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Construction Cost Estimation for Greek Road Tunnels in Relation to the Geotechnical Conditions

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Contracting Tunnels and Underground Works

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- Cost Analysis of Greek Road Tunnels
- Construction Cost vs. Geotechnical Indexes GSI & RMR
- Conclusions

Introduction

Underground works part of modern engineering practice

- transportation network expansion (e.g. subway, road and train tunnels)
- utilization of subsurface space for other purposes (e.g. storage facilities, industrial facilities, recreational facilities)

Decision making process

- restrictions derived from the total-as completed cost
- conceptual and preliminary stages (limited information available)

"The purposes of construction cost estimation is to provide information for construction decisions including areas in the procurement and pricing of constructions, establishing contractual amount of payment and controlling actual quantities (Bari, 2008)."

Introduction

Estimation of the project's cost

- important
- shift decisions
- misleading assumptions → cost overruns

U.S. National Committee on Tunnelling Technology (1984)

- almost 60% of 84 tunnels reported cost overruns and contractor claims
- the final as-completed cost including claims differs even at 50%

Flyvberg et al. (2002)

- tunnels tend to exceed the as-completed cost (average of 34%)
- tunnel construction cost underestimation → global phenomenon

Objective

Pressing need of further analysis of construction cost of underground works.

The analysis attempts

- to provide more insight of the construction cost of Greek road tunnels

How?

- data examination and evaluation from selected case studies
- cost data extraction with respect to the encountered geotechnical conditions
- data re-evaluation at the current unit prices
- construction cost functions development with respect to geotechnical classification indexes

Cost Estimation of Construction Activities

Construction Cost

- decisive factor for the successful project completion → examined and reviewed in every stage of the construction process
- differs from project to project (time scheduling and availability of resources)

Underground Construction

- uncertainty of the geological medium
- shortage of data and information availability at the first stages of the preliminary design

Cost Estimation of Construction Activities

Cost Estimation Methods

Optimum Choice

- time and information available
- engineer's experience
- estimation purpose
- activities to be modelled

Commonly used methods

- Regression Analysis (RA)
- Case Based Reasoning (CBR)
- Artificial Neural Networks (ANN)

Methods Used

- CBR → investigation of the overall cost of comparable projects and examination the cost composition data (Wagner, 2006)
- RA → relation between construction cost and geotechnical indicators

Cost Estimation of Construction Activities

Construction Cost Estimation of Underground Works

- purpose
- geometrical characteristics and length
- **geotechnical and in-situ stress conditions**
- **excavation process - methods**
- respective machine characteristics
- environmental restrictions and policies

Romero and Stolz (2002)

- underground works → special heavy-civil construction
- lead to construction cost miscalculation
- differ from aboveground works
- linearity of construction sequence → small variances result to large cost variations

Cost Estimation of Construction Activities

Other researches

(Zhao et al., 1996; Sinfield and Einstein, 1997; Isaksson and Stille, 2005; Flyvberg et al., 2008)

- typical single-case studies
- specific construction areas
- overall cost of certain type of projects (e.g. metros, oil caverns etc.)

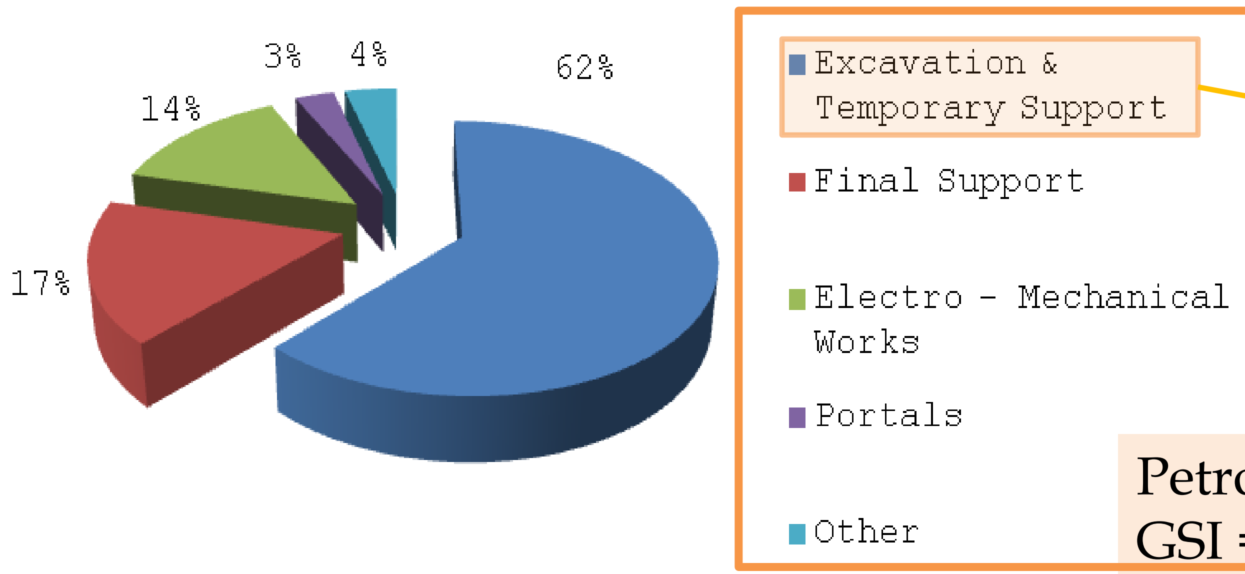
Swiss Tunnelling Society (2001)

- Switzerland
- final tunnel construction cost (as-completed cost)
- 1,200 tunnels of total length 1,600 km
- 110 €/m^3 - 1,077 €/m^3 (from good to poor quality rock masses)

Cost Estimation of Construction Activities

Lambropoulos et al. (2005)

- Greece
- final tunnel construction cost (as-completed cost)
- Egnatia Odos tunnels of total length 100 km
- 8,000 €/m – 30,000 €/m (from good to poor quality rock masses)



65% - 75%

Petroutsatou (2008)
GSI = 10-30 → 100-300 €/m^3
GSI = 25-40 → 50-100 €/m^3
GSI = 40-60 → 30-50 €/m^3

_Distribution of Tunnel Construction Cost (Lambropoulos et al., 2005)

Cost Analysis of Greek Road Tunnels

Data from 21 Greek tunnels

#	Tunnel Name	Excavation and Temporary Support Cost (€/m)
1	Rapsomatti	3,901.25
2	Agios Elias	15,484.20
3	Dodoni	4,819.57
4	Kastro	3,680.95
5	Vasilikos	4,743.11
6	Egnatia Road S1 (right tunnel)	6,065.05
7	Driskos	6,764.36
8	Kalamon	4,305.87
9	Egnatia Road S1 (left tunnel)	8,957.53
10	Egnatia Road S2 (left tunnel)	16,180.42
11	Egnatia Road S2, part 5.2.	17,778.55
12	Egnatia Road S4, part 5.2.	25,358.35
13	Egnatia Road S5, part 5.2.	6,483.24
14	Paliou	2,512.05
15	Timfristos	20,488.15
16	Pathe tunnels K1 - K4 (Patra's detour)	8,191.38
17	Pathe tunnels K1 - K4 (Patra's Wide detour)	8,900.44
18	Pathe tunnels ("Ghrokomeio")	6,770.19
19	Agia Kyriaki	8,557.42
20	Kakia Skala	17,123.30
21	Knimida	7,209.75
Cost Deviation		2,512 - 25,358
Average Cost		9,727.39

_Excavation and Temporary support cost of Greek Tunnels (before VAT)

Cost Analysis of Greek Road Tunnels

Tunnels examined

- Rapsommati Tunnel
- Agios Elias Tunnel
- Agia Kyriaki Tunnel
- Tunnel AS1 – Kakia Skala
- Knimida Tunnel

Why these?

- wide spectrum of geological conditions in Greece
- constructed during the last decade → standards and regulations
- cost data from as-built or final design studies

Cost Analysis of Greek Road Tunnels

Five major geotechnical categories

- emphasis on the lower quality rock mass conditions → heavier and complex support measures
- better and more precise interpretation in high construction cost areas

Rock Mass Categories	GSI	Rock Mass Quality (RMR - Bieniawski)
A	GSI=55-100	Good to very good - RMR=60-100
B	GSI=35-55	Fair - RMR=40-60
C	GSI=15-35	Poor - RMR=20-40
D	GSI<15	Very Poor - RMR<20
E	Soil	Soil Behaviour

The analysis

- for each individual type of tunnel cross-section
- cost data → latest pricing units (July 2011)
- no inflation impacts → bias elimination
- costs in **€/m³** and in €/m

_Rock mass categories as established for the analysis

Cost Analysis of Greek Road Tunnels

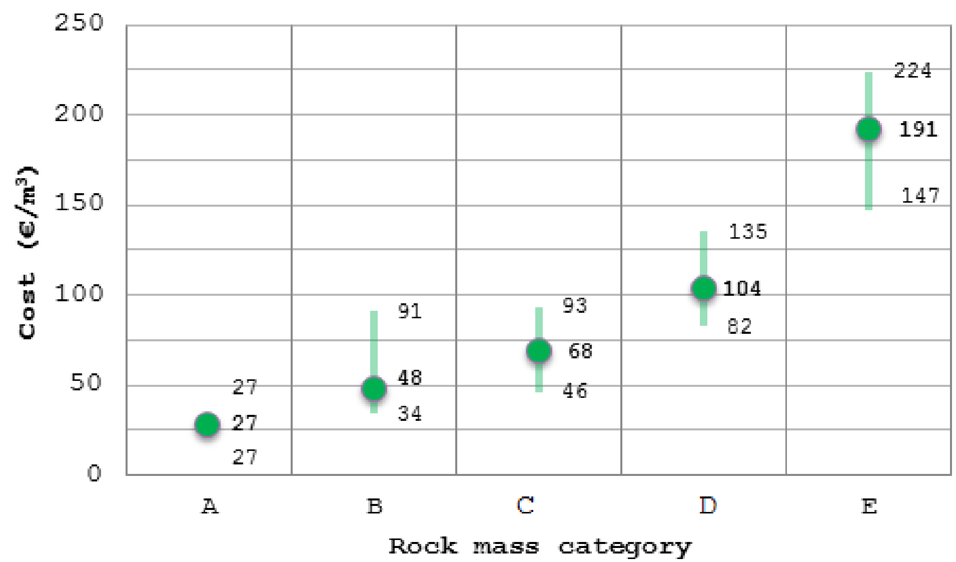
Rock Mass Category	Tunnel name and total length (m)	Application length (m)	Cost per m³ (before VAT)	Cost per m³ (after VAT=23%)
A (GSI=55-100)	Knimida (5,000)	676.00	27.02	33.23
Average Cost			*27.02*	*33.23*
B (GSI=35-55)	Rapsomatti (1,405.5)	570.00	34.04	34.04
	Agia Kyriaki (1,030)	61.00	90.90	111.81
	Knimida (5,000)	309.64	36.49	44.89
		1,606.45	38.12	46.89
		1,715.91	39.91	49.09
Average Cost			*47.89*	*57.34*
C (GSI=15-35)	Rapsomatti (1,405.5)	300.00	61.14	73.06
		300.00	63.22	75.54
	Agia Kyriaki (1,030)	741.00	93.46	114.96
		237.00	82.98	102.06
	Kakia Skala - AS1 (843.5)	8.740	66.37	79.31
		475.60	98.95	118.24
	Knimida (5,000)	401.80	46.11	56.71
		65.36	47.96	58.99
		511.95	53.23	65.47
Average Cost			*68.16*	*82.70*
D (GSI=<15)	Rapsomatti (1,405.5)	34.00	82.41	98.47
	Agios Elias (644)	153.00	112.81	134.80
	Kakia Skala - AS1 (843.5)	150.58	135.06	161.39
	Knimida (5,000)	72.00	83.74	103.00
Average Cost			*103.51*	*124.42*
E (GSI<15 - soil behaviour)	Agios Elias (644)	140.00	146.91	175.55
		153.00	224.19	267.88
			203.30	242.92
Average Cost			*191.47*	*228.78*

_Excavation and temporary support cost €/m³) and per rock mass category

Cost Analysis of Greek Road Tunnels

Average cost

Per cubic meters (€/m^3)



Rock mass category	Average excavation and temporary support cost per cubic meter (€/m^3)	Revised average excavation and temporary support cost per cubic meter (€/m^3)
Category A	21	27
Category B	39	48
Category C	51	68
Category D	82	104
Category E	127	191

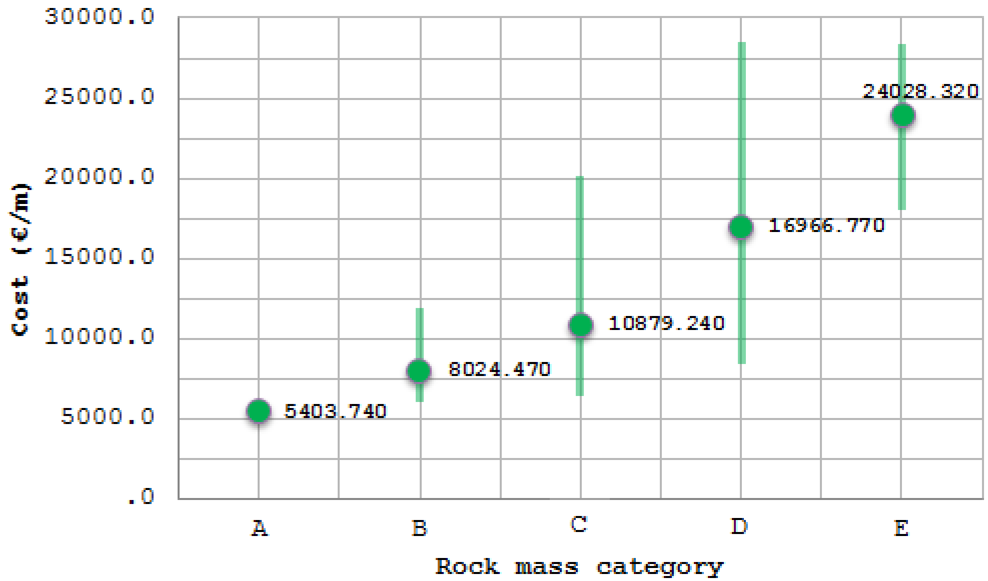
27 – 190 €/m^3

_Average excavation and temporary support cost (€/m^3 or €/m) per rock mass category

Cost Analysis of Greek Road Tunnels

Average cost

Per tunnel meter (€/m)

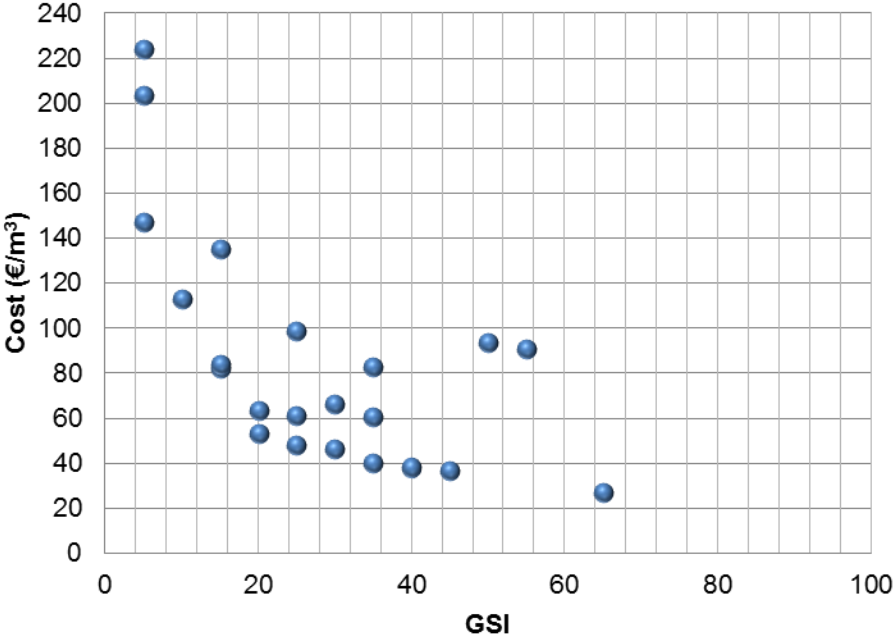


Rock mass category	Average excavation and temporary support cost per tunnel meter (€/m)	Revised average excavation and temporary support cost per tunnel meter (€/m)
Category A	3,638	4,579
Category B	5,100	6,800
Category C	6,980	9,220
Category D	12,467	14,404
Category E	13,662	20,363

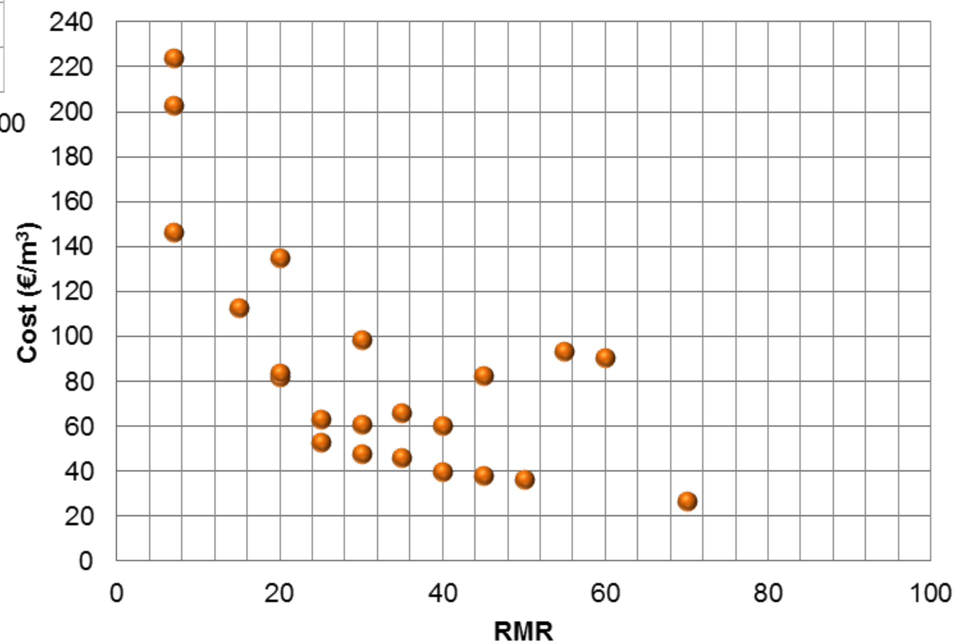
4,600– 20,300 €/m

_Average excavation and temporary support cost (€/m³ or €/m) per rock mass category

Construction Cost vs Geotechnical Indexes GSI & RMR

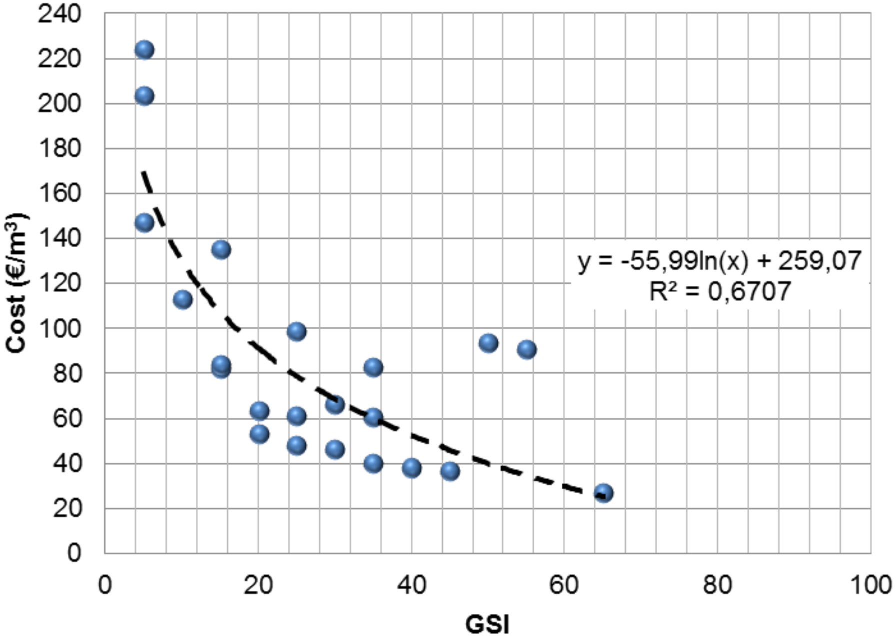


GSI



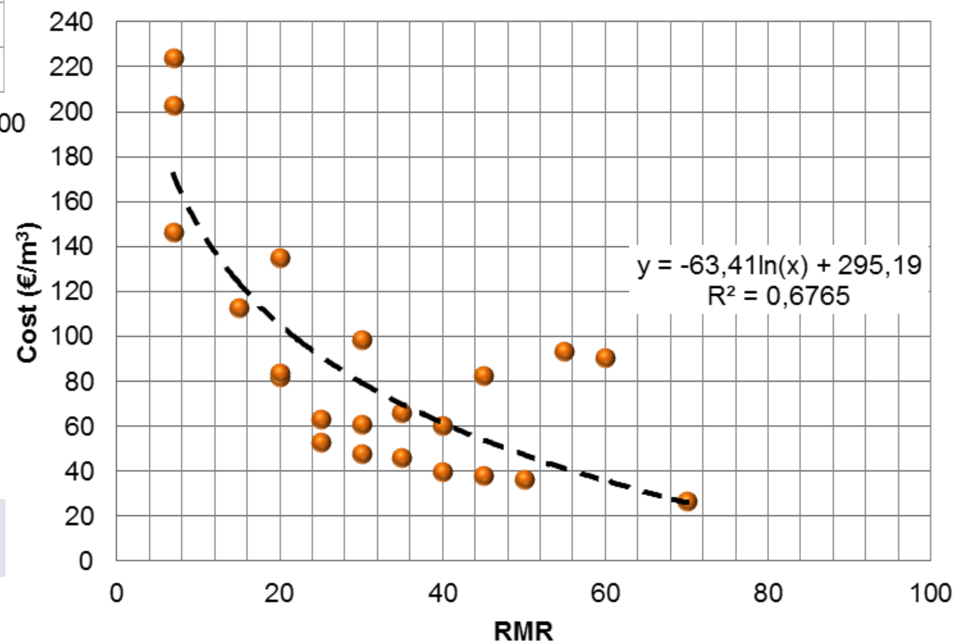
RMR

Construction Cost vs Geotechnical Indexes GSI & RMR



GSI

Cost (€/m^3) = -55.91 * ln (GSI) + 259.1



RMR

Cost (€/m^3) = -63.41 * ln (RMR) + 295.2

Conclusions

- The analysis aims to analyze the cost of Greek road tunnels and provide key data which would allow for a rapid and accurate assessment of construction cost estimation even at the preliminary stages of tunnel design.

- The analysis re-evaluated and assessed cost data from five selected Greek road tunnels.

- The significance of the geotechnical conditions to the construction cost is proved.

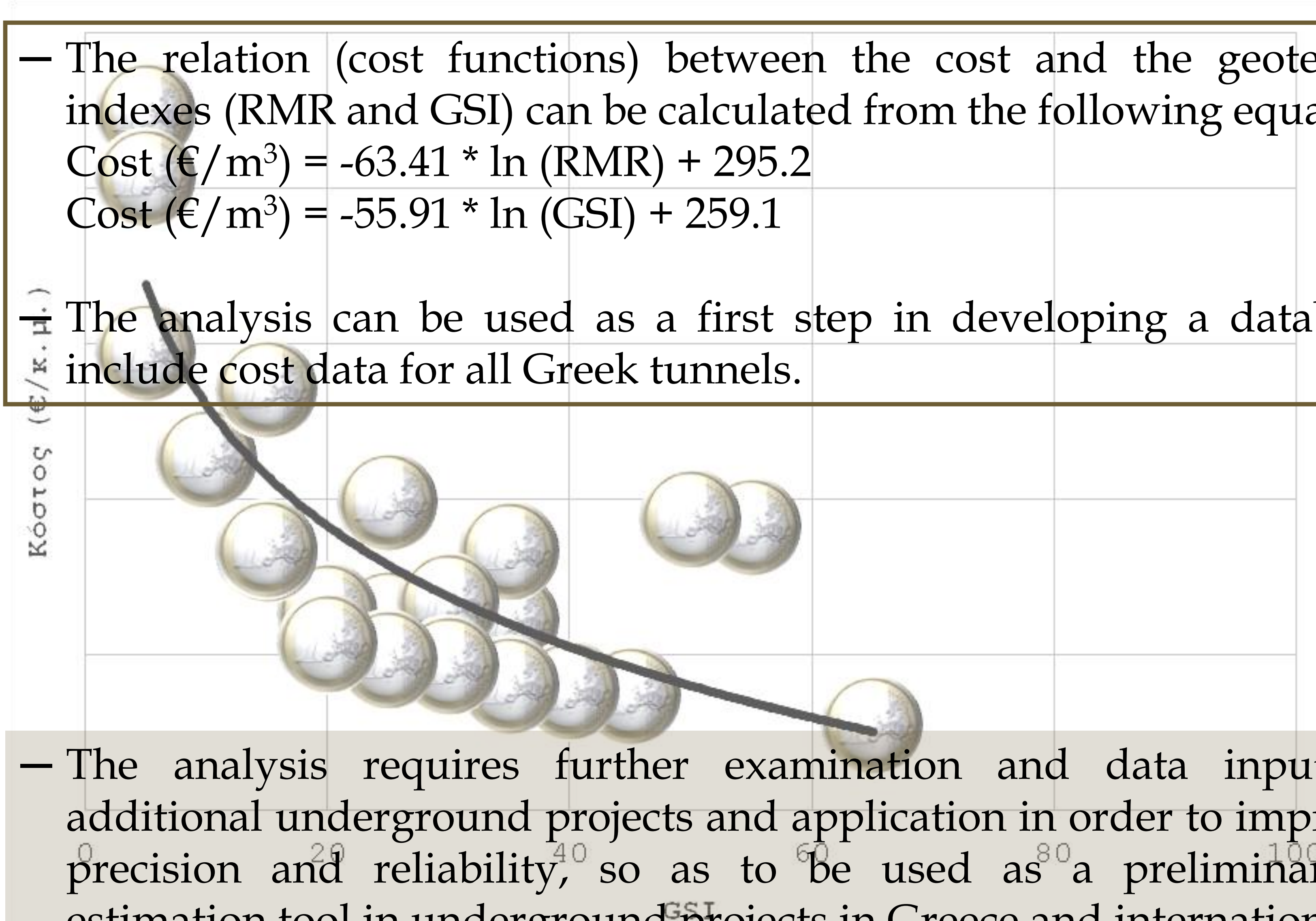
- It is concluded that:
  - construction cost for category "A" (GSI = 55-100): 27 €/m^3
  - construction cost for category "B" (GSI = 35-55): 48 €/m^3
  - construction cost for category "C" (GSI = 15-35): 68 €/m^3
  - construction cost for category "D" (GSI < 15): 104 €/m^3
  - construction cost for category "E" (soil behaviour): 191 €/m^3

Conclusions

– The relation (cost functions) between the cost and the geotechnical indexes (RMR and GSI) can be calculated from the following equations:
Cost (€/m^3) = -63.41 * ln (RMR) + 295.2
Cost (€/m^3) = -55.91 * ln (GSI) + 259.1

– The analysis can be used as a first step in developing a database to include cost data for all Greek tunnels.

– The analysis requires further examination and data input from additional underground projects and application in order to improve its precision and reliability, so as to be used as a preliminary cost estimation tool in underground projects in Greece and internationally.



Thank you

Questions?