项目背景 Background

在建的秦岭终南山特长公路隧道北起长安县的青岔口南止柞水县的小峪口，是西康公路的控制工程。西康公路属于国家规划的“五纵七横”中的纵向，隧道穿越秦岭山脉主峰牛背梁，全长18.02km，双洞单向交通，最大埋深超过1700m，其建设规模居世界第一。

通风技术面临的主要问题：Principal problem of Ventilation technology

✦ 项目背景 阶段：目前公路隧道汽车污染物基准排放量和各影响因素的值采用国外标准推荐值；
✦ 隧道区部分处于国家级自然保护区内；
✦ 这么长的公路隧道，国内外可借鉴资料很少，通风方案的确定成关键和难点；
✦ 长大、深埋特性使得通风系统复杂，需要优化；
✦ 相邻铁路隧道对通风系统有无借鉴作用？
✦ 通风系统运营效果如何评价？
项目背景

研究内容

研究内容 Contents

汽车动态排放参数研究
The research on emission standard of vehicles

汽车排放因子的试验研究
The testing on emission factors of vehicles

海拔高度对汽车排放影响的试验研究
The experimental study on effects of elevation height on vehicles emission

道路纵坡对汽车排放影响的试验研究
The experimental study on effects of road grade on vehicles emission

技术进步因子的分析确定
The definition on factors of technological progress

Contents

Background


前期调研

研究项目建议

立项调研

立项申请及科研合同

西部交通工程科学研究院

The research on emission standard of vehicles
The research on control standard and environment effects of Ventilation
The simulation on operating mode of ventilation system
The research on ventilation scheme comparison
The optimization research of ventilation system
The on-site testing of ventilation parameters is made
研究内容 Contents

♦通风控制标准及环境影响研究
The research on control standard and environment effects of Ventilation
污染物浓度控制标准
The control standard of pollutants density
隧道内纵向污染物浓度分布模拟
The longitudinal distribution of pollutants density in the tunnel is simulated
隧道竖井排风污染环境研究
The environment effects of pollutants in shaft and openings are evaluated
隧道出口局地污染物浓度场及环境影响
The distributing and environment effects of pollutants density in openings

♦通风方案比选研究
The research on ventilation schemes comparison
不同建设长度通风方案研究
The research on ventilation schemes of different length
其他通风方案研究
The research on other ventilation schemes
竖井分段纵向通风方案研究
The research on shaft segment longitudinal ventilation scheme

♦通风系统优化研究
The optimization research of ventilation system
联络风道局部压力损失分析与结构优化
The analysis and optimization on local stress loss of ventilation section network
隧道主体送排风口间短流态分析
The short section flowmeter analysis on air in and air out ventilation of tunnel
射流风机升压效率计算分析
The analysis on boosting efficiency of jet fan
紧急停车带几何形状计算分析
The analysis on geometry shape of emergency parking place
隧道进出口段交叉流态分析
The cross flowmeter analysis of tunnel portal
竖井进出口区域交叉流态分析
The cross flowmeter analysis of shaft portals
竖井底部中隔板高度优化试验
The optimization testing on diaphragm height of shaft bottom
竖井送排风口优化试验
The optimization testing on the shaft portals of air in and air out ventilation
通风短道长度试验分析
The testing on length orientation short section
该研究内容为通过实验测试分析隧道通风基础参数、选择性测试喷射混凝土衬砌风阻系数、以及试验测试隧道洞口室气候环境等，最终研究通风系统工况模拟，以确保隧道内空气流通和温度适宜。该研究的成果为隧道通风系统的优化提供了科学依据和数据支持。
2. 明确给出了特长公路
隧道洞内卫生控制标准
2. The hygienic standard in
extra-long tunnel is established

主要结论 results:
（1）确定出隧道污染环境下柴油车动态烟雾基准排放量取值2.0；
（2）确定出隧道污染环境下汽油车动态CO基准排放量为0.007 m3/km, veh；
（3）确定出海拔高度对柴油车烟雾排放量、汽油车CO排放量的变化规律，并建立了计算模型；
（4）确定出不同车速下柴油车烟雾排放量、汽油车CO排放浓度随坡度变化的规律。
3. 建立了隧道内污染物浓度分布模型，对竖井和洞口排风污染环境影响进行了评估

3. The concentration distribution of pollutants in the tunnel is simulated and the environment effects of pollutants in shaft and openings are evaluated.
研究成果 Results-3

根据交通量、车型分类与排放因子，计算出各特征年高峰小时交通量时，隧道内污染物的排放强度，以此为基础，分别计算出各年限隧道内污染物浓度分布。由于秦岭终南山隧道2#竖井所处地区为国家级自然保护区，执行一级标准，故而评估竖井排风污染对环境的影响，并提出竖井设计建议。同时还开展了洞口段局地污染物环境影响模拟，评估洞口污染物对周围环境和通风的影响。
The distributing and environment effects of pollutants density in openings are evaluated.

4. The complicated ventilation network technology of highway tunnel is established and calculating program is work out.

主要结论 results

1. The distributing and environment effects of pollutants density in openings are evaluated.

2. The complicated ventilation network technology of highway tunnel is established and calculating program is work out.

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50. The complicated ventilation network technology of highway tunnel is established and calculating program is work out.
针对秦岭终南山公路隧道多竖井复杂通风特性，引入通风网络理论，建立了各通风动力（交通通风力、风机风压、自然风压和火风压）计算模型，在此基础上编了公路隧道复杂通风网络仿真程序，可用于公路隧道复杂通风系统的风网自然分风计算、多方案比选研究，模拟通风状况，预测通风效果等。

通风网络是由表示通风系统内各风流路径及其分合关系的网状线路图和其赋权通风参数两部分组成。隧道通风网络图是反映隧道中各风流分合关系的网络状示意图，是有向赋权连通图。隧道通风网络图是用图论的概念和方法来表示通风系统，并籍以利用图论的理论与方法来分析复杂通风系统，采用计算机解算通风网络和保证按需分风的风流调节等问题。

隧道通风网络遵循的基本规律

1. 风量平衡定律
   假定空气密度不变、无漏风、忽略空气中水蒸气的变化，则风网内任意节点（或回路）相关分支的风量代数和为零；
2. 风压平衡定律
   风网的任何闭合回路内，各分支风压代数和为零。分支风压含通风阻力和通风动力两部分；
3. 阻力定律
   隧道风路中正常风流一般均为紊流。各分支的风压和风量均符合紊流阻力定律。

隧道通风网络
分析基本模型
1. 通风阻力模型
2. 轴流风机风压
3. 通风压力模型
4. 射流风机升压力模型

计算模型

隧道通风网络
数值模型建立
1. 送排风口压力模型
2. 送排风反向压力模型
3. 送排风口正向压力模型
4. 排风口正向压力模型
5. 自然风压模型
6. 紊流风压模型
7. 紊流风压模型
研究内容

送风口正向、反向压力模型计算图
press calculation model of air in opening

排风口正向、排风口反向压力模型计算图
press calculation model of air out opening

计算程序流程图
technological of program

公路隧道通风网络计算程序

版本: V1.0
长安大学公路学院
2004年5月

程序计算方法

- 运营工况通风计算
- 火灾工况通风计算

程序计算方法

- 自然风流计算（正向计算）
- 风机配置计算（反向计算）

复杂公路隧道通风网络仿真分析应用程序包括三大功能:

- 实现运营通风网络分风解算（正向分析）
- 运营通风网络风机配置解算（反向分析）
- 火灾工况模拟计算
5. The advanced physical model experiment system is established.

The theory condition about physical model experiment of ventilation

1. Flow similarity principle
   (1) Geometric similarity
   (2) Kinematic similarity
   (3) Dynamic similarity

2. Tunnel ventilation basic assumptions
   (1) Incompressible flow
   (2) Isothermal flow
   (3) Steady flow
   (4) Continuous medium
   (5) Flow energy conservation law

The selection of similitude rule

According to the similarity theory, select Reynolds number as the similarity criterion of the tunnel ventilation physical model. Under the same conditions, the aerodynamic characteristics of the tunnel are consistent. The system is designed and tested, and the similarity is verified. The system is tested and verified under the premise of similarity. The system is tested and verified under the premise of similarity.
确定自模区
The definition of self-simulate area

雷诺数大于第二临界值时，流体流动时的流速分布、流动状态不再发生变化，与雷诺数无关，即第二自模区。但雷诺准数达到多少才能进入第二自模区，只有通过试验才能得知，这给模型设计带来困难。

确定第二自模区的试验过程
（1）确定所研究的区域；
（2）在此区域内测定流体速度、压降、选定当量直径、流体参数等；
（3）计算一组雷诺数和欧拉数，描绘成曲线；
（4）当雷诺数和欧拉数无关时，该雷诺数即为第二临界值。

隧道通风物理模型试验系统
physical model experiment system of ventilation

设计制作两套试验模型：
（1）1:24模型：该模型全长107.10m，分160节，每节长70cm，另配套3组送风竖井通道和3组排风竖井通道，配备8台离心风机供通风动力。可根
据需要自由组合，完成4竖井、3竖井、2竖井、单竖井送排式通风、竖井集中供（排）风及整体方案的验证优化。

（2）1:8模型：该模型全长50m，分52节，每节长100cm，另配套1组送、排风竖井通道。配备2台大功率轴流风机及变频器，通过变频器提供可连续
变化的通风动力。该模型可完成大比尺条件下不同工况的通风局部优化模拟。

数据采集系统
Data acquisition system

试验数采监控系统是以工业化自控软件组态
王KingView为基础设计开发的，压力测量采用毕
托管，可分别测量全压、动压和静压。
研究成果 Results-6

6. 开发出基于Matlab语言的公路隧道纵向通风设计计算平台
   6. The program based is work out with matlab, which is fit for one dimension longitudinal ventilation
程序的主要功能有：
● 根据交通量的分布特征，计算隧道需风量的分布特征；
● 隧道近、远期的通风计算和风机功率配置；
● 计算隧道运营期间射流风机随交通量的变化而需开启的台数。推算运营期间风机开、停管理和隧道通风用电量预测；
● 计算隧道多竖井送排式各段的轴流风机、射流风机所需功率曲线，完成轴流风机、射流风机等的通风系统配置。

基于matlab语言—维纵向通风计算程序
program based is work out with matlab

7. 深入开展了秦岭终南山公路隧道通风方案比选研究

7. The ventilation scheme comparison of Qinling Extra-long highway tunnel is made
不同设计方案通风技术比选研究
The research on ventilation schemes of different length

- AK方案（18020m）
  - 两竖井分段纵向通风
  - 三竖井分段纵向通风
  - 三竖井全横向通风方案
- A1K方案（11145m）
  - 两竖井分段纵向通风
  - 两竖井半横向通风
  - 两竖井全横向通风方案
- A2K方案（13175m）
  - 两竖井分段纵向通风
  - 两竖井半横向通风
  - 两竖井全横向通风方案

其他通风方案适应性研究
The research on other ventilation schemes

- 小竖井无动力通风方案
  - without physics power of small shaft
- 列车活塞风利用方案
  - use the piston wind of train

研究手段 research method

1. 物理模型（1:24）试验模拟
2. 数值仿真分析
   - 基于计算流体力学软件CFDesign，其功能与特征:
     - 二维平面、轴对称和三维空间流体问题
     - 可压缩和不可压缩流体的计算问题
     - 稳定状态和短暂状态流体运动问题
     - 显流和层流问题
     - 可以采用笛卡尔坐标和圆柱坐标
     - 牛顿流和非牛顿流的分析
     - 外部流体和内部流体
The physical model experiment of shaft segment longitudinal ventilation

The numerical simulation of shaft segment longitudinal ventilation

Key point ～ definition of desired wind

(1) Traffic构成（汽车比）
(2) 汽车CO、V1基准排放量
(3) 设计浓度限值（卫生控制标准）
(4) 设计车速工况

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### 三竖井方案隧道上、下行线所需风机功率及布置表远期（2025年）

**desired fan power of three shaft scheme**

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### 两竖井方案隧道上、下行线所需风机功率及布置表远期（2025年）

**desired fan power of double shaft scheme**

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<table>
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<tr>
<th>上行线</th>
<th>射流风机</th>
<th>风流风机</th>
</tr>
</thead>
<tbody>
<tr>
<td>功率 (kW/台)</td>
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<td>520</td>
</tr>
<tr>
<td>台数</td>
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<td>功率小计 (kW)</td>
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<td>590</td>
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<tr>
<td>总计 (kW)</td>
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</tr>
</tbody>
</table>

8. 系统进行了秦岭终南山特长公路隧道通风系统优化研究

8. The optimization research of ventilation system is made
为进一步指导通风设计，利用数值仿真平台对通风系统局部进行仿真分析，主要分析了联络风道局部压力损失、隧道主体送排风口间短道流态、射流风机升压效率、紧急停车带几何形状、隧道进出口段交叉流态和竖井进出口区域交叉流态等的模拟分析，与之相验证和补充，在物理模型试验系统上也进行了竖井底部中隔板高度优化试验、竖井送排风口优化试验和通风短道长度试验等，提出了结构优化建议，有力支持了泰岭终南山公路隧道通风系统设计，降低了工程造价，减少了运营费用。

在送排联络风道拐弯处必须设置导流板以减少压力损失，在给定的联络风道形式的基础上，建议2D（联络风道设置的内外弯风道断面当量直径）应尽量取较大的值。
The analysis and optimization on local stress loss of ventilation section network.

The short section Flowmeter analysis on air in and air out ventilation of tunnel.
隧道主体送排风口间短道流态分析
The short section Flowmeter analysis on air in and air out ventilation of tunnel

射流风机升压效率计算分析
The analysis on boosting efficiency of jet fan

当风机轴线与拱顶之间距离与射流风机叶轮直径的比值取较大值时，隧道内的流体更容易达到流速均匀状态；
射流风机出口向下倾斜一定角度时，隧道内的流体更容易达到流速均匀状态；
建议安装射流风机时，比值尽量取大，同时在条件允许条件下，将射流风机出口向下倾斜一定角度。

紧急停车带几何形状仿真分析
The analysis on geometry shape of emergency parking place

隧道进出口段交叉流态分析
The cross flowmeter analysis of tunnel portals
9. The operating mode simulation method is put forward, which is used to simulate the operating mode simulation of Qinling Extra-long highway tunnel.
10. The on-site testing of ventilation parameters is made.
**Results-10**

**Filed test on climate environment of tunnel portals**

- **North portal climate**
  - Opposite moisture of tunnel portals
  - Air pressure of tunnel north portals
- **South portal climate**
  - Opposite moisture of tunnel south portals
  - Air pressure of tunnel south portals

**Field test on ventilation resistance factor of shotcrete lining**

- K65+500～K66+154.5: Shotcrete lining ventilation resistance factor λ is 0.051～0.053, which is within the recommended range.
（1）秦岭隧道埋深大，对应区段地热明显，隧道中部岩层温度高达38℃，大部分区段也在20℃以上；
（2）公路东线隧道9月份测试时期，洞内自然风速很小，最大风速2.0m/s，平均风速1.0m/s；
（3）公路东线隧道内气温明显高于外界气温，温差多在5℃以上；
（4）公路东线隧道测试时洞内风流主要由北向南，从而使隧道内南段气温明显高于北段，且南段洞内气温高于岩层温度，多数区段气温在25℃以上；
（5）铁路西线隧道内日平均气温明显高于洞口外界气温，温差多在5～10℃之间；
（6）铁路西线隧道测试时期，隧道南北两端外界日气温变化大，分别达到22.0℃和19.5℃；
（7）昼夜温差变化的影响范围仅在距洞口2km以外，测试表明距南口进风段的1.6km测点处，洞内气温日较差仅4.5℃，而距风段的隧道北口，在洞内距洞口0.1km测点处，气温日较差仅3℃；
（8）秦岭特长隧道内洞内风速的瞬时变化对洞内气温影响甚小，且影响范围仅在距洞口2～3km区段，隧道中部区段气温基本保持恒定。