

Analysis and Study on Traffic Evacuation Control Strategy of Expressway Network in Sichuan Province under Earthquake

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Abstract: Based on the analysis of the current situation of expressway network and the location distribution of earthquake disaster in Sichuan province, the paper did integration analysis to the evacuation control strategy, researched on reverse traffic control model and phased control model, finally proposed that the comprehensive evacuation strategy model of sub-regional and sub-staged should be adopted under the condition of earthquake events in Sichuan province, to achieve the optimization of evacuation traffic control in road network.

Key words: Sichuan Province; expressway; earthquake disaster; evacuation strategy

During recent years, earthquakes take place frequently in Sichuan Province, especially Wenchuan Earthquake in 2008, Lushan Earthquake in 2014, and so on, which brings different influences to the traffic of the whole province. In fact, traffic emergency evacuation control aims to use various traffic organizational methods, strategies, means, and so on, peak-load shifting in time and density filling thin in space and to use limited traffic facility and equipment to make proper evacuation control strategy according to the severity and scope of earthquake after overall consideration of the optimal emergency evacuation path, so as to realize quick emergency rescue.

1. Location analysis

As to the geographical distribution, earthquakes mostly take place in the mountain terrain of western Sichuan, with linear distribution parallel to the boundary of mountainous area---- basin area; according to the regionalism, it can be roughly divided into three districts, which can be seen in Figure 1.



Fig.1 Distribution of earthquake risk regions in Sichuan province

From the expressway planning of Sichuan Province, it can be seen that in western Sichuan area, with such factors as terrain, landform, climate, economy and so on, the density of expressway network is not as much as 1/5 in the eastern district; however, earthquakes take place rather frequently among these mountainous area in western Sichuan, where expressway network is least developed.

2. Evacuation strategy and model analysis

2.1 Strategic analysis

According to such features of expressway as closure and high-speed, and the experience of “5.12 Wenchuan Earthquake” and “4.20 Lushan Earthquake”, expressway is the main channel of emergency evacuation and the emergency traffic evacuation object is mainly traffic stream; therefore there are mainly 2 kinds of evacuation control schemes: traffic stream evacuation and regional evacuation.

2.2 Model analysis

2.2.1 Model of reversal vehicle motion control

Considering the characteristic of reversal vehicle motion control, path selection optimization model is chose based on path to construct reversal vehicle motion control model. The objective function and constraint condition of the model are the same as those of path selection optimization model, with following constraint conditions in addition:

$$C_{i^+}^t = \sum_{ln \in LN(i)} C_{ln^+}(t)(1 - \delta_{ln}) \quad (1)$$

$$C_{i^-}^t = \sum_{ln \in LN(i)} C_{ln^-}(t)\delta_{ln} \quad (2)$$

In the formula, i^+ 、 i^- —— corresponding index numbers of normal and reverse cellular in path i ; $C_{i^+}^t$ —— traffic capacity of cellular i^+ within the time interval of t ; $C_{i^-}^t$ —— traffic capacity of cellular i^- within the time interval of t ; $C_{ln^+}(t)$ —— forward direction traffic capacity of lane ln within the time interval of t ; $C_{ln^-}(t)$ —— reverse direction traffic capacity of lane ln within the time interval of t ; ln —— lane number in lane i (count from the far left lane); δ_{ln} —— binary variable; when the lane conducts reverse operation, the value is 1; otherwise, it is 0.

Besides, the decision of lane reverse operation satisfies following logical relation:

$$\delta_{ln} \geq \delta_{ln'}, ln \leq ln' \quad ln, ln' \in LN(i) \quad (3)$$

$$\delta_{ln} + \delta_{ln'} \leq 1 \quad ln = 1 \in LN(i) \quad ln' = 1 \in LN(j) \quad (4)$$

2.2.2 Staged evacuation control model

Suppose that the safe time window is predefined in various evacuation area; once evacuation instructions are published, the load mode for total demand and dynamic demand of all the starting points is defined; it will start from the designated nodes in the road network and make prior estimation on the evacuation demand of any starting point; once the evacuation order is received on any starting point, evacuation demand will be uploaded to the road network according to predetermined model, so as to build staged evacuation model.

(1) Objective function

① Objective function 1 ---- weighted time of evacuees leaving evacuation area.

$$\min \sum_z \left\{ w_z \sum_t \left[\sum_{i \in S_z^r} x_i^t + \sum_{r \in S_z^r} \left(x_r^t + \sum_{r \in S_z^a \cup cw_r} x_i^t \right) \right] \right\} \quad (5)$$

② Objective function 2 ---- weight waiting time for those cars which should but not be put in road network as for jams .

$$\min \sum_z w_z \left[\sum_{r \in S_z^r} \sum_t \left(x_{cw_r}^t - \sum_{j \in \Gamma^{-1}(cw_r)} y_{cw_r,j}^t \right) \right] \quad (6)$$

In the formula, z —— evacuation area number; w_z —— weight for z zone in emergency state; S_z —— section of the road in z zone (ordinary cellular); S_z^r —— starting point in the zone (original cellular); S_z^a —— set of auxiliary cellular section of road for modeling delay in evacuation orders for starting point r ; cw_r —— road section of waiting cellular before vehicles entering evacuation road network produced on starting point r .

(2) Constraint conditions

Describe traffic stream constraints according to non-iso-scale cellular transfer concept, and the conditions are as following:

$$x_i^{t+1} = x_i^t + \sum_{k \in \Gamma(i)} y_{ki}^t - \sum_{j \in \Gamma^{-1}(i)} y_{ij}^t, \quad i \in S \cup S_s \quad (7)$$

$$x_i^{t+1} = x_i^t + d_r^t - \sum_{j \in \Gamma^{-1}(r)} y_{rj}^t, \quad i \in S_r \quad (8)$$

$$\sum_{k \in \Gamma(i)} y_{ki}^t \leq \min \{ Q_i^t, N_i^t / I_i, N_i^t - x_i^t \}, \quad i \in S \cup S_s \quad (9)$$

$$\sum_{j \in \Gamma^{-1}(i)} y_{ij}^t \leq \min \{ Q_i^t, N_i^t / I_i \}, \quad i \in S \cup S_r \quad (10)$$

$$\sum_{j \in \Gamma^{-1}(i)} y_{ij}^t \leq x_i^{t-I_i+1} - \sum_{k \in \Gamma^{-1}(i)} \sum_{m=t-I_i+1}^{t-1} y_{ij}^m, \quad i \in S \cup S_r \quad (11)$$

$$\sum_{p \in phl} \{ y_{ij}^t / Q_i^t, ij \in p \} \leq 1 \quad (12)$$

$$\sum_{i \in S_s} x_i^{T+1} = \sum_{r \in S_r} D_r \quad (13)$$

In the formula: x_i^t — number of vehicles at the initial time of time interval t of cellular i ; d_r^t — evacuation demand produced by endogenous cell r within time interval t ; Q_i^t — number of vehicles entering/exiting cellular i within time interval t ; N_i^t — number of vehicles that can be accepted in cellular i within time interval t ; I_i — dimension of cellular i ; r — indexical labeling of derived cell; i, j, k — other indexical labeling of cellular; D_r — overall evacuation demands produced by starting point r .

2.2.3 Comparative analysis of two models

Make simulation comparison of the model of reverse vehicle motion control and staged control model, and come to the following conclusions (Table 2):

Tab.2 analysis and comparison of the two models

Characters	Strategic model of reverse vehicle motion control	Strategic model of staged evacuation
➤ Feature	<ul style="list-style-type: none"> ➤ Increase the length of reverse vehicle motion control within the road section; able to increase the road network traffic capacity to certain degree; local road sections may have traffic saturation. ➤ With the increase of reverse vehicle motion control road section, the minimum evacuation and clearance time decrease therewith; the traffic capacity of network is enhanced greatly. 	<ul style="list-style-type: none"> ➤ It can effectively remit the jam degree under different evacuation demand model and significantly shorten the average journey time that evacuees pass road network. ➤ It can effectively decrease the delay of entering road network under different evacuation demand model, and greatly shorten the average waiting time of evacuees at various starting points.
Suitable for	The density of road network is relative high; transfer is convenient; the traffic nodal points are linearly distributed.	The density of road network is relative low; the demand area of traffic gathering and distribution has high management uniform degree.

In conclusion:

As for the strategic model of reverse vehicle motion control, the maximum traffic quantity of evacuation will not increase progressively in a linear way along the length of reverse vehicle motion control road section, but tend

to be stable along with the progressive increase of the length of reverse vehicle motion control road section.

As for the strategic model of staged evacuation, it not only relies on the danger degree of evacuation area, but also depends on the evacuation demand model of different starting points of different evacuation areas; meanwhile, the result differences of demand distribution of different starting points, and of publishing time and routing selection of various sections, will exert influence on the average of its effectiveness.

3. Case Study

Suppose that earthquake takes place in Kangding --- Xichang area, according to *Special Emergency Plan of Rehabilitation and Protection of Expressway Network During Earthquake in Sichuan Province*, and *Special Emergency Plan of Rehabilitation and Protection of Expressway Network During Earthquake of Panxi Area in Sichuan Province*, Yaxi- Xipan expressway will become the lifeline in earthquake relief work, which decides that the direction of land evacuation channel of this area will be southwest-northeast (Figure 2).

Meanwhile, Chengya Expressway, ChengwenQiong--Qiongming Expressway, Chengle--Leya Expressway, and other expressway will become important rescue route, and it is necessary to do well in the traffic facilities, traffic control along the line. All the relevant emergency rescue teams should be quick in road repair and obstacle removal on damaged expressway, so as to ensure that expressways available.

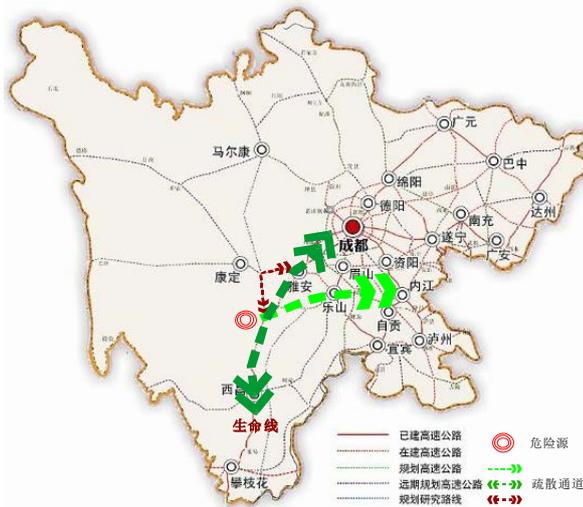


Fig.2 Diagram of evacuation direction

As is shown in Figure 3, the evacuation area can be divided into numerous evacuation control area according to the incidence of earthquake, which can be marked as from interior to exterior: district 1, district 2, district 3 district N. In each district, it is necessary to consider the earthquake incidence degree, demand on evacuation traffic, evacuation network, and so on; evacuation and depot spots are set specially for evacuation personnel to concentrate temporarily, who are waiting for evacuation; the evacuation and depot spots should better be set at the entrances and exits along expressway; the specific locations should selected within the walking area of shelters, so as to ensure shelter safety and increase evacuation efficiency; in the levels outside of district 3, it is proper to conduct reverse traffic control on some routes according to the density and connectivity of road network, so as to increase the traffic capacity of road network.

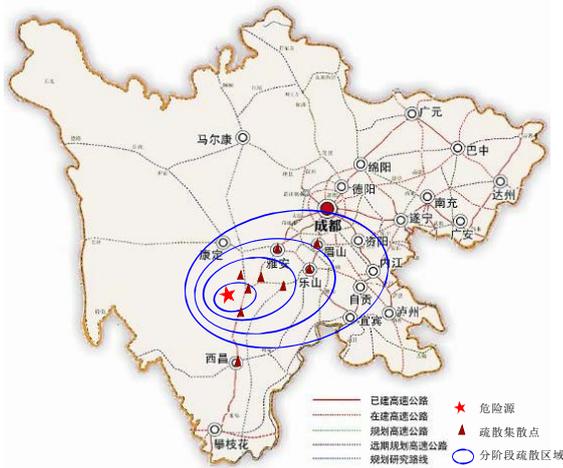


Fig.3 Figure of phased evacuation control

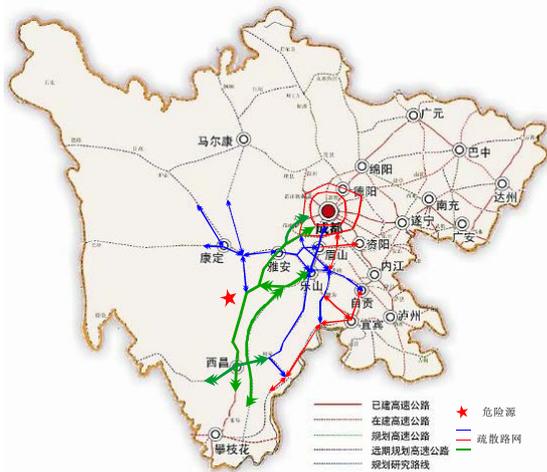


Fig.4 Distribution sketch map of disaster relief path

The rescue traffic stream mainly refers to the emergency rescue traffic stream in rescue and earthquake; this part of traffic stream has high demand on the connectivity of routes and has the highest right of way; for example, in the network composed of green and blue routes shown in Figure 4, green route has the highest right of way.

(1) Distribution of evacuation path

The evacuation traffic flow mainly refers to evacuation traffic demand that needs evacuation transfer; this part of traffic flow will overlap the lifesaving traffic flow path; for example, in the network composed of green, blue, and red routes shown in Figure 4, in implementation process, it is necessary to distribute the right of way reasonably.

(2) Guarantee of emergency evacuation

① Start the traffic management emergency plan and conduct traffic control on the vehicles entering disaster area; only fire fighting trucks, ambulances, and other rescue vehicles, and professional vehicles for rescue and relief work can be allowed to enter; the passageways are strictly controlled to enhance the efficiency for rescue and relief.

② Clear the main land branch channels and paths for emergency shelters, to ensure the effectiveness of path resources. Adjust the signal lamp phase position in real time, to make sure that all the evacuation channels have enough green light resource; multichannel cooperative control can be adopted for entrance and exit control, so as to ensure the integral idea of “emergency shelter, dynamic evacuation” for the whole expressway network.

③ Conduct passageway control strategy of strict control on the expressways along the evacuation region, including opening up emergency channels and developing conditional admittance measures (rescue and relief vehicles and evacuation vehicles can enter and exit with priority).

④ Traffic management department and emergency command center manipulate the routing, vehicle dynamic scheduling of traffic evacuation, to make sure that vehicles in different directions can evacuate and transfer rapidly and efficiently.

⑤ Provide information and tips for group to evacuate through facilities of different levels of shelters; gather

people to the nearest emergency public transportation evacuation and concentration spot, to evacuate.

⑥ Adjust the evacuation motorcade at proper time through the coordination of monitor and command center, to implement orderly safe evacuation, and lead groups to outskirts emergency shelters.

⑦ Add such signs as temporary directions, instructions and warnings, and induct drivers to pass reverse lane control section safely, and such measures as setting temporary sign boards, establishing changeable information signs, and so on; it is necessary to take traffic radio, weibo, wechat, and so on, to remind drivers of the specific paths of evacuation channel and round path.

4. Conclusions

Based on the location analysis and road network traffic impact factor analysis, this paper makes thorough analysis on the traffic stream of road network after earthquakes, which are the characteristics of road network, and puts forward the traffic control strategies of emergency evacuation; during earthquakes in our province, it is proper to take regional and staged comprehensive evacuation strategies, so as to realize the optimization of road network evacuation traffic control.

① In the western area, the expressway network is thin but earthquakes take place frequently with high risk and emergency degree, and it is proper to adopt staged evacuation strategy, to effectively remit the road network jam and journey delay under different evacuation demand models;

② In the middle eastern area, the expressway network is dense, and as outskirts evacuation area, it is proper to take reverse vehicle motion control strategy to promote the traffic capacity of evacuation expressway network.

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