

ROCK FRACTURE IN GEOTHERMAL ENERGY SOURCES. APPLICATION OF THE THEORY OF CRITICAL DISTANCES

Author: Jon Justo Urrutia

Director: Jorge Castro González

Codirector: Cesar Sagaseta Millán

NATIONAL PLAN PROJECT
(Ref.: BIA2015-67479-R)

INDEX

- ▶ INTRODUCTION
 - ▶ PERSONAL MOTIVATION
 - ▶ MOTIVATION OF THE PROJECT
- ▶ RESEARCH TOPIC
- ▶ INITIAL PLANNING
 - ▶ METHODOLOGY
 - ▶ SCHEDULE
 - ▶ COLLABORATIONS
- ▶ PROGRESS OF THE PROJECT

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

INTRODUCTION

▶ PERSONAL MOTIVATION

▶ PRECEDENTS/BACKGROUND:

- GEOTECHNICS: WORKED ON THE CONSTRUCTION OF A HIDRAULIC TUNNEL IN UNDURRAGA (VIZCAYA).
- INVESTIGATION: MADE THE THESIS OF THE MASTER (RESEARCH PROJECT) IN THE CLIMATE REASEARCH GROUP OF IHCANTABRIA.

▶ VERY INTERESTING AND PROMISING RESEARCH TOPIC.

▶ GREAT OPPORTUNITY TO WORK WITH JORGE CASTRO, CESAR SAGASETA AND OTHER EXPERTS IN THE FIELD.

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

INTRODUCTION

► MOTIVATION OF THE PROJECT

► GEOTHERMAL ENERGY:

- CLEAN AND RENEWABLE ENERGY.
- MINIMUM SURFACE SPACE REQUIREMENTS.
- GREAT POTENTIAL FOR EXPANSION.
- THE COST OF WELLS IS ABOUT 40% OF THE TOTAL INVESTMENT COST.
- INCREASE IN GEOTHERMAL POWER PRODUCTIONS OF 1400 TWh/year IS EXPECTED FOR 2050 (IEA), WITH A DIRECT HEAT USE OF 1600 TWh/year.
- CANTABRIA: AIMS TO INCREASE THE INSTALLED POWER FROM THE 0.18 Ktoe OF 2012 TO 3.67 Ktoe IN 2020 (PSEC2014-2020).
- IN CONCLUSION: GEOTHERMAL ENERGY IS IN FULL DEVELOPMENT.

GEOTHERMAL POWER PRODUCTION



RESEARCH TOPIC

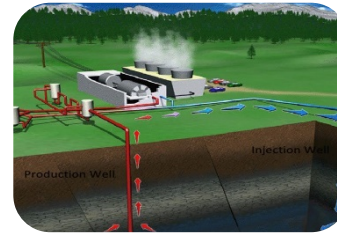
- ▶ BRITTLE FAILURE OF ROCKS → THE THEORY OF THE CRITICAL DISTANCES (TCD)
- ▶ STRESS RISERS IN ROCKS: DISCONTINUITIES, MICROCRACKS, PORES, GRAIN BOUNDARIES, ETC.
 - ↳ Stress concentration → crack initiation → propagation → brittle failure
- ▶ OF INTEREST FOR SEVERAL FIELDS:



Civil
Engineering



Mining
Engineering



Energy
Engineering

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

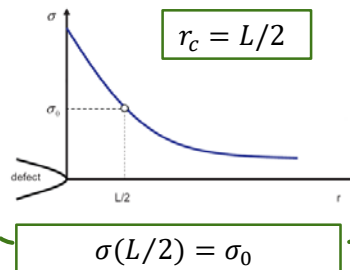
TCD

ICM & FFM

- Based on energy concepts for the assessment of a finite size crack propagation.
- Use of material parameters:
 - Critical strain energy release rate during crack growth, G_c .
 - Fracture toughness, K_c .

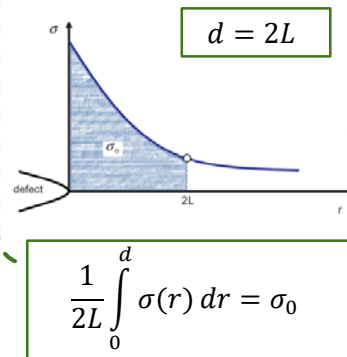
PM

- Simplest form of the TCD.
- Focused on the stress field at the defect tip.
- Failure occurs when stress at a distance r_c reaches σ_0 (Taylor 2007):



LM

- Focused on the stress field at the defect tip.
- Failure occurs when the average stress through a distance d reaches σ_0 (Taylor 2007):



AM & VM

- Focused on the stress field at the defect tip.
- Stress is averaged over a certain area in the neighbourhood of the notch or over a volumen respectively.
- Requires Finite Element Analysis.

RESEARCH TOPIC - OBJECTIVES

- ▶ STUDYING THE POSSIBILITIES OF USING A NON-CONVENTIONAL METHODOLOGY (BASED ON THE TCD) FOR THE STUDY OF THE RESISTANCE AND BRITTLE FAILURE OF ROCKS AT BOTH ROOM TEMPERATURE AND HIGHER TEMPERATURES.
- ▶ ADAPTATION OF THE TCD TO MIX MODE FRACTURE CONDITIONS IN ROCKS (MODE I AND II).
- ▶ IMPROVING THE RELIABILITY AND REDUCING THE FINANCIAL COSTS OF THE DRILLING OPERATIONS, OBTAINING MORE EFFICIENT DESIGNS IN GEOTHERMAL ENERGY SOURCES FOR EXAMPLE.
- ▶ PROMOTION OF THE USE OF GEOTHERMAL ENERGY AS A SAFE, PRODUCTIVE AND CLEAN ENERGY.
- ▶ VALIDATION OF THE METHODOLOGY WITH NON-CONVENTIONAL LABORATORY TESTS, LOOKING FOR A PHYSICAL MEANING OF THE CRITICAL PROPERTIES OF THE ROCK AND ANALYSING THEIR VARIATION WITH TEMPERATURE.

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

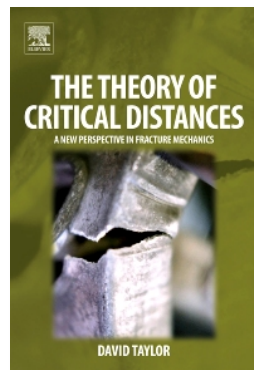
PROGRESS OF
THE PROJECT

INITIAL PLANNING - METHODOLOGY

THREE INTERACTING LEVELS DURING THE DEVELOPMENT OF THE PROJECT:

1) THEORETICAL LEVEL:

- Bibliographic and theoretical background analysis.
- Mathematical development of the TCD.
- Development of practical applications in the design of geothermal energy sources.



THE THEORY OF CRITICAL DISTANCES
A new perspective in fracture mechanics.

David Taylor, 2007.

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

INITIAL PLANNING - METHODOLOGY

THREE INTERACTING LEVELS DURING THE DEVELOPMENT OF THE PROJECT:

2) EXPERIMENTAL LEVEL:

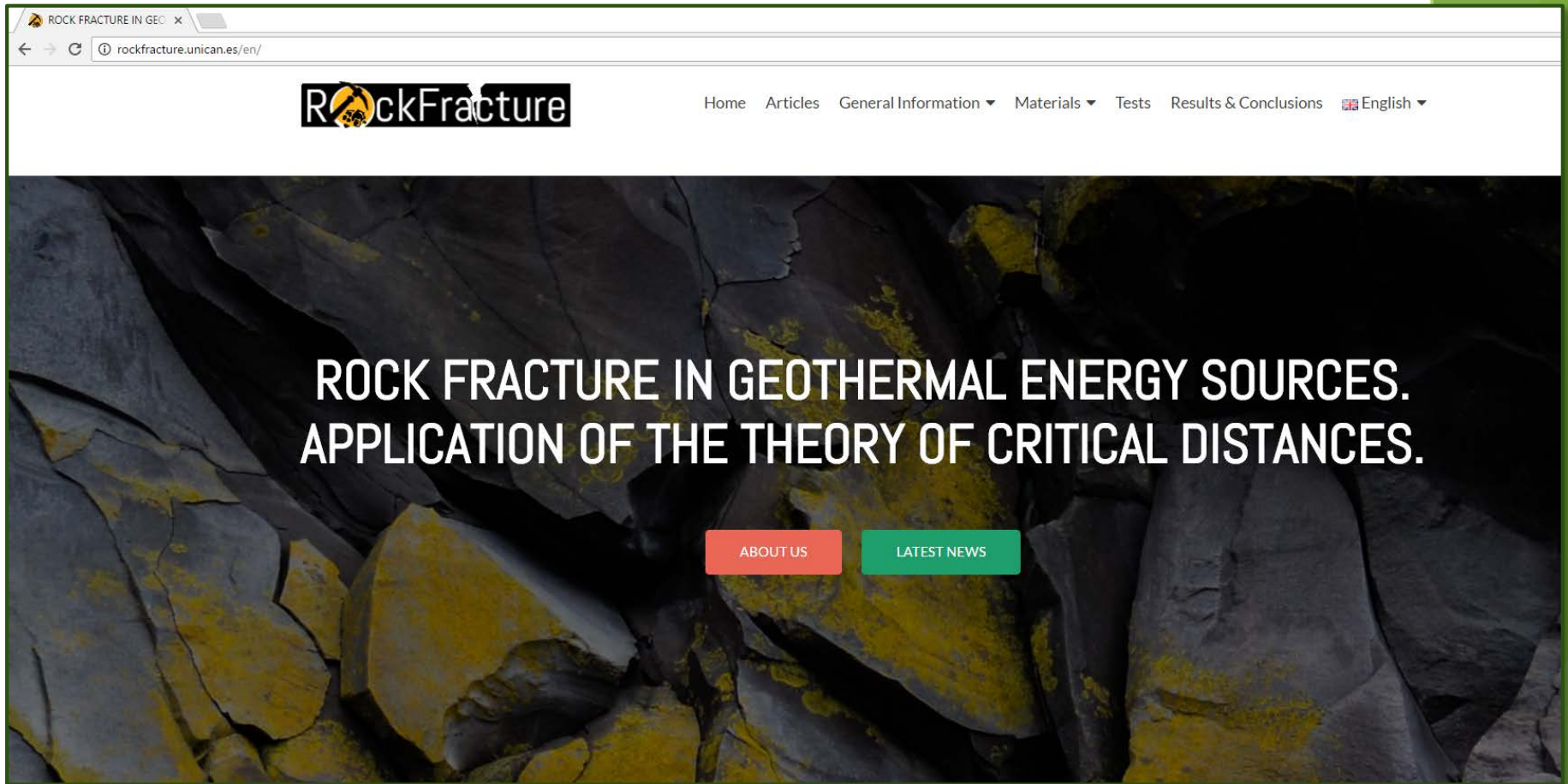
TESTS	TYPES OF ROCKS	REPETITIVENESS	VARIATIONS	TOTAL
Simple Compression Tests (with strain gauges)	4	6	4	96
Brazilian Tests	4	6	4	96
Triaxial Tests	4	3	6	72
4-point Bending Tests	4	6	8	192
3-point Bending Tests	4	6 and 2	8x2 + 5x5x3	480
Petrographic characterization of rocks using microscope	4	1	1	5
Brazilian Tests with notches with variable radii and angles	4 and 1	2	5x5 + 5x5x3	350
Simple Compression Tests with strain gauges and notches with variable radii and angles	4 and 1	2	5x5 + 5x5x3	350
Triaxial Tests with notches with variable radii and angles	4	1	5x5x3	300
Microscopic analysis of the cracking process	4	2	30	240

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT



<http://rockfracture.unican.es/>

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

INITIAL PLANNING - SCHEDULE

ACTIVITIES	Year 1				Year 2					Year 3			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
1. Bibliographic and theoretical background analysis													
2. Theoretical development													
2.1. Development an approximate model for Mode I													
2.2. Study of the influence of Mode II													
2.3. Improvement of the model to include Mix Mode I-II													
2.4. Validation with the laboratory results (Room temperature)													
2.5. Comparison with numerical simulations													
2.6. Study of the influence of temperature													
2.7. Validation with the laboratory results (High temperature)													
3. Laboratory tests													
3.1. Selection of the materials													
3.2. Machining of the specimens to introduce the notches													
3.3. Simple Compression, Brazilian and Triaxial tests													
3.4. 4-point bending Tests													
3.5. Notched tests													
3.6. Tests and high temperatures													
3.7. Microscopic analysis of cracking process													
3.8. Interpretation of results													
4. Dissemination and results													
4.1. Elaboration of presentations at national and international events													
4.2. Development of publications in international journals JCR													
4.3. Development and maintenance of the website and social networks													
4.4. Disclosure activities													
4.5. Examples of practical application													
5. Summary and conclusions													

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

INITIAL PLANNING - COLLABORATIONS

- ▶ GROUP OF GEOTECHNICS (UC)
- ▶ GROUP OF MATERIALS - LADICIM (UC)
- ▶ GROUP OF APPLIED GEOLOGY (UC)
- ▶ POLYTECHNIC SCHOOL OF MINING AND ENERGY ENGINEERING OF TORRELAVEGA (UC)
- ▶ TU BERGAKADEMIE FREIBERG (GERMANY) - Prof. Heinz Konietzky
 - ▶ DEVELOPMENT OF THE NUMERICAL SIMULATION
 - ▶ COLLABORATION IN THE EXPERIMENTAL PROGRAM
- ▶ COLLABORATING COMPANIES: ALDRO Energía y Soluciones, Envirosoil, Cantera Aizkoltxia, GRUPO EPC, TRIAX S.A. & Terrasolum S.L.



INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

PROGRESS OF THE PROJECT

- ▶ FIRST RESULTS HAVE PROVEN TO BE SATISFACTORY AND PROMISING. → INTERNATIONAL SYMPOSIUM ON NOTCH FRACTURE (SANTANDER, 2017):
 - ▶ Notch effect on the fracture of several rocks: application of the Theory of the Critical Distances. *Justo, J.; Castro, J.; Cicero, S.; Sánchez-Carro, M.A.; Husillos, R.*
- ▶ AN ENERGETIC CONTINUUM APPROACH HAS SUCCESSFULLY BEEN APPLIED FOR ROCK FRACTURE PREDICTIONS. STRAIN ENERGY DENSITY CRITERION. → EUROPEAN PLAXIS USERS MEETING (SCHROBENHAUSEN - GERMANY, 2017):
 - ▶ Finite element analyses for fracture assessment on rocks containing U-shaped notches: An energetic continuum approach. *Justo, J.; Castro, J.; Sagaseta, C.*

INTRODUCTION

RESEARCH
TOPIC

INITIAL
PLANNING

PROGRESS OF
THE PROJECT

**THANK
YOU FOR
YOUR
ATTENTION**

The right side of the slide features a decorative graphic composed of several overlapping, semi-transparent green triangles and polygons of varying shades, creating a modern, abstract background element.