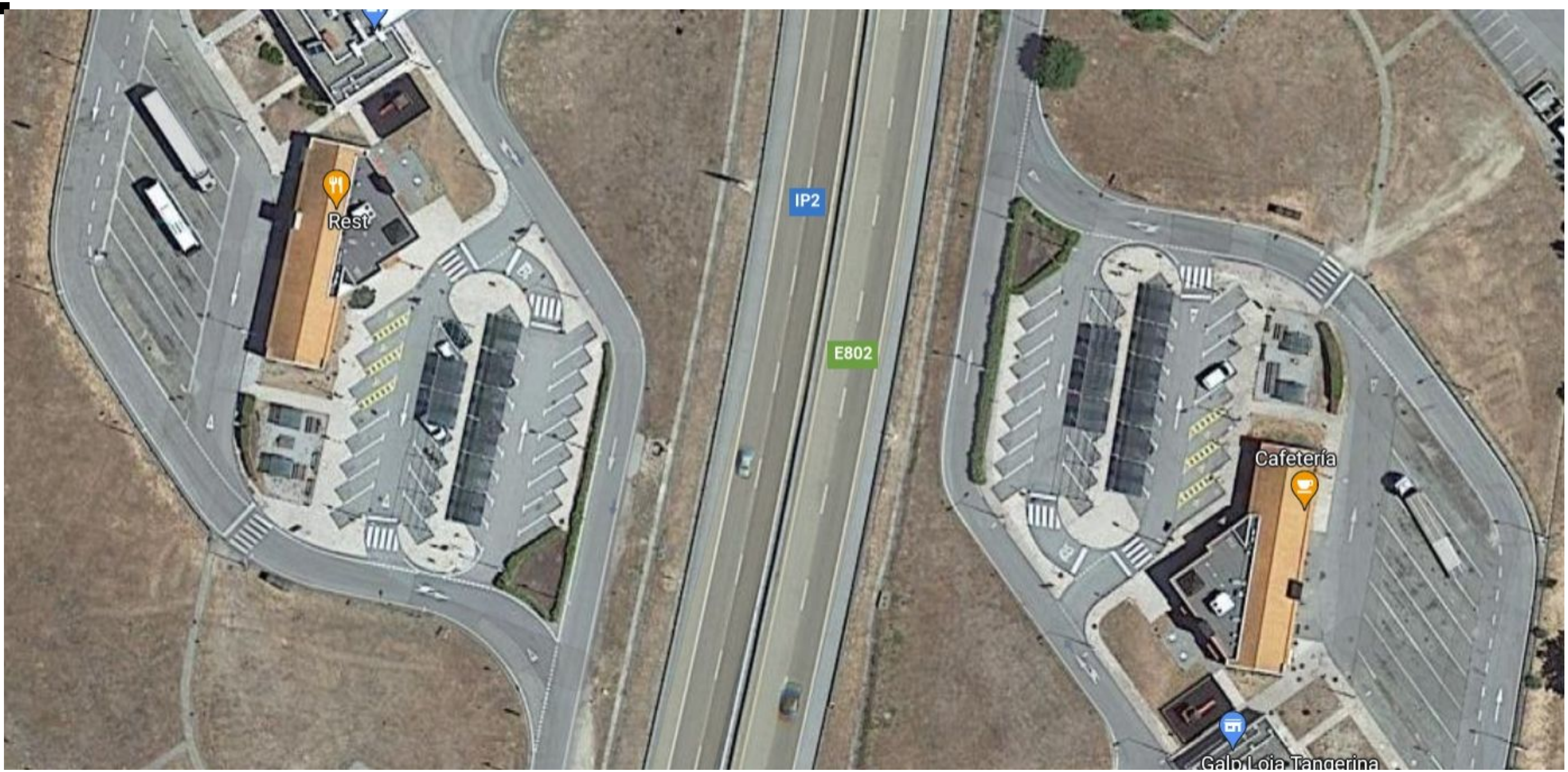


Beam





The problema: Crossing a highway on foot

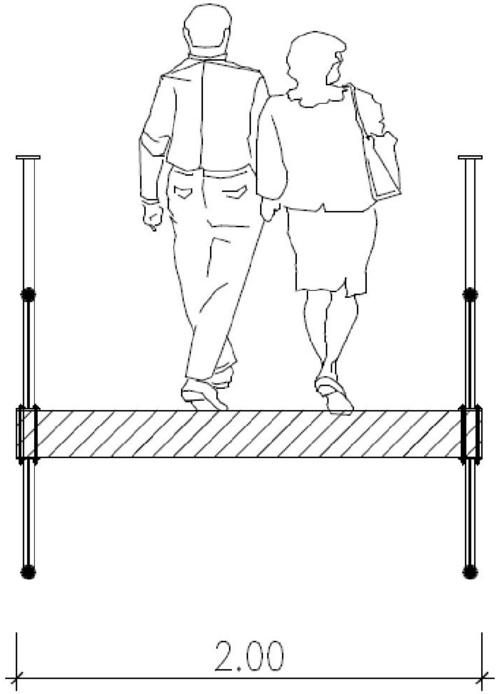


The situation: A23 highway – Guarda service area

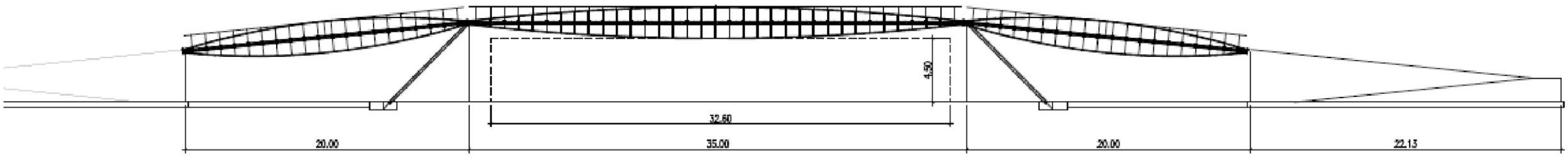
- The challenge: to design a standard footpath using granite
  as a technically efficient solution

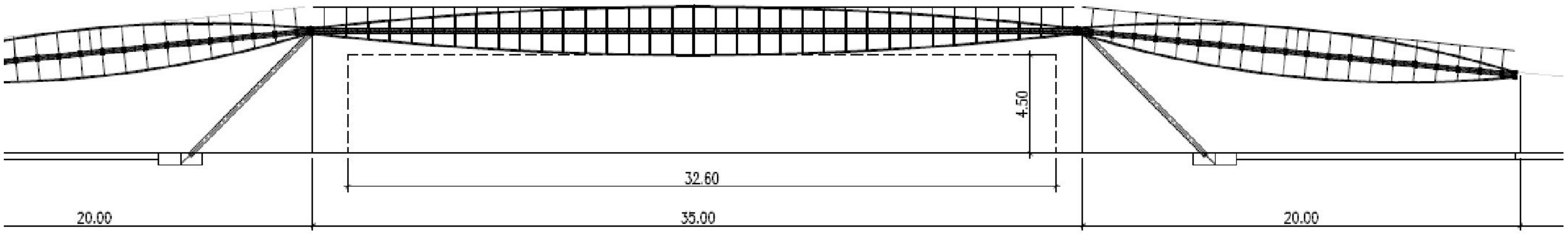
- Proposed solution: Arch bridge L=45 m f=6 m

Layout and section

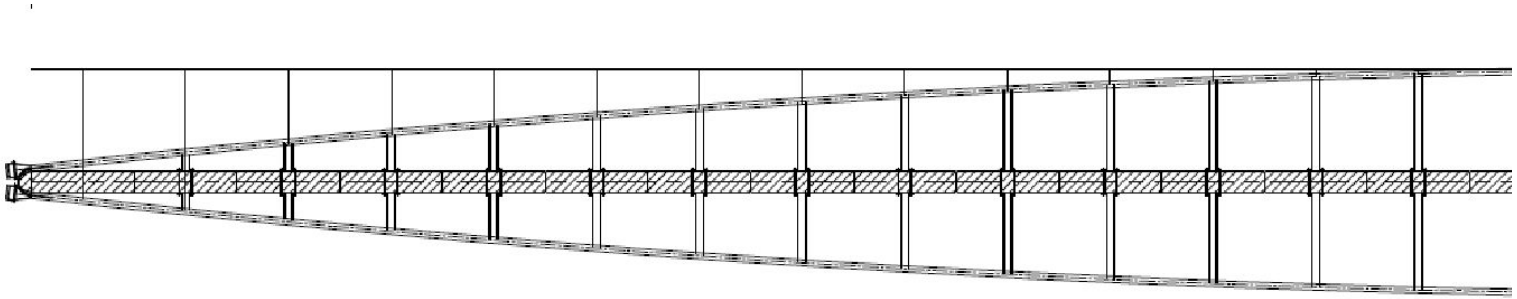


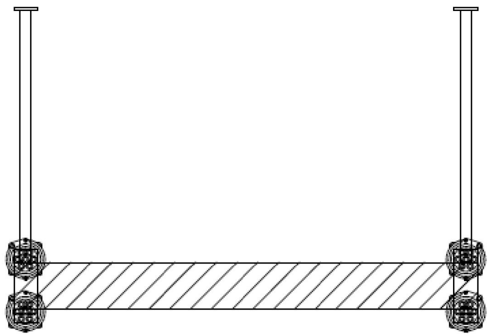
Side view

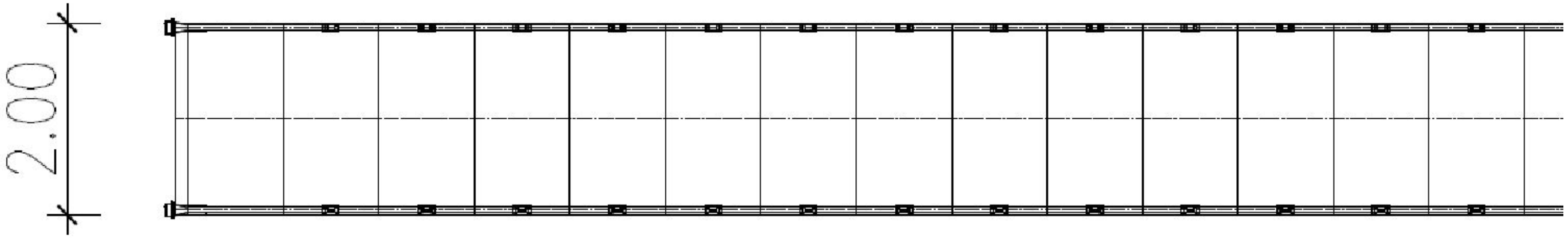




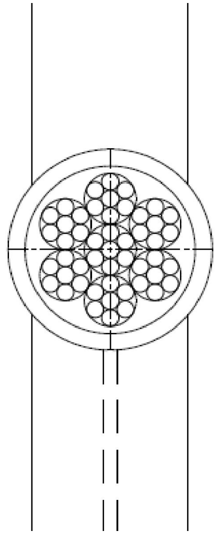
Side view – plan view

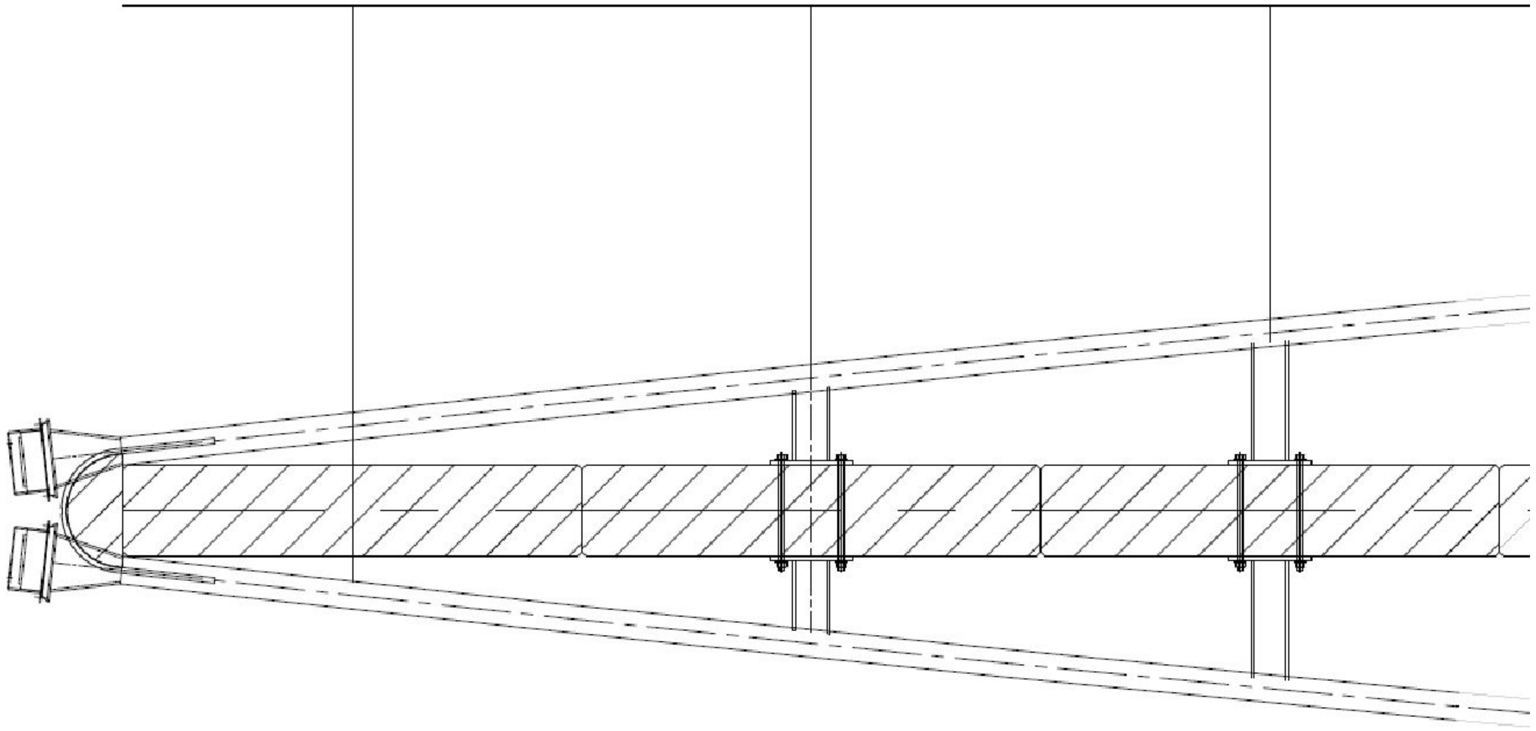


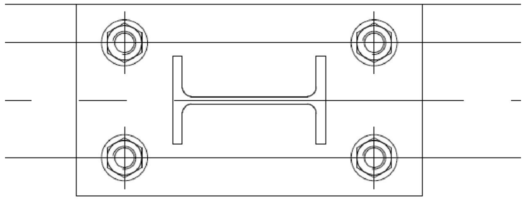


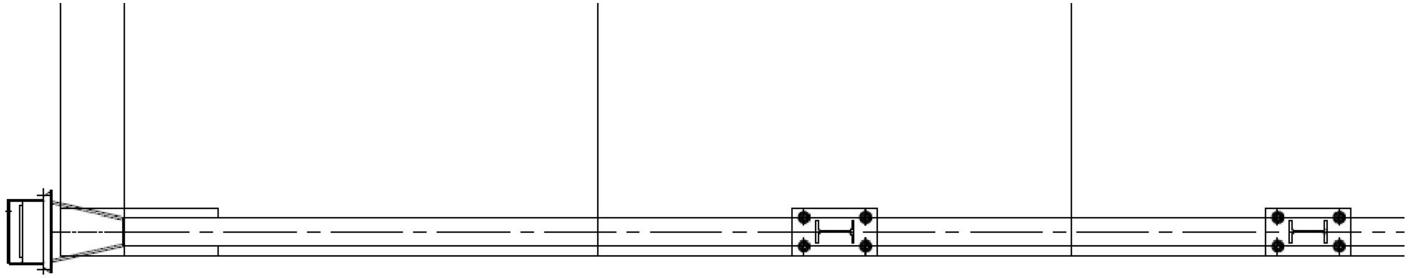


Details









Status of project development 5/10

- Self-weight of 35 m beam: ~35 ton
- Self-weight of two 20 m beams: ~40 ton

- 75 equal granite pieces 2000x1000x200 chamfered
- 12 prestress cables with 7 strands (2,5 ton)
- 4 vertical steel ties anchoraged in the foundations

UNIVERSIDADE
BEIRA INTERIOR

Call to action

How will your first stone structure be?

Muito obrigado!

Clemente Pinto

Professor e Investigador em Mecânica Estrutural

UNIVERSIDADE da BEIRA INTERIOR / C-MADE

cmp@ubi.pt