公路隧道运营管理与安全国际学术会议
论文汇报
First International Seminar on Road Tunnel Operation Management and Safety

苍岭特长公路隧道通风系统创新设计

Development of Ventilation System for Cangling Expressway Tunnel

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报告内容 (Content)

1. 引言(Introduction)
——浙江概况(About Zhejiang Province)

浙江-多山省份
Zhejiang : a mountainous province

国土：10.2 万KM²
人口：4600万（2005）

浙江－多隧道的省份
Zhejiang: a province with numerous tunnels

公路隧道（含通车与在建）600多座，其中80%以上由ZJIC完成设计。

There are more than 600 road tunnels in Zhejiang, and 80 percents are designed by ZJIC.

ZJIC概况(About ZJIC)

历年来设计完成高速公路2000多公里，大型、特大型桥梁500余座，隧道400多座，港区、码头400余座，航道4000余公里。

ZJIC ,a large state-owned consultant engineers for public works, has completed consult &design of about 2000km expressways, more than 400 tunnels, etc.

目前正在进行的长隧道项目
(some long road tunnels under construction by ZJIC)

No.	隧道名称 Tunnel name	左洞长 L tube length (m)	右洞长 R tube length (m)	所在高速公路 (Expressway name)
1	**苍岭隧道 Cangling Tunnel**	**7536**	**7605**	**台缙 Taizhou-Jinyun Expressway**
2	括苍山隧道 Kuocangshan Tunnel	7929	7869	诸永 Zhuji-Yongjia Expressway
3	双峰隧道 Shuangfeng Tunnel	6180	6187	

长隧道面临的挑战(Challenges of Long Tunnels)

1. 如何选择节能的通风方式？
   How to select a *economical ventilation system*?
2. 如何评估和应对火灾危险？
   How to evaluate and control *fire hazard*?
3. 如何控制下坡隧道火灾时的“烟囱效应”？
   How to control *chimney effect* in down-grade mountainous tunnels in case of fire.

开发新通风系统的目的
(To develop a new longitudinal ventilation system)

非火灾纵向通风与火灾排烟通风有机结合，探索一种具有独立排烟系统，土建费用增加不多，运营费用相对节省，防灾通风效果好的特长隧道通风系统。

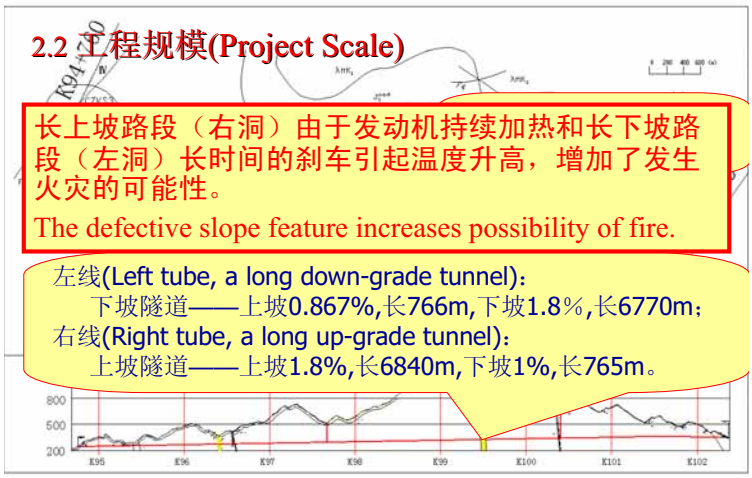
To develop a new longitudinal ventilation system with a stand-alone ex-smoke conduit, which has the following functions of
-competitive construction costs
-lower power consumption under operation
-better safety of road users in fire accidents

2.工程概况(About the Project)
2.1 工程位置(Project Location)

位于浙江省台州～缙云高速公路段。

Taizhou-Jinyun expressway

2.2 工程规模(Project Scale)



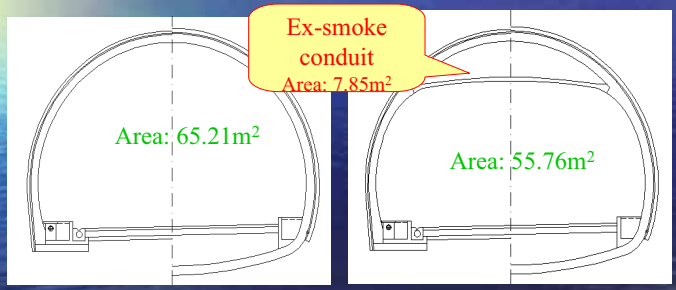
长上坡路段（右洞）由于发动机持续加热和长下坡路段（左洞）长时间的刹车引起温度升高，增加了发生火灾的可能性。

The defective slope feature increases possibility of fire.

左线(Left tube, a long down-grade tunnel)：
下坡隧道——上坡0.867%,长766m,下坡1.8%,长6770m；
右线(Right tube, a long up-grade tunnel)：
上坡隧道——上坡1.8%,长6840m,下坡1%,长765m。

横断面(Cross Section)

隧道主风道断面净面积：65.21m²（不设排烟道段，进出口两端各长1500m）及55.76 m²（设排烟道段，位于隧道中间段），排烟道面积7.85 m²。



无排烟道断面　　有排烟道断面

2.3 山岭气象与地形地貌情况 (Meteorologic and Topographic Information)

山岭气象

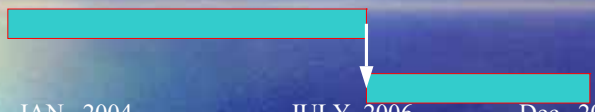
路线带位于东南沿海，属典型的亚热带季风气候，温暖湿润，四季分明，光照充足，雨量充沛。区域内气候的月变化呈单峰型：1~7月气温逐月升高，7~下年1月又逐月降低。

隧道穿越分水岭，两端气压差较大。

地形地貌

隧道位于浙东中低山丘陵区，最大海拔高程1076米，地形自然坡度45-60度，局部山体陡峭，构成悬崖，植被发育。

2.4 施工情况(Construction Schedule)



JAN., 2004	JULY, 2006	Dec., 2007
开工建设	贯通	计划通车日期
Started to excavate	Cut through	Date to open to operation

2.5 工程难点(Key Problems)

1. 深埋问题（800m）-岩爆问题(rockburst)
2. 断层破碎带承压水水文问题(artesian water)
3. 营运通风和火灾安全问题(ventilation and fire control)

3. 交通量分析及需风量 (Traffic Volume Analysis & Air Demand)

3.1 交通量分析(Traffic Volume Analysis)

隧道预测交通量(Predicted Traffic Quantity)

年 度	2007	2010	2015	2020	2025	2027
预测交通量(pcu/d)	11179	15706	24166	35508	49801	55956

隧道车型比例组成(Vehicle Classification and Ratio)

车型	小型货车	中型货车	大型货车	大客	小客	挂车	集装箱
比例系数	0.2000	0.2133	0.0865	0.2211	0.1814	0.0567	0.0410

3.2 通风卫生标准(Hygienic Standard)

根据《公路隧道通风照明设计规范》（JTJ026.1—99）及本隧道实际情况，本隧道设计采用的通风卫生标准如下表:

通风卫生标准

CO浓度 (CO concentration)	单向正常情况(unidirection) 200ppm 双向正常情况(bidirection) 250ppm 单向阻塞情况(traffic jam) 300ppm
烟雾浓度 (VI concentration)	单、双向正常情况(normal traffic) 0.007~0.0075m^{-1} 单、双向阻塞情况(traffic jam) 0.009m^{-1}

3.3 尾气排放标准(Emission Standard)

国外欧美地区汽车排放在过去30年中下降每年平均为4～6%。设计计算中2007～2017年间排放基准值以规范推荐值不变，而**2017年后汽车排放基准值按每年平均5%折减率递减。**

Decreasing 5% annually from 2017.

3.4 火灾释热量(Heat Release Rate)

英国规范中隧道火灾规模建议值

Fire load in a tunnel suggested by British Specification (BD 78/99)

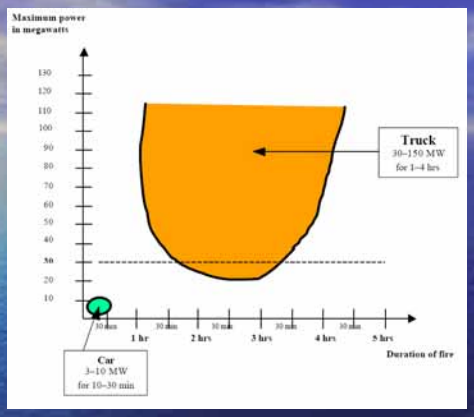
Road Tunnel Length/Type	Equivalent Ventilation Design Load (MW)			
	Motorway	Urban Major Route	Rural Major Route	B Route
Length > 2000m	50	50	20	20
Length < 2000m	50	20	20	20

Table 8.1 Equivalent Longitudinal Ventilation Design Fire Loads (minimum values)

不同车型火灾规模之PIARC建议值

Fire load of different vehicle type suggested by PIARC

Vehicle type	Typical fire loads (MJ)	Typical fire powers (MW)	Remarks
Passenger car	3 000 – 3 900	2.5-5	Fire loads used in fire tests in Finland
Bus Truck load Heavy goods vehicle	41 000 65 000 88 000	20 20-30 30	Fire loads used in EUREKA fire tests. Heat release rates without very combustible goods
Tanker carrying 50m^3 of gasoline	1 500 000	300	Levels assumed by Dutch authorities for fires of extreme dimensions



小汽车和货车火灾发展规律之比较

Fire process comparison between a car and a truck

本隧道火灾频率(fire frequency)：

远期其火灾事故频率将约为每年2-6次左右。

Long-term fire frequency is about 2-6 times annually.

本隧道火灾释热量(HRR)：

本隧道火灾释热量当双洞单向交通时按50MW设计(约为2辆货车碰撞火灾之释热量)，当单洞双向交通时按20MW设计。

Unidirection Traffic HRR:50MW

Bidirection Traffic HRR: 20MW

3.5 交通模式及通风计算工况考虑 (Work Condition Considered)

A、正常交通(normal traffic)：60~80km/h车速；

B、车辆慢速行驶(slow traffic)：40km/h车速；

C、交通堵塞(traffic jam)：考虑不同阻塞区段，堵塞长度按1000m计，其余地段正常行车；

D、双向交通(bidirection traffic)：隧道内拖挂车、大货车、中货车禁止通行，以保证隧道内的交通安全，行车速度按40km/h计算；

E、换气通风(air exchange)：按每小时换气3次，换气风速不低于2.5m/s。

对危险品运输车辆（有毒、易燃易爆等）的特殊考虑：

About vehicle with dangerous goods:

单向正常交通时：洞口设置危险品运输引导区，等候引导护送通行；

Unidirection traffic: permitted, but must be lead by pilot vehicle.

双向交通时：禁止危险品运输通行。

Bidirection traffic: not permitted.

3.7 隧道设计需风量(Fresh Air Demand Calculation)

计算方法及依据：规范JTJ026.1 1999及预测交通量；
PIARC 1995-EURO 2。

公路隧道通风计算分析系统的研发
Software developed to calculate fresh air demand

隧道计算需风量表(Table of Fresh Air Demand)

工况 (working condition)	设计车速 (design velocity)	设计需风总量Q_{req}(m^3/s)	
		右线隧道 (right tube)	左线隧道 (left tube)
2017年单向,正常交通(unidirection)	60km/h	733.5	414.8
2027年单向,正常交通(unidirection)	60km/h	829.1	414.8
2017年单洞双向交通(bidirection)	40km/h	459.8	459.8
2027年单洞双向交通(bidirection)	40km/h	519.8	519.8
2017年单向,阻塞交通(traffic jam)	组合	682.8	414.8
2027年单向,阻塞交通(traffic jam)	组合	812.2	448.4
火灾事故(fire, unidirection)	-	200	200
火灾事故(fire, bidirection)	-	80	80

注：右线隧道需风量由VI浓度控制，左线隧道由CO浓度控制。
Fresh air demand of right tube depends on required VI concentration, while fresh air demand of left tube depends on CO concentration.

4. 通风模式的选择(Ventilation System Selection)

4.1 横向通风模式（Transverse Ventilation System）

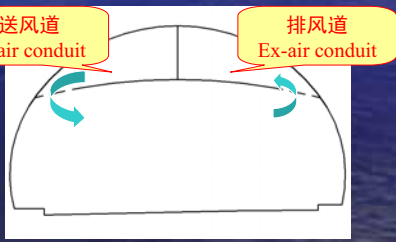
特点(features)：

正常营运阶段：专门布置一条送风道，供给新鲜空气；并通过专门的排风道，排除废气。

In normal service condition, a special in-air conduit is used to supply fresh air, and an ex-air conduit to discharge polluted air.

火灾情况下：排风道被打开至满负荷工作状态，抽排烟气。

In case of fire, the ex-air conduit is used to discharge smoke.



优点(advantages)：

在整个隧道中，空气中的污染物质浓度固定不变，因此适用于长度较长的隧道中，对于隧道的长度没有任何限制。

As for CO and VI concentration keep changeless, adaptive tunnel length is almost unlimited.

缺点(shortcomings)：

需要修建专门的送、排风管道来供应与排出通风空气，因此隧道横断面要求较大，造价较高，且不节能。

Cross section is so large that both construction cost and consumption are very high.

由于交通风力（活塞风）的存在，与隧道纵向完全交叉的气流实际上很难实现。

Because of piston effect, it's difficult to get transverse air flow.

4.2 半横向通风模式 (semi-transverse ventilation system)

特点(features)：

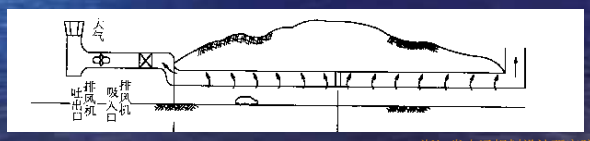
送风型(blowing model)：新鲜空气通过专门的管道均匀添加，污染气流则纵向排放到隧道的进出口；

排风型 (exhausting model)：新鲜空气从隧道进出口进入，污染空气则通过专门的管道被抽排出隧道。

优点、缺点(advantages and shortcomings)：

同横向通风模式

Same to transverse ventilation system.



4.3 纵向通风模式 (Longitudinal Ventilation System)

特点(features)：

隧道内污染物质浓度隧隧道长度线性增加。

CO & VI concentration increases as the tunnel lengthens.

优点(advantages)：

不需要专门的送、排风管道，隧道横断面积相对较小，工程造价较低；

Neither in-air conduit nor ex-air conduit is necessary, so the cross section is relatively small and the cost is low.

增加竖(斜)井分段送排风，理论上长度不受限制；

Adaptive length increases accordingly as shafts are added.

在单向交通隧道中，能充分利用"活塞效应"促进空气的流动。

In unidirection-traffic tunnels, piston effect can be made full use.

缺点(shortcomings)：

火灾情况下，烟雾排放路径较长，高温区段较长，防灾能力较差；

In case of fire, both smoke discharging path and high-temperature lining section are long, and hazard resistance is poor.

在双向交通工况下，交通通风力成为阻力，通风系统的动力消耗剧增。

In a bidirection-traffic tunnel, ventilation power consumption increases sharply as the piston effect disappears.

4.4 带独立排烟道的纵向通风模式 (Longitudinal Ventilation System with a Special Ex-smoke Conduit)

正常营运阶段——纵向通风

(using longitudinal ventilation in normal service traffic)

充分利用纵向通风经济、高效的优势。

to take advantage of economy and efficiency of longitudinal ventilation system.

火灾情况——利用独立排烟道排烟

(using the stand-alone ex-smoke conduit in case of fire)

可有效控制烟气漫延及沉降，提高防灾救援能力，将火灾对隧道内装修与设备损坏最小化。

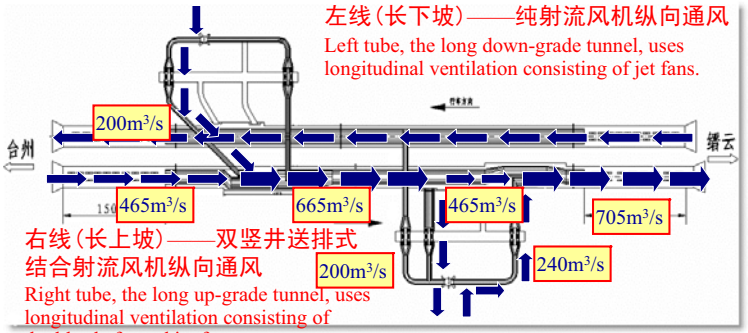
to prevent smoke from spreading and falling down, improve hazard resistance, and minimize lining and equipment loss.

5. 苍岭隧道通风系统与工作原理 (Ventilation System & Operation Principle)

5.1 通风系统(Ventilation System Design)

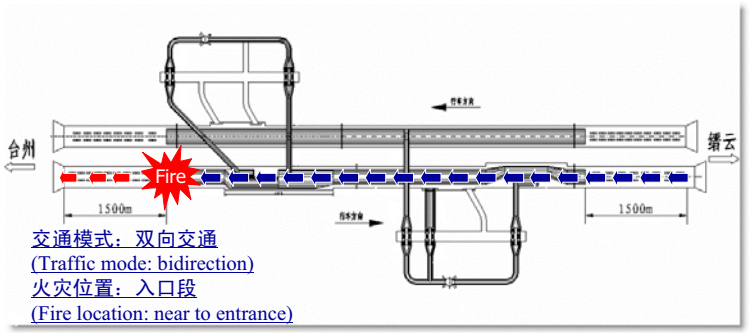
5.2 正常通风条件(Normal Service Ventilation)

左线(长下坡)——纯射流风机纵向通风
Left tube, the long down-grade tunnel, uses longitudinal ventilation consisting of jet fans.

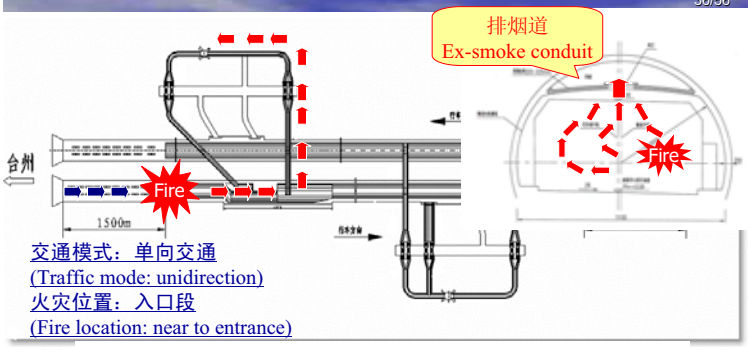


右线(长上坡)——双竖井送排式结合射流风机纵向通风
Right tube, the long up-grade tunnel, uses longitudinal ventilation consisting of double shafts and jet fans.

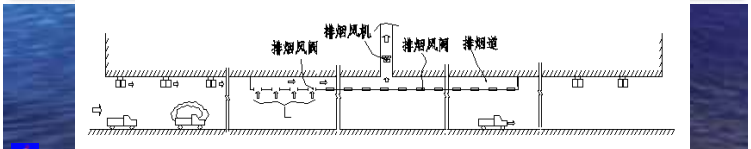
5.3 火灾工况通风模式(Ventilation in case of fire)

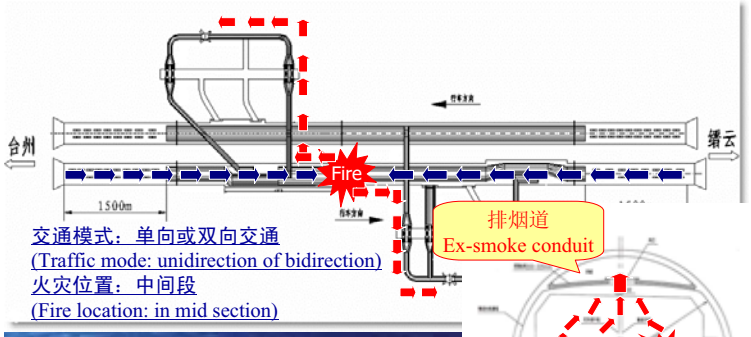


交通模式：双向交通
(Traffic mode: bidirection)
火灾位置：入口段
(Fire location: near to entrance)

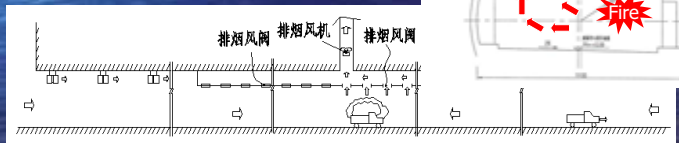


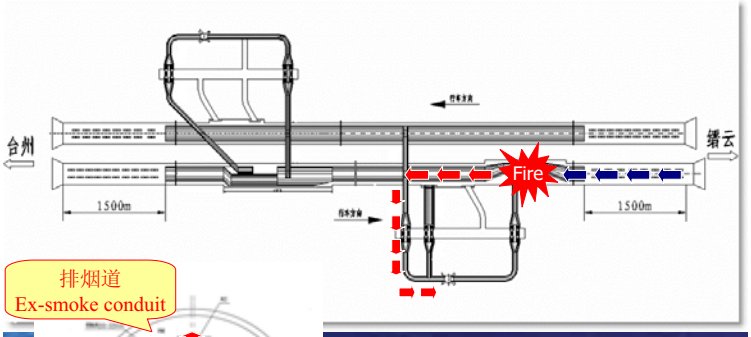
交通模式：单向交通
(Traffic mode: unidirection)
火灾位置：入口段
(Fire location: near to entrance)



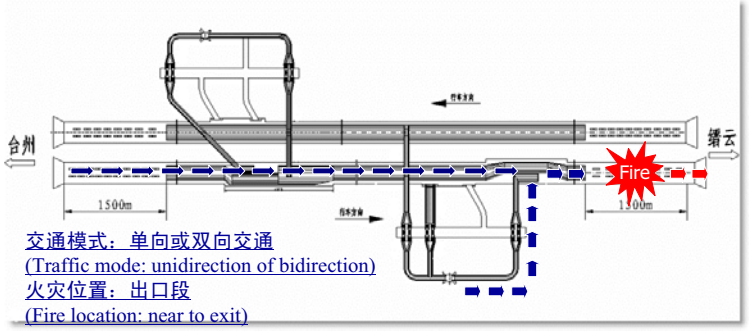


交通模式：单向或双向交通
(Traffic mode: unidirection of bidirection)
火灾位置：中间段
(Fire location: in mid section)

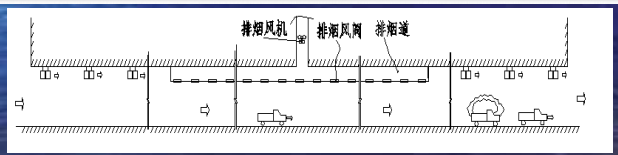




交通模式：单向或双向交通
(Traffic mode: unidirection of bidirection)
火灾位置：中间段(2#竖井下游)
(Fire location: in mid section (right to shaft 2))

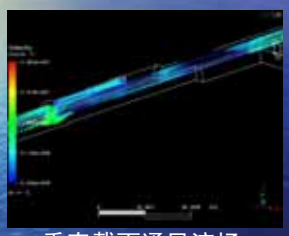


交通模式：单向或双向交通
(Traffic mode: unidirection of bidirection)
火灾位置：出口段
(Fire location: near to exit)



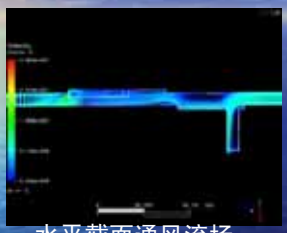
6.CFD分析技术(CFD Simulation)

6.1竖井底部气流短路问题分析
(Verification of Flow Short-circuit Problem)

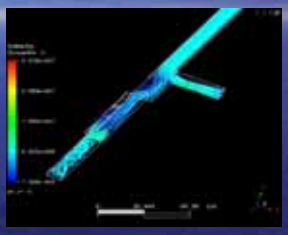


垂直截面通风流场
flow field in vertical cross section

水平截面通风压力场
pressure field in horizontal cross section

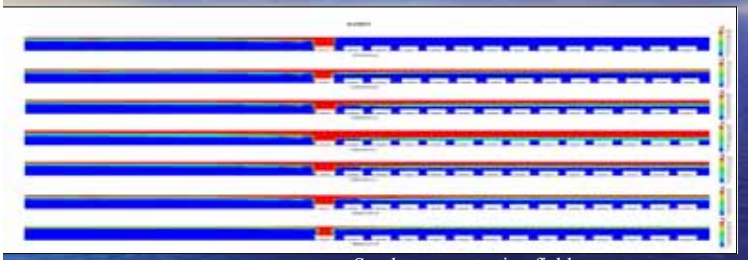


水平截面通风流场
flow field in horizontal cross section



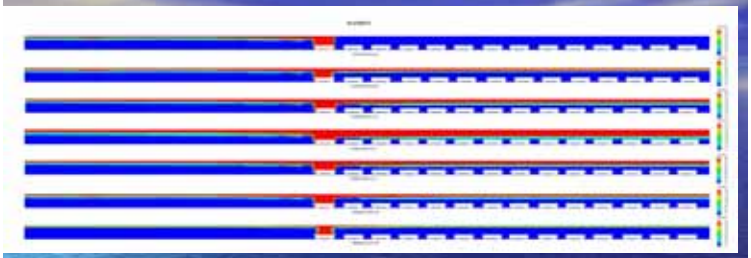
流线示踪
flow line track

6.2 火灾工况下烟雾场、温度场分析 (smoke field and temperature field in fire case)



隧道中段之50MW火灾摸拟(单向行车；半横向排烟)之烟雾浓度分布

Smoke concentration field
fire location: in the center section
HRR: 50MW
traffic mode: unidirection
ventilation mode: semi-transverse



隧道中段之50MW火灾摸拟(单向行车；半横向排烟)之温度场分布

temperature field
fire location: in the center section
HRR: 50MW
traffic mode: unidirection
ventilation mode: semi-transverse

隧道进口段50MW火灾摸拟(单向行车；纵向通风+半横向排烟)之烟雾浓度扩散分布

Smoke concentration field
fire location: near to entrance
HRR: 50MW
traffic mode: unidirection
ventilation mode: longitudinal and semi-transverse

隧道进口段50MW火灾摸拟(单向行车：纵向通风+半横向排烟)之温度场分布

temperature field
fire location: near to entrance
HRR: 50MW
traffic mode: unidirection
ventilation mode: longitudinal and semi-transverse

6.3 “烟囱效应”的分析(Chimney Effect Analysis)

烟囱效应的原因(driving forces of chimney effect)：

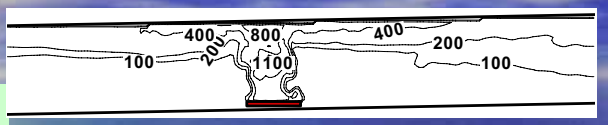
① 隧道两端洞口，洞口与竖井口之间的大气压差
(atmospheric pressure difference between point A and point B, between A and C)

② 隧道内外的温度差
(temperature difference between in and out of the tunnel)

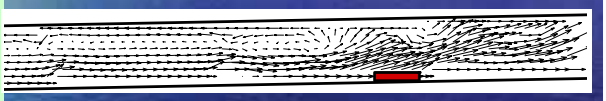
③ 隧道外大气自然风的作用
(the effect of natural wind out of the tunnel)

单向行车，50MW，通风系统失效

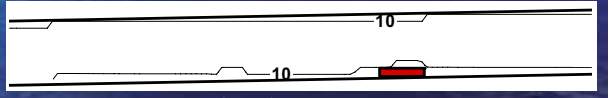
Unidirection, 50MW, no ventilation



温度分布(temperature field)



速度分布(velocity field)



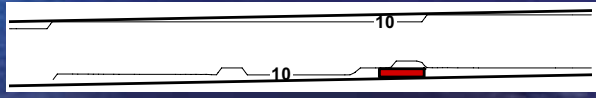
能见度分布(visibility field)

单向行车，50MW，通风系统工作

Unidirection, 50MW, ventilation system works.

温度分布(temperature field)

速度分布(velocity field)



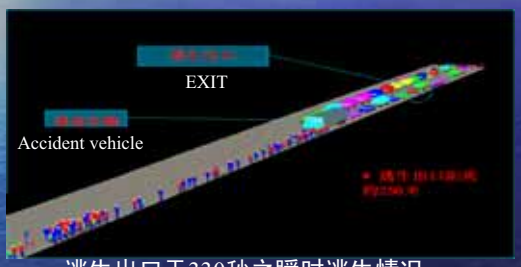
能见度分布(visibility field)

6.4 隧道温升分析
（Temperature Increasing Analysis）

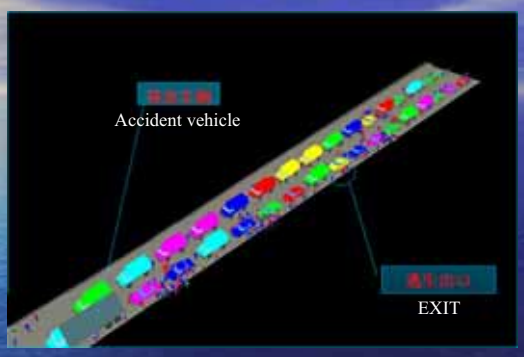
在正常交通情况下，温升为2℃左右；在全阻滞交通的不利工况下，全隧道温升仅12℃左右。

When in normal traffic condition, temperature in the tunnel increases only 2℃. While traffic jams, temperature increases about 12℃.

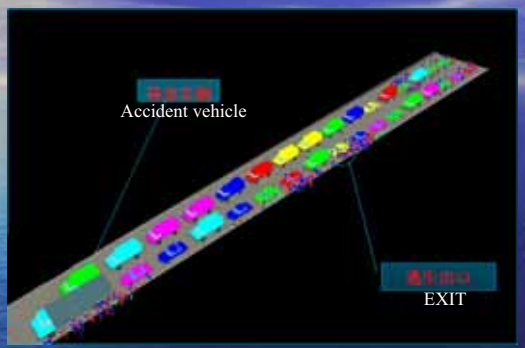
6.5 疏散分析（Evacuation Analysis）



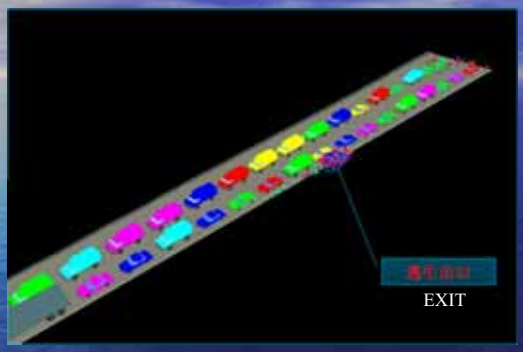
逃生出口于330秒之瞬时逃生情况
Time: 330s



逃生出口于410秒之瞬时逃生情况
Time: 410s



逃生出口于490秒之瞬时逃生情况
Time: 490s



逃生出口于580秒之瞬时逃生情况
Time: 580s

7. 结语(Conclusions)

① 正常运营通风采用相对节能的纵向方式，而在火灾工况开启隧道顶部独立排烟道进行排烟。
In normal service condition, the economical ventilation system, longitudinal ventilation system is adopted. While in case of fire, the ex-smoke conduit works rapidly to discharge smoke and control fire.

② 对大交通量、高客车比的特长隧道，设置专用排烟道，避免主风道烟雾纵向蔓延的危害，提高安全性。
In a long expressway tunnel with heavy traffic flow and high passenger vehicle ratio, a special ex-smoke conduit is necessary to prevent smoke from spreading and to improve safety in the tunnel.

③ 本通风系统设计无需增加主隧道断面积，与横向、半横向通风方式相比，经济节能。
The ventilation system, presented in this article, does not need to enlarge the cross section of the tunnel. As a result, it's much more economical than a transverse or semi-transverse ventilation system.

④ 本通风系统设计可适用于拱形、圆形、矩形等各种断面的单向、双向公路隧道。
Furthermore, the ventilation system mentioned above is adaptive to most cross section types in both unidirection and bidirection traffic tunnels , including vaulted, circular, and rectangular cross section.

综上所述，带独立排烟道的纵向通风系统的研发是一项有意义的工程实践，它适用于长度5km以上的公路隧道(尤其是山岭隧道)，是今后长大隧道通风发展的方向。

The new ventilation system with a special ex-smoke conduit, a significative practice, is adaptive to all road tunnels longer than 5km, especially to mountain road tunnels, and shows fine promise.

谢谢！

Thanks for your attention!

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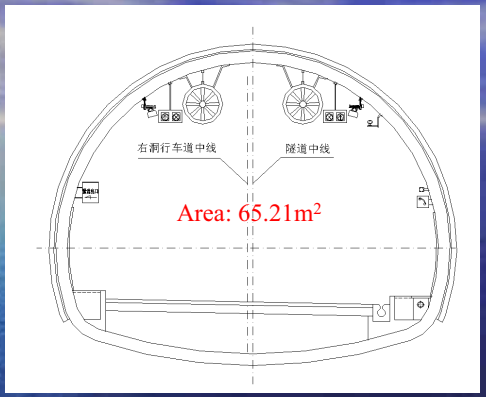
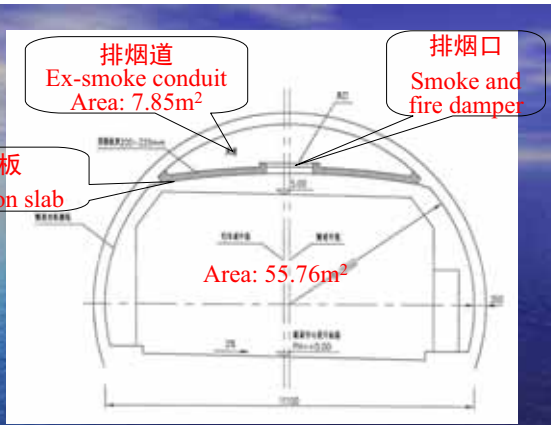
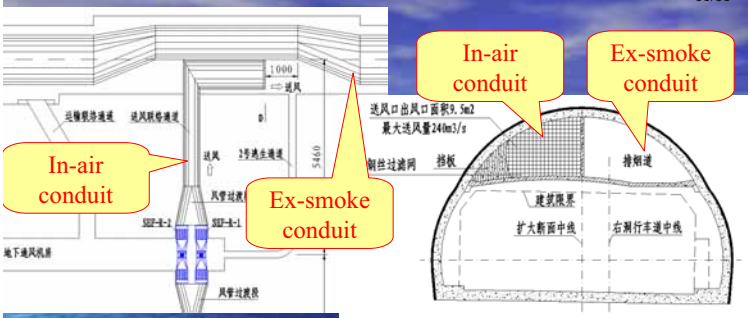
E-mail:zpdic@mail.hz.zj.cn



进、出口段横断面
(Cross section of entrance and exit section)



中间段横断面和顶隔板
(Cross section and ventilation slab of mid section)



送风口与排烟道交界处的设计
(Joint Design of In-air & ex-smoke Conduit)

高温工作性能(high-temp index)：

250℃/2h，400 ℃/1h

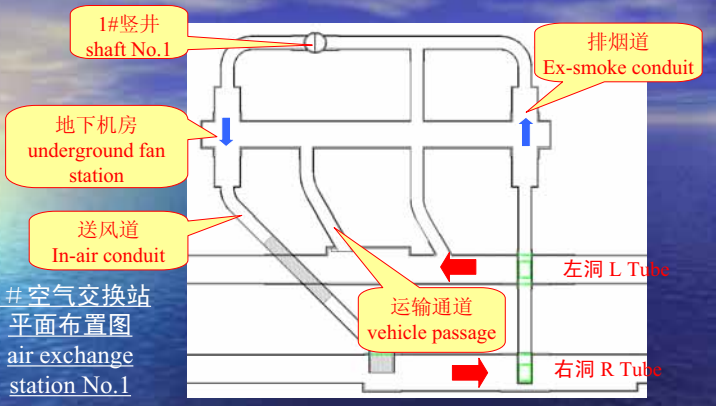
尺寸和间距(size & span)：

1.25m×2.00m@25m

控制模式(control mechanics)：

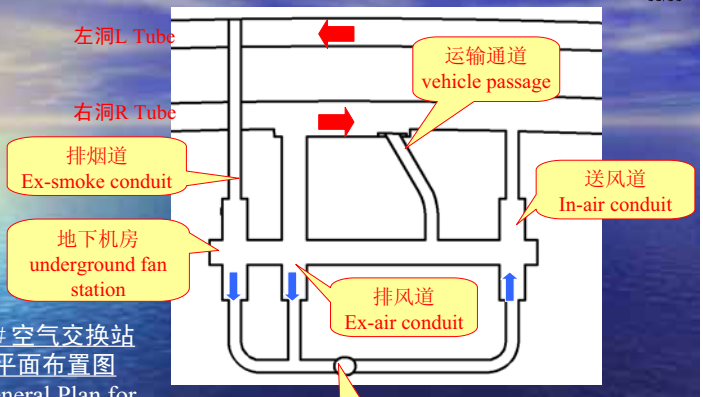
开启火灾处100m范围及车行方向200m

排烟阀
smoke damper



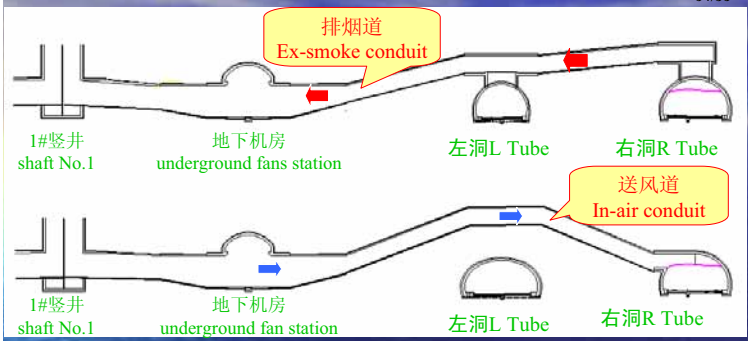
1＃空气交换站
平面布置图
air exchange station No.1

送风道、排烟道纵断面图
竖井风塔设计

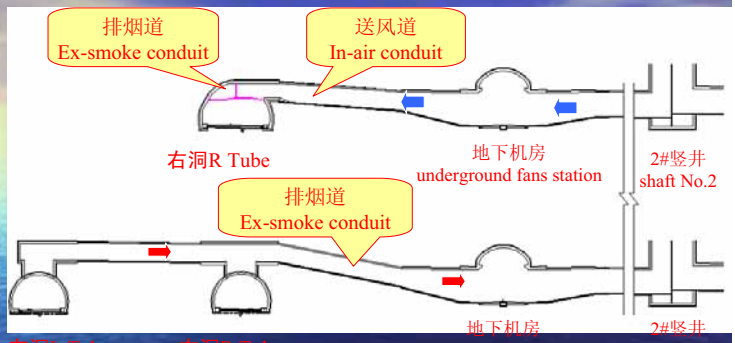


2＃空气交换站
平面布置图
General Plan for air exchange station No.2

送风道、排烟道纵断面图
竖井风塔设计

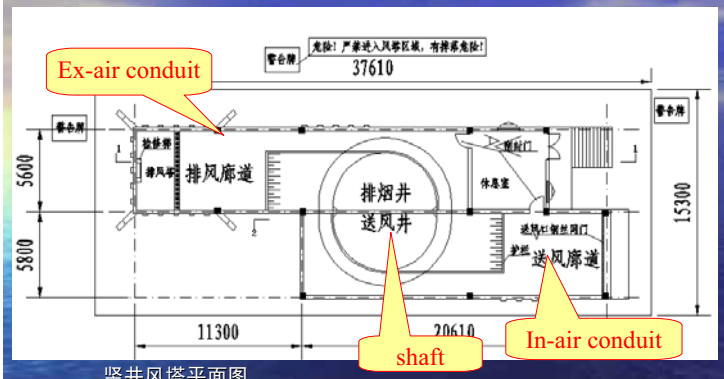


1＃空气交换站送风道、排烟道纵断面图
Profile of in-air & ex-smoke conduits for air exchange station No.1



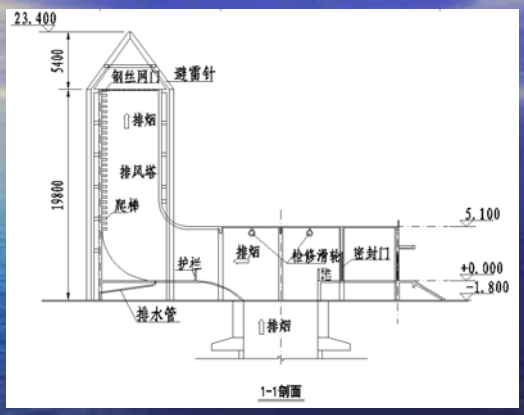
2# 空气交换站送风道、排烟道纵断面图

Longitudinal profile of air exchange station No.2

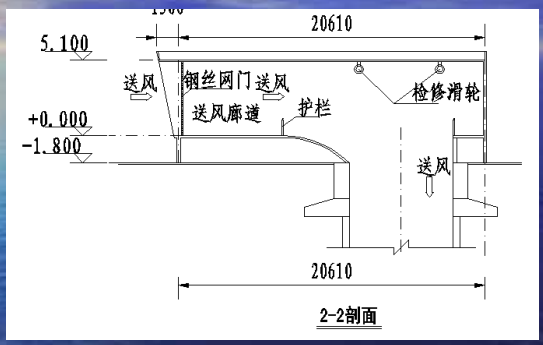


竖井风塔平面图

Plan of ventilation tower in open area



cross section 1-1 of ex-air conduit for the ventilation tower



cross section 2-2of in-air conduit for the tower