Selecting efficient support methods for tunnels

Assistant Professor Dr. Hossam Toma

Department of Construction Engineering

Faculty of Engineering

Zagazig University

Introduction

- Selection of an efficient support method is a key factor for the success of the tunnel project
- Efficient method is the method which satisfies efficiently the controlling factors which are technical and non-technical factors
- Almost all the empirical models that are used for determining support methods are related to the ground classification systems

Research objectives

- The objective of this research is to develop an easy and flexible model that helps decision makers in selecting efficient support methods, in preliminary stages of tunnel projects, taking into consideration the most important factors that may have influence on the selection of the support methods

Selecting efficient support method model

- The model calculates efficiency percentages (EPs) of the support methods for controlling factors which represent project's technical and non-technical conditions
- Calculation of the EP for a support method depends on two factors which are the efficiency degrees (EDs) of the method for the particular controlling factors and the importance percentages (IPs) of the controlling factors

Calculations of the "EPs"

$$W_{Ai} = ED_{Ai} * \frac{IP_i}{100}$$

$$EP_A = \frac{\sum_{i=1}^{n} W_{Ai}}{T} * 100$$

Where:

W_{Ai} **= the weighted efficiency of support method "A" for controlling factor "i"**

ED_{Ai} **= efficiency degree of support method "A" for controlling factor "i"**

IP_i **= importance percentage of the controlling factor "i" related to the other controlling factors**

T **= the maximum efficiency degree which is "4"**

EP_A **= efficiency percentage of support method "A"**

Research methodology

1. Determination of the controlling factors

3. Consulting the opinion of tunnel experts to determine the efficiency degrees (EDs) of support methods for controlling factors

Research methodology

1. Development of the proposed model

4. Application of the model in real projects

Support methods

Side wall and crown support methods

- Rock bolts
- Dowels
- Steel arches
- Sprayed concrete
- Precast concrete segments

Face support methods

- Forepoling
- Pipe umbrella
- Doorframe slab
- Earth wedge
- Sprayed concrete

Controlling factors

Technical controlling factors

- Ground conditions
- Tunnel depth
- Constructibility
- Tunnel excavation method

Non-technical controlling factors

- Cost
- Time

Table (1) Comparing between support methods based on technical factors

Support Methods / Factors			Side wall & Crown support					Face support				
			Rock bolts	Dowels	Steel arch	Sprayed concrete	Precast concrete segments	Forepoling	Pipe umbrella	Doorframe slab	Earth wedge	Sprayed concrete
Ground conditions	Ground is soil											
	Rock quality (RMR values)	0 - 20										
		21 - 40										
		41 - 60										
		61 – 80										
		Over 80										
	Prevent failure	Failure due to weathering										
		Failure due to moving water										
		Failure due to corrosion of support										
		Failure due to squeezing & swelling										
		Failure due to overstress										
Tunnel depth	Less than 30m											
	30 – 50m											
	50 – 100m											
	100 – 500m											
	500 – 1000m											
	Over 1000m											

Table 1 Comparison between support methods based on technical factors (continue)

Factors		Support Methods	Side wall & Crown support: Rock bolts	Dowels	Steel arch	Sprayed concrete	Precast concrete segments	Face support: Forepoling	Pipe umbrella	Doorframe slab	Earth wedge	Sprayed concrete
Constructibility		Circular or mouth cross section										
		Oval or Horseshoe cross section										
		Other cross sections										
	Tunnel span	Less than 1.5m										
		1.5 – 4m										
		4 – 6m										
		6 – 10m										
		Over 10m										
Tunnel excavation methods		Excavator / Front shovel / Backhoe										
		Hand excavation										
		Drill & blasting										
		Roadheader										
		Micro-tunnelling machine										
		Shield machine										
		TBM (open machine)										

Table (2) Comparing between support methods based on cost

Support Methods / Factors	Side wall & Crown support					Face support				
	Rock bolts	Dowels	Steel arch	Sprayed concrete	Precast concrete segments	Forepoling	Pipe umbrella	Doorframe slab	Earth wedge	Sprayed concrete
Cost / 1m length of tunnel										

Table (3) Comparing between support methods based on time

Support Methods / Factors	Side wall & Crown support					Face support				
	Rock bolts	Dowels	Steel arch	Sprayed concrete	Precast concrete segments	Forepoling	Pipe umbrella	Doorframe slab	Earth wedge	Sprayed concrete
Production rate = 75m/week										

Calculations of the "EDs"

- The matrices were sent to tunnel experts to consult their opinion about the "EDs" of support methods for each controlling factor

- The "EDs", which are the database of the model, are the average values of the "EDs" assigned by the experts

Input data by the user

- The user of the model should determine the importance degrees (IDs) of the controlling factors
- The user should determine also the technical data of his project

Calculations of "IPs"

Table (5) Form used to assign IDs to the factors

IDs given by the user	Controlling factors	Sub-Factors will have the same ID of the parent factors	ID that will be used in the model
X1	Ground conditions	RMR value	X1
		Failure due to weathering	X1
		Failure due to moving water	X1
		Failure due to corrosion of support	X1
		Failure due to squeezing & swelling	X1
		Failure due to overstress	X1
X2	Tunnel depth	---------	X2
X3	Tunnel shape	---------	X3
X4	Tunnel span	---------	X4
X5	Tunnel excavation method		X5
X6	Cost	---------	X6
X7	Time	---------	X7
X8	Others	---------	X8
Total number of ID values			n = 13 values

Calculations of “IPs”

$$IP_i = \frac{ID_i}{\sum_{i=1}^{n} ID_i} * 100$$

Where:

***IP_i* = importance percentage of the controlling factor “i” related to the other controlling factors**

***ID_i* = importance degree of the controlling factor as assigned by the user**

***n* = number of controlling factors**

Determination of technical data of the project

Table (4) Technical data of the project

Select one option for each factor *Tunnel span* □ 1.5m or less □ 2.0 – 4.0m □ 5.0 – 6.0m □ 7.0 – 10.0m □ over 10m
RMR value □ 0 - 20 □ 21 - 40 □ 41 - 60 □ 61 - 80 □ over 80 □ ground is soil
Select failure reasons (you can select more than one reason) □ failure due to weathering □ failure due to moving water □ failure due to support corrosion □ failure due to squeezing and swelling □ failure due to overstress
Tunnel depth □ 30m or less □ 31 – 50m □ 51 – 100m □ 101 – 500m □ 501 – 1000m □ over 1000m
Tunnel cross section profile □ circular or mouth profile □ oval or horseshoe □ other profiles
Tunnel excavation method □ excavator / front shovel / backhoe □ hand excavation □ drill & blasting □ roadheader □ micro-tunnelling machine □ shield machine □ TBM (open machine)

Calculations of the "EPs"

$$W_{Ai} = ED_{Ai} * \frac{IP_i}{100}$$

$$EP_A = \frac{\sum_{i=1}^{n} W_{Ai}}{T} * 100$$

Where:

W_{Ai} = the weighted efficiency of support method "A" for controlling factor "i"

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EP_A = efficiency percentage of support method "A"

Application of the model

Table (8) Comparison between the results of the model and the support methods used in the projects

Methods / Project	Support method used in the project	Support method selected by the model
Wienerwald tunnel	Precast concrete segments	Precast concrete segments
U2/2 Taborstraße	Sprayed concrete	Sprayed concrete
Gotthard tunnel – Amsteg section lot 252	Sprayed concrete	Precast concrete segments

Thank you