城市高架路－匝道－地面交通的交互作用及交通流特性研究

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● 专 业：流体力学

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Investigation on Interaction and Characteristics of Traffic Flows in Urban Elevated Road-Ramp-Ground Road System

Candidate：Lei Li
Major：Fluid Mechanics
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上 海 大 学

本论文经答辩委员会全体委员审查,确认符合上海大学博士学位论文质量要求.

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答辩委员会对论文的评语

　　雷丽同学的博士学位论文从交通实际观测入手,选取合适的交通流理论模型,对高架路—匝道—地面交通三者间相互作用的各种不同情况进行模拟,揭示了它们的交通动态演化特性和拥堵形成机制,得到了一系列有实际意义的结果.该选题有前沿性和科学性,有重要的学术意义和应用前景.论文作者对交通流研究进行了广泛的文献查阅,对国内外动态有清晰的认识.

　　该论文的创新性工作主要表现在:

　　(1)通过对上海市高架路典型路段的实测分析,掌握了高架道路交通流的主要特征,得到适用于不同交通流的两种速度—密度关系式;

　　(2)采用改进的一维管流模型,对地面相交主干道右转车辆造成的"挤压"效应进行了数值模拟,指出"挤压"效应是导致某些下匝道直行交通出流不畅的重要原因,对高架路匝道的正确设置有指导作用;

　　(3)从各向异性的流体动力学模型出发,增加了匝道交通的影响项,通过数值模拟,论证了上匝道处采用信号定时调节措施的可行性,并给出了合理的信号配时优选方案;

　　(4)采用 FI 元胞自动机模型,首次对上匝道与主干线合流处建立了交替通行的交通流模型,考察了各种典型交通流情况下交替通行规则对高架道路交通的改善效果,为交通规则的优化提供了科学依据;

(5) 采用 NaSch 元胞自动机模型,对单车道高架路主线的交织区路段进行了数学建模和模拟分析,研究了车流交织行为对高架系统交通状况的影响,并对交织区长度的设计提出了独到见解.

答辩中,雷丽同学能够正确回答所提出的问题.答辩委员会认为,该论文选题合理,逻辑严密,行文流畅,理论正确,数据可靠,是一篇优秀的博士学位论文.该论文充分表明作者掌握了坚实宽广的基础理论和系统深入的专业知识,具有独立从事科研工作的能力.

答辩委员会表决结果

经无记名投票表决,答辩委员会全票(7 票)通过雷丽同学的博士学位论文答辩,并建议授予工学博士学位.

答辩委员会主席：顾国庆

2004 年 12 月 30 日

摘　　要

汽车工业的迅速发展与道路建设的相对落后,已经成为非常突出的世界性矛盾.为了解决"交通难"问题,国内外许多大中城市兴建了快速通行的高架道路.但高架道路往往在建成之后不久便出现频繁的交通阻塞,究其原因,除了交通需求猛增因素之外,规划设计的缺陷以及建成后的交通管理与控制不当这两个因素也不可忽视.高架路、匝道与地面道路组成了城市的立体交通网络,三者之间息息相关、密不可分.基于实际的交通观测,本文利用交通流理论中的宏观和微观方法(即流体力学模型和元胞自动机模型)对高架路、匝道和地面道路之间的交互作用开展研究,对匝道附近的高架路段和地面交叉口进行了数学建模以及数值模拟,分析了交通流的复杂动力学行为,并且定性地为交通规划设计及交通管理控制提出了一些建议.论文的主要工作如下:

(1)选取上海市高架道路系统的局部路段,采用人工测量和摄像技术相结合的手段进行了大量的交通观测,掌握了高架道路交通流的主要特征.对实测获取的大量数据进行处理和分析,得出了分别适用于稀疏交通流和拥挤交通流的两种速度—密度关系式,并据此给出了畅行速度与阻塞密度这两个重要参量的数值.由实测数据得到的基本图揭示了高架路上实际存在的几种不同的交通相.

(2)以上海市内环线高架的武宁路匝道作为典型案例,实

际观测并细致分析了下匝道附近交叉口的交通流,直观地确认了地面相交主干道的右转车辆对下匝道直行交通的"挤压"效应.基于一维管道流模型,在连续性方程中引入源项,运动方程中引入弛豫项,对右转车辆干扰效应进行了数值模拟,结果与实测数据基本吻合.从模拟结果来看,"挤压"效应随着右转车辆的数目增多而加剧,是导致某些交叉口出流不畅的重要原因,而设置在繁华路口的高架路下匝道加剧了这种拥塞状况.因此建议在高架路的设计阶段应正确地选择匝道位置,而在制定此类交叉口的交通管理措施时,设置右转方向的专用交通灯是一种较好的解决方案.

(3)针对上海市高架道路系统存在的交通拥堵问题,论证了在上匝道处采用信号定时调节措施的可行性,并确定了合理的信号配时方案.从本课题组发展的各向异性的流体动力学模型出发,在运动方程中计及匝道交通影响项,对上匝道附近的高架路段进行了数值模拟.模拟结果表明,与无任何控制措施时相比,对上匝道实行定时调节,可以优化高架道路上的交通流参数,改善高架道路的交通状况.对设计的六种信号配时方案进行对比分析,找出了最合理的优选方案.

(4)论证了上海市交通管理部门在高架路上匝道的合流处所实施的交替通行规则的合理性和可行性.以 FI 元胞自动机交通流模型为基础,对实施交替通行规则前后的上匝道合流处分别建立合理的交通流模型,并对其交通流状况进行了数值模拟和分析,结果表明:当高架路主线和上匝道的来流车辆较多时,实施交替通行规则可以大大改善高架道路交通;当交通流比较稀疏时,实施该规则前后交通流状况基本不发生变化.当车流

较为畅通或比较拥堵的状态下,主干线和上匝道两股车流容易实现1∶1的交替通行;而当车辆中速行驶时,更容易实现两股车流2∶1交替行驶的局面.

(5)高架道路上的交织区经常成为交通瓶颈.论文以NS元胞自动机交通流模型为基础,考虑到换道因素,对高架路主线为单车道时的交织区路段进行了数值模拟和分析.结果表明:当交通流稀疏时,车流的交织行为对系统影响不大,即使加大交织区长度,整个系统的交通流参数也变化不大;当交通流拥挤时,交织行为会对系统产生不良影响,此时加大交织区长度,可以改善整个系统的交通流状况.模拟结果显示,交织区长度并非越大越好,工程设计中应该选取一个适宜的中间值,整个系统就可以获得很好的运行效果.

最后,对我国未来的交通流研究进行了展望,并提出了一些建议.

关键词 高架道路,匝道,地面道路,速度—密度关系式,"挤压"效应,定时调节,交替通行规则,交织区

Abstract

The rapid development of the automobile industry and the relative lag of the road construction have constituted a prominent contradiction all over the world, particularly, in most of large cities. To cope with it, elevated roads have been built in many cities both at home and abroad. However, traffic jams frequently appear on elevated roads immediately after the completion of their construction. The awkward situation mainly results from the planning bug or the unsuitable control, apart from drastic increase in transportation demand. Elevated roads, ramps and ground roads are closely interconnected in three-dimensional urban traffic networks. Based on the field measurements, in this dissertation, by using the macroscopic and microscopic methods, i. e., the hydrodynamic models and cellular automaton models for traffic flows, the relations among the three interacting parts were investigated. The mathematical modeling and numerical simulation were conducted for the sections of elevated roads and for the interaction of elevated roads and intersections on the ground. After having analyzed the complicated dynamic behavior on the elevated roads,

some suggestions were put forward for the transportation planning and management. The contents of the dissertation are as follows:

(1) By combining manpower survey with the video recording, a series of field measurements were conducted on several sections of the elevated road system in Shanghai and then the main characteristics of the elevated road traffic flow were captured. By means of data processing and analysis, two speed-density relations were established, which are suitable for the free flow and the congested flow respectively. And thus two important parameters, namely, the free flow speed and the jamming density, were determined. The fundamental diagram obtained from the measured data reveals three distinct traffic phases.

(2) With the Wuning Off-Ramp of the Inner Ring Elevated road in Shanghai as a representative case, meticulous observations were carried out on traffic flow at the intersection near the off-ramp. And it was found that the "squeezing" effect of right-turning vehicles from the intersecting main road on the straight motion of vehicles from the off-ramp is the main reason of the existing traffic jam. A modified 1-D pipe-flow model was established by introducing a source term into the continuity equation and a relaxation term into the motion equation in Wu Zheng's model. With the modified model, numerical simulation was performed

with special attention to the disturbing effect of right-turning vehicles. The results agree quite well with the observed data. The analysis shows that the "squeezing" effect，which exacerbates with the increasing number of right-turning vehicles，is the principal cause of congested traffic at certain intersections. The inappropriate design and construction of ramps in front of busy crossings enhances the congestion. Thus，installing the right-turning traffic lights may be a promising way of solving the problem.

（3）There exist severe problems in the transportation on elevated road system in Shanghai，such as frequent congestions or jams on the elevated roads and their ramps. For this reason，measures of controlling the on-ramp traffic with timing signals were suggested in this dissertation. The reasonable timing scheme was recommended for signal controlling. On the basis of an anisotropic hydrodynamic traffic model developed by our research group，a ramp-effect term was introduced in the motion equation and traffic flows on the elevated road sections near the on-ramp were numerically simulated. The results show that signaling control of on-ramp is helpful for the improvement of traffic on the elevated roads. We also found the best timing scheme after comparison among six choices of signaling period.

（4）The gear-alternating regulation was first actualized at the interfluent location of on-ramps in Shanghai elevated

roads, which was theoretically studied in this dissertation. Different traffic flow models were established for the cases with and without the alternate running rule based on the FI cellular automaton traffic model. With the models, the traffic behavior at the interfluent location of on-ramp was investigated and some results were concluded. When there are many inflowing vehicles on the elevated road and ramp, the traffic situation on the elevated road with the alternating regulation is much better than that without the regulation; when there are less inflowing vehicles, the elevated road situation keeps unvaried on the whole in the two cases. The ·vehicles on the elevated road and the on-ramp are easily to move forward with 1 : 1 proportion in congestion or free flow states and often with 2 : 1 proportion in the medium-speed flow.

(5) The weaving areas often turned into the bottleneck on the elevated roads. On the basis of the NS cellular automaton traffic model, the weaving section with one-lane main road was simulated and analyzed. For the free traffic flow, weaving operations almost has no influence on the system, even with the weaving length being increased. On the other hand, when the traffic flow is in congested state, weaving conflicts have negative effects on the system. The traffic situation will be improved with the increase of weaving length. Our simulation results suggest that the length of

weaving sections need not to be inappropriately increased, and a proper medium value can be chosen to get an optimal traffic situation.

Finally, the prospect was briefly reviewed for the future advances in the research of urban traffic flows in China.

Key words　elevated road, ramp, ground road, speed-density relation, " squeezing " effect, timing signal controlling, gear-alternating regulation, weaving area

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