PLANNING OF RESIDENTIAL STREET NETWORK FOR DISASTER PRONE URBAN AREAS

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Abstract

A considerable number of streets could not be used by traffic because of the collapse of adjacent buildings during the Great Hanshin-Awaji Earthquake in January 1995. The challenge to planners is to ensure disaster-resilient urban planning by provision of thoroughfares, which would function adequately during times of disasters. It is the purpose of this study to propose a street network of district and local distributors, which would satisfy the functional requirements during times of large disasters.

INTRODUCTION

A considerable number of streets could not be used by traffic because of the collapse of adjacent buildings during the Great Hanshin-Awaji Earthquake in January 1995. This particular earthquake affected Hanshin-Awaji region was resulted in more than 6000 fatalities and caused damage to large portion of the street network in the region. The challenge to planners is to ensure disaster-resilient urban planning by provision of thoroughfares, which would function adequately during times of disasters. It is the purpose of this study to propose a street network of district and local distributors, which would satisfy the functional requirements during times of large disasters. The criterion adopted here is the minimisation of area isolated from the surrounding arterial streets.

There are different types of special events with different types of transport implications. From an engineering design point of view, these are low probability events, usually associated with less than 0.5% probability of occurring in a given day. There is a difference in the manner planners address transport implications of events that occur on a regular basis compared to those that are irregular in their occurrence. The regular event's category, which can be sub-classified into spatial regular events and temporal regular evens, has some advanced warning. In comparison, the random category including naturally caused events and events caused by human being provides little or no warning (Vandebona, 1997). These event categories are illustrated in Figure 1.

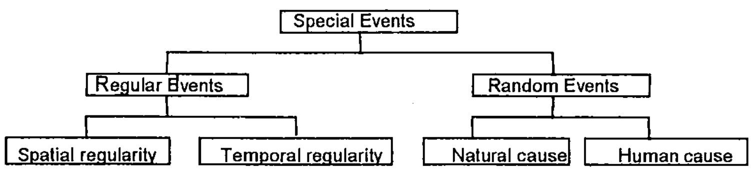

Figure 1 - Classification of unusual events

The high level of saturation experienced during regular special events is mainly due to the increase in transport demand and the resulting traffic flow. A large volume of return trips to hometowns in the end and beginning of a year in Japan for example, are classified in this category, but daily surge in commuter traffic during morning and afternoon peaks are not classified under such special events since the transport system is designed to cater for that function. On the other hand, random events reach saturated conditions because of the unexpected reduction of capacity of the transport system. Events such as earthquakes and landslides caused by nature are relevant for transport planners where they may find the system capacity reduced causing high level of saturated conditions. Floods and volcanic activities also tend to cause similar results for some of our neighbouring countries. In this study we treat naturally caused random events and focus on large earthquakes that are characterised by very low probability of occurrence and very large damage to urban infrastructure. Often, coping with such events is considered transport management issue. However, it is important to recognize that proper street network planning is essential element of the disaster preparedness.

Literature survey has shown numerous case studies and research activities related to residential street networks. The underlying principle in general residential street planning work is how to reduce the volume of through traffic to maintain a pleasant residential environment. However, networks thus evolved perform poorly in a natural disaster. As mentioned above, in the Great Hanshin-Awaji Earthquake, there were many places to which even emergency vehicles could not access, because of access network failure. Thus, disaster relief activities as well as search and rescue activities were hampered.

Under these circumstances, it is necessary to reconsider the suitable street network in residential areas, especially where street widths are insufficient. This study uses the data of the Great Hanshin-Awaji Earthquake and case study applications in Japanese cities are included for validation purpose. Nevertheless, the methodology outlined here is generic in nature and should have worldwide applications.

DISTRICT AND LOCAL NETWORK CONCEPT

Implication of road hierarchy

Transport networks, including road networks and railway networks have a hierarchical structure. In general, the road network consists of an arterial street network and a local street network. There is a large amount of research about the reliability of arterial street network, which is mainly designed to cope with daily surge in commuter traffic during morning and afternoon peaks. On the other hand, there is little research on reliability of residential street network so far, because the main subject on planning objective of residential street network is how to restrain through traffic, ensure safety and comfort for pedestrians and facilitate resident's car use.

Transport planners and urban planners have made efforts to protect residential environment from increasing vehicular traffic since 1920s. Needless to say, the neighbourhood unit and the environmental area are carefully considered to protect a residential area from vehicular traffic with introduction of several district and local distributors. There have been numerous improvements introduced to residential street network planning. However, there has been no consideration given to involuntary street closures, partly because a probability of a large earthquake is very low and in the European practice wide local streets tend to ensure at least part of the street is available for use in a calamity.

Residential street network planning in Japanese urban areas has been faced with severe situations compared to the U.S. and Europe, because of insufficient street width and high density of population.

Historical developments

Roughly speaking, there are two types of residential areas. One is developed by design such as one based on land readjustment project, and the other is developed without much planning philosophy as in a sprawled area. In the former case, there is a proposal related to planning of residential streets in Japan by Takeuchi (1986), from view point of restraint of through traffic and traffic related factors.

It is in the latter case that both of traffic restraint and accessibility improvement are necessary in planning local street network. Therefore, historical backgrounds of such work are reviewed. During the rapid economical growth in Japan in early 1960's, a lot of farmland was changed to residential and industrial areas and sprawled areas have appeared. The total street space in sprawled areas including private streets is not necessarily small, but the areas consist of narrow streets in generally random fashion without adherence to district and local distributor framework. Therefore, it is difficult for emergency vehicles to approach these areas. In those days, the city planning act and the building standard act were substandard. Since it is necessary to establish an effective urban planning system in order to prevent sprawling development, the city planning act has been revised. However, it is still difficult to prevent sprawling. Therefore transport planners need to construct or improve a framework of street network in such areas. As street space in these areas is quite insufficient from viewpoints of residential environment and disaster prevention, it is quite important to increase street space, especially for local and district distributors in these areas.

The importance of streets which agree the framework of the district distributor system and its early construction in sprawled areas were pointed out by Yamakawa (1980,1981) and Obase (1983, 1985). These streets have been named as ***Chu-gairo*** (medium street in Japanese) by Saito and Akasaki (1989) and allow the network to maintain a level of residential environment. In the concept of ***Chu-gairo*** originated by Saito and Akasaki (1989), the function is not only traffic movement (improvement of accessibility), but also formation of a residential area with reasonable living environment. The effect of ***Chu-gairo*** on accessibility of emergency vehicles and street environment were evaluated and desirable density or interval of them are proposed by Tsukaguchi et al. (1991, 1995a, 1995b), and Yamanaka et al. (1994,1995). There is no suitable term in English for ***Chu-gairo***, and it may consist of district distributors and local distributors since ***Chu-gairo*** plays almost same roles as district or local distributors from a transport planning point of view. This paper uses terms local and district distributor instead of ***Chu-gairo*** in the following sections.

Before the Great Hanshin-Awaji Earthquake, most of residential areas in Japanese cities were not considered dangerous except for sprawled areas described above. In large earthquakes, at least from transport planning view point, they were assumed to be robust even though fire threat has been recognized to be very dangerous. It was not expected that a lot of isolated areas existed at such times other than in sprawled areas. But since the Earthquake, residential street networks in both sprawled areas and other areas developed according to strict design such as a district based on land readjustment projects have required re-analysis. Therefore, this study expands the concept of ***Chu-gairo***, and tries to apply it to planning in residential areas as a whole.

METHODOLOGY

In this study, we consider the planning of district and local distributors in residential areas in order to propose a network, which would function even during times of a large disaster. The main objective is to minimise isolation from the surrounding arterial streets. Main steps of this study are found in Figure 2 as a flow diagram.

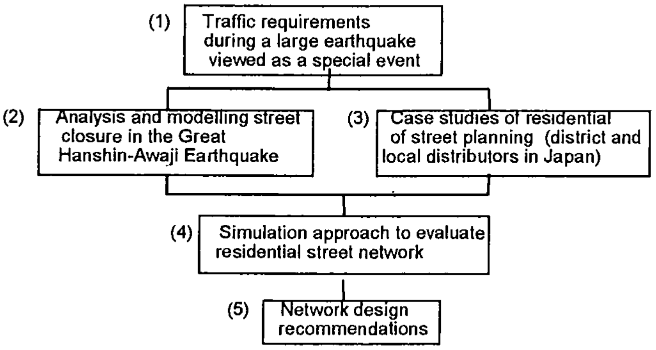

Figure 2 - Flow chart of the methodology

Procedures numbered (1), (2), (3) and (4) in Figure 2 are explained as follows;

1) Using the data obtained from air photos taken directly after the Great Hanshin-Awaji Earthquake, isolated places that could not be reached by vehicles and/or pedestrians are identified. Characteristics of the location of such isolated areas have been documented and analysed.
2) An analysis is carried out to clarify what factors affect street closure. Descriminant models is developed and refined during this process.
3) Several alternatives for street networks including district and local distributors are presented for the analysis. Here, this study considers different types of networks, such as grid type street networks and sprawled areas.
4) Using the descriminant model developed before, simulation analysis is done on the alternative networks in several districts mentioned above. Here, we investigate all nodes of the alternative networks as to whether they are accessible by vehicles and/or pedestrians in an earthquake and then a rate of inaccessible nodes are also estimated.
5) Volume of district and local distributors required are determined based on the above analysis. Accessibility of emergency vehicles and traffic management in the district are specifically considered in this analysis.

MODELLING OF STREET CLOSURE IN THE GREAT HANSHIN-AWAJI EARTHQUAKE

Street damage in the study area

Since there are no on-site survey data about all streets including local streets in a wide-spread area just after the Earthquake, the use of air photos taken by Asia Air Survey Co.,Ltd at 8:30~9:00 am, January 18th and at 10:00~11:30 am, January 20th is found to be invaluable. As a single air photo only expresses the place information of the ground, the method of using a stereoscope and watching two photos, which have some overlaying area, is adopted to observe the condition of the objects in three dimensions. This makes it easier for to understand the extent of street damage. This study has investigated a district located in Kobe, that is, Roko district illustration of the condition of street damage is given in Figure 3. In this figure, levels of street damage are classified into four ranks as follows;

rank 1 : Almost no damage
rank 2 : Little damage but accessible by vehicles
rank 3 : Unpassable by vehicles but accessible by pedestrians
rank 4 : Unpassable by neither vehicles nor pedestrians

In Figure 3, it is clear that most arterial streets were passable even though some of them were very crowded, on the other hand, local streets show high level of damage, which led the streets to be inaccessible.

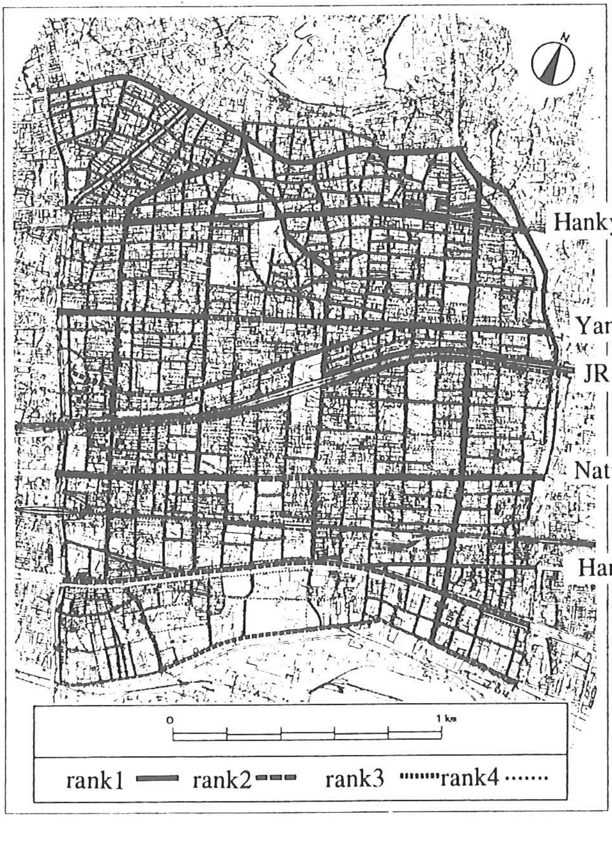

Figure 3 - Street damage in Roko district

Factors in relation to street closure

The factors in relation to street closure can be suggested as 1) intensity of earthquake, 2) condition of foundation, 3) street width, 4) structure and number of stories of buildings on street frontage, 5) existence of sidewalks, 6) existence of street trees. In this section, we describe the relation between street width and street closure, and the relation among above factors would be investigated in the next section.

Street damage by street width from the viewpoint of closure of street are shown in Figure 4. It can be seen that there are some differences at the widths of 8, 10 and 12 meters. As for streets 12 meter wide and up, almost all streets belong to ranks 1 and 2 which means they are accessible by vehicles. In the case of streets of between 10 and 12 meters of width there are few inaccessible streets, and amount of these streets increase when the width becomes less than 8 meters.

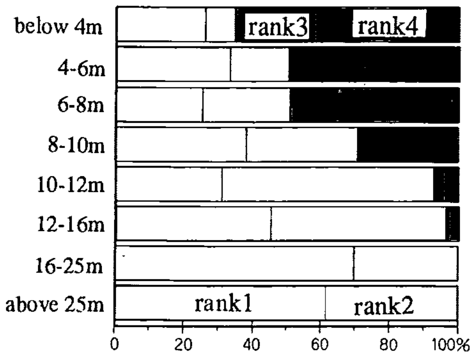

Figure 4 - Street closures by street width

Modelling of street closure

A discriminant model is developed with dummy variables in which the external criteria are the above mentioned ranks of street closure and explanatory variables are the severity degree of earthquake, street width, building structure, existence of sidewalks, and existence of street trees (Tsukaguchi, et al., 1996). This model is a rational model as a whole, however, there are some reversed category scores in certain items. Therefore, even though this model can be used to clarify the factors, which affect the street closures, it is not suitable for estimating the condition of a given link. Also, it is inappropriate for that purpose since the air photos taken in January 18th and 20th are used in the same model.

In these circumstances, this study develops two discriminant models A and B. The external criteria of the models A and B is the same, that is, the four ranks of street damage described above. The explanatory variables in the model A are street width, percentage of wooden houses, and existence of street-side trees which are expressed by dummy variables and that in the model B are limited to street width, percentage of timber houses. Here, the percentage of timber houses is determined by the sum of street length faced with wooden houses divided by the total length of the street. As for wooden houses, we exclude such wooden houses as having space more than 3 meter in front of their adjacent streets, because of their unlikely contribution to street closure.

Also, this study defines the study area between Yamate-kansen and Hanshin Railway, which is covered by the air photos taken in January 18th. The scope of models A and B are found in Table 1 and 2 respectively.

Table 3 shows level of reproducibility of the model A. As shown in this Table, conformity between the actual condition and the model estimation is about 50 %, when we divide the condition into the four ranks. However if we use this model to estimate the two ranks, that is, putting ranks 1 and 2, and ranks 3 and 4 together, the conformity level becomes about 80% (77.9%) as shown in Table 4. This modification is useful, because whether vehicles are able to access or not is very important when evaluating street networks. In addition to this, the errors appear on the safe side from a planning point of view. Therefore the model is suitable for practical applications to estimate street damage.

The same process has been followed for the model B. As for this model, when ranks 1 and 2, and ranks 3 and 4 are put together, the conformity rate amounts to 71.3 %. Therefore, the model B can also be used in practical application to estimate street damage.

Table 1 - Discriminant model A

item	category	sample size	category score	range
street width	4-6 m	148	-0.5806	2.1163
	6-8	106	-0.3954	
	8-10	27	0.0571	
	10-12	20	0.6726	
	12-16	24	0.6729	
	16-25	48	0.9268	
	25-	34	1.5357	
percentage of wooden of wooden	0-20	81	0.5849	0.9052
	20-40	123	0.0069	
	40-60	113	-0.1911	
	60-80	68	-0.3203	
street trees	none	311	-0.1136	0.5504
	one side	26	0.1835	
	both sides	70	0.4368	

external criteria 1: rank 1, 2: rank 2, 3: rank 3, 4: rank 4, correlation ratio: 0.49

Table 2 - Discriminant model B

explanatory veritable	Coefficient of discriminant	standardised coefficient
street width	0.1601	0.9426
percentage of wooden houses	-0.0089	-0.2274
constant	-1.0595	

external criteria 1: rank 1, 2: rank 2, 3: rank 3, 4: rank 4, correlation ratio: 0.47

Table 3 - Reproducibility of model A (for four ranks)

	rank 1	rank 2	rank 3	rank 4	Total
rank 1	71 (17.4)	14 (3.4)	1 (0.2)	7 (1.7)	93 (22.9)
rank 2	35 (8.6)	47 (11.5)	14 (3.4)	51 (12.5)	147 (36.1)
rank 3	0 (0.0)	9 (2.2)	11 (2.7)	54 (13.3)	74 (18.2)
rank 4	0 (0.0)	8 (2.0)	10 (2.5)	75 (18.4)	93 (22.9)
total	106 (26.0)	78 (19.2)	36 (8.8)	87 (45.9)	407(100.0)

Note : Percentage values are shown within parenthesis

Table 4 - Reproducibility of model A (for two ranks)

	rank 1 and 2	rank 3 and 4	total
rank 1 and 2	167 (41.0)	73 (17.9)	240 (59.0)
rank 3 and 4	17 (4.2)	150 (36.9)	167 (41.0)
total	184 (45.3)	223 (54.8)	407 (100.0)

Note : Percentage values are shown within parenthesis

EVALUATION OF RESIDENTIAL STREET NETWORK

Simulation approach to evaluate street network

So for, we have regarded ***Chu-gairo*** as a district or local distributor with 8 to 12 meters considering the present condition of urban areas in Japan. Also we proposed a desirable density of these streets in sprawled areas, that is, 200 to 250 meter interval from a viewpoint of accessibility of emergency vehicles in an ordinary condition (Tsukaguchi, et al, 1995a, 1995b). Based on these findings, this paper considers several street network alternatives whose details are explained in the following sections. The districts in the study are Roko district as a typical example of the grid type street network, and two sprawled areas, Ishihara-Okura district and Kiyotaki district.

A simulation model is developed to investigate whether each node in the study area remains connected for vehicles to a surrounding arterial street. The outline of the process was already described in section 3 and the detailed procedure of calculating percentage of inaccessible nodes is shown in Figure 5.

Evaluation of alternative street networks

Case study in Roko district

The Roko district studied in this section is the same as the area described in section 4, which has been illustrated in Figure 6. And the composition of street width is shown in Figure 7. Most streets in this district are 4 to 8 meters wide except for surrounding arterial streets. There are very few streets less than 4 meters wide, but they are negligible from planning viewpoint. As far as land use in this district is concerned, it is located surrounding a railway station in the central area. There are commercial facilities, but as a whole we can regard this area as a residential area.

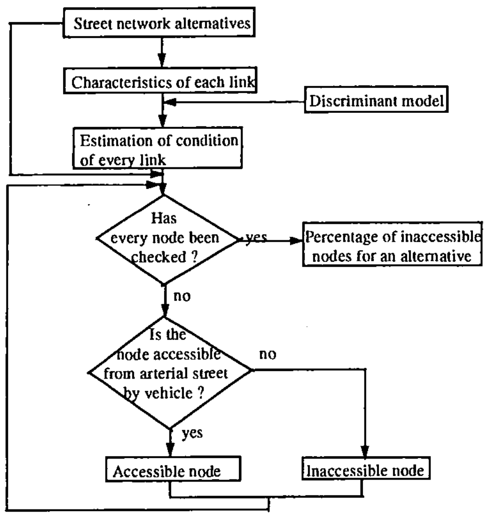

Figure 5 - Flow chart of calculation of percentage of inaccessible nodes

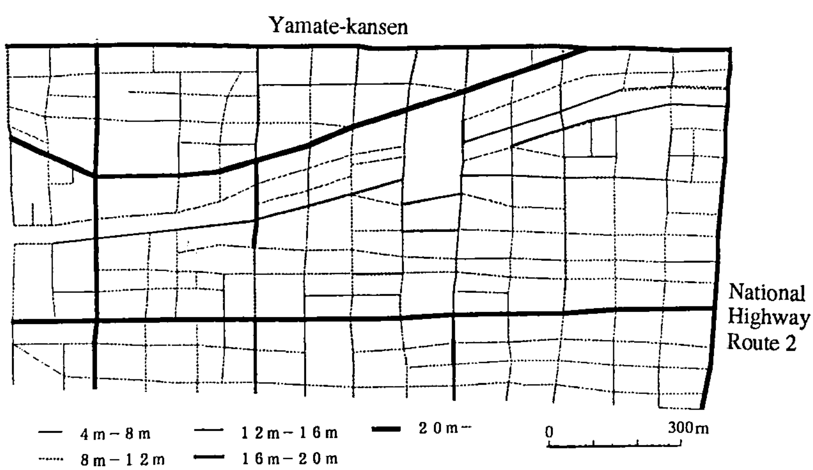

Figure 6 - Present street network in Roko district

Considering findings of the previous studies, eight alternatives are considered for final evaluation. Features of alternatives are as follows;

case 1 : The present street network

case 2 : District and local distributors with 12 meter width are arranged at 300 meter intervals, by the use of the present street network as far as possible.

case 3 : District and local distributors with 12 meter width are arranged at 300 meter intervals, giving a priority to the same interval arrangement over the present network.

case 4 : District and local distributors with 12 meter width are arranged at 200 meter intervals forming a grid type street pattern.

case 5 : District and local distributors with 12 meter width are arranged at 200 meter intervals and the network is well arranged in order to restrain through traffic.

case 6 : District and local distributors with 8 meter width are arranged at 200 meter intervals and the network is well arranged in order to restrain through traffic.

case 7 : District and local distributors with 8 meter width are arranged at 200 meter intervals and the network is well arranged in order to restrain through traffic. Also, percentage of wooden houses is kept to less than 20%.

case 8 : District and local distributors with 8 meter width are arranged at 200 meter intervals and the network is well arranged in order to restrain through traffic. Also, percentage of wooden houses is kept below 40%.

Street network patterns, of cases 5 to 8 are the same. Street network alternatives adopted for cases 2 to 5 are illustrated in Figure 8.

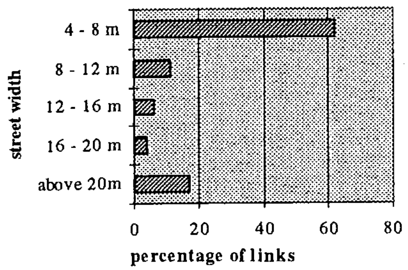

Figure 7 - Composition of street width in Roko district

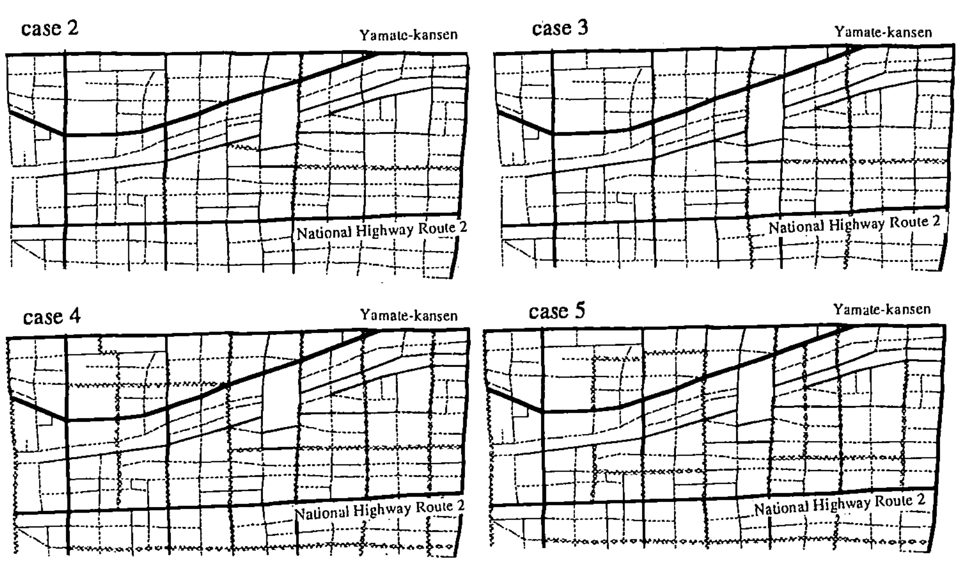

Figure 8 - Street network alternatives for Roko district

Inaccessible nodes are investigated based on the simulation analysis of model A. The inaccessible nodes in the some alternative networks are illustrated in Figure 9 and also the percentages of inaccessible nodes for all alternatives are shown in Figure 10. It is clear that the difference is very large between cases 2 and 3 in which the interval of district and local distributors is approximately 300 meters, and cases 4 and 5 in which the interval is about 200 meters. In the case of 200-meter interval arrangement, that is, case 4 and 5, a few percentages of inaccessible nodes still remain. The reason is because the alternative network consists of streets, which are comparatively wide at present. This is also one of reasons why cases2 and 3 do not have an effect on decreasing inaccessible nodes compared with the present network. We anticipated the case 4 to be different from case 5 from the point of view of accessibility and traffic management. However, the simulation has shown there is only little difference between these two cases in disaster resilience. Therefore, considering other factors (such as traffic management) in favour of case 5, it could be regarded as the more suitable network. Regarding type of building structures, it can be seen that replacing wooden houses to solid ones has almost the same effect on decreasing inaccessible nodes as widening street width.

According to the above analysis, it is necessary to arrange 12-meter wide street by 200-meter intervals, if we want to keep the percentage of inaccessible nodes less than a few percent. And almost the same effect can be expected, if the street network consists of 8-meter wide streets at 200-meter intervals and also with solidly built frontage buildings.

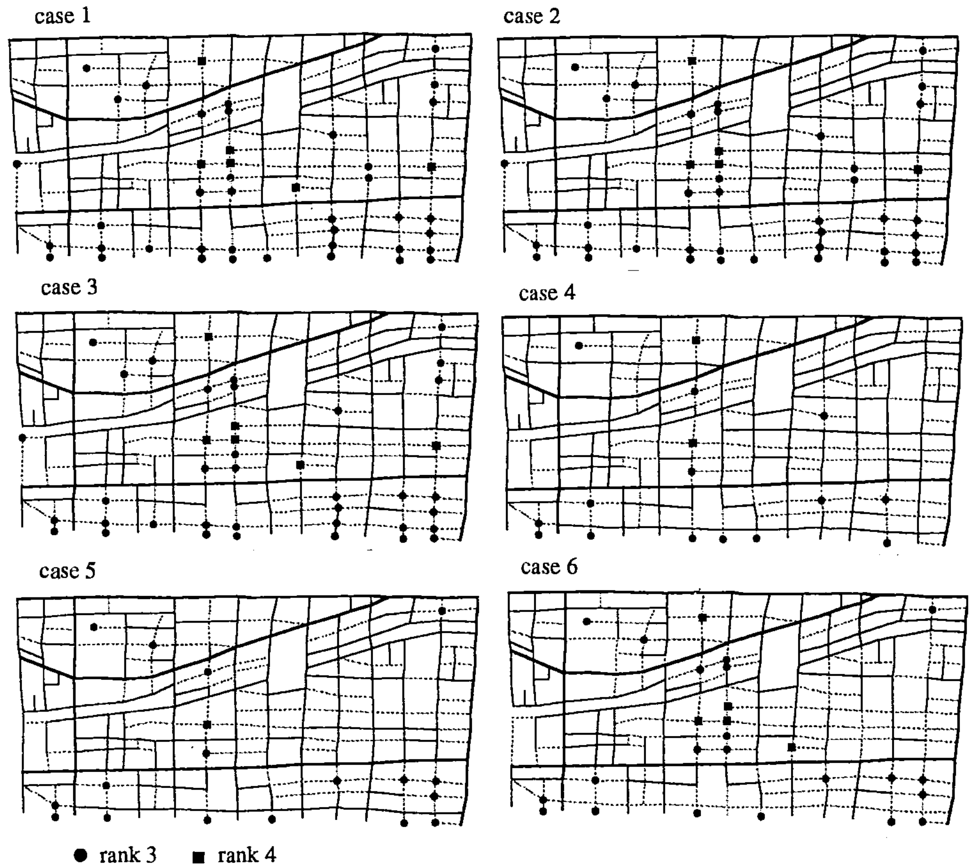

Figure 9 - Location of inaccessible nodes

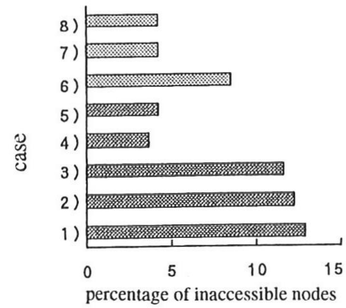

Figure 10 - Percentage of inaccessible nodes in Roko district

Case study in Sprawled District

There are two important problems in the planning of district and local distributors in sprawled areas. One is the planning in built up areas and the other is the planning in areas that are in progress of sprawl or in danger of sprawl in the near future. This study aims to examine the planning of both areas. Ishihara-Okura district in Kadoma City, Osaka was chosen as the typical case of the former, and Kiyotaki district in Shijonawate City, Osaka was chosen for that of the latter case. In the case of the Osaka region, many residential areas have been developed by land readjustment projects or as a newly developed area, but there are sprawled areas surrounding

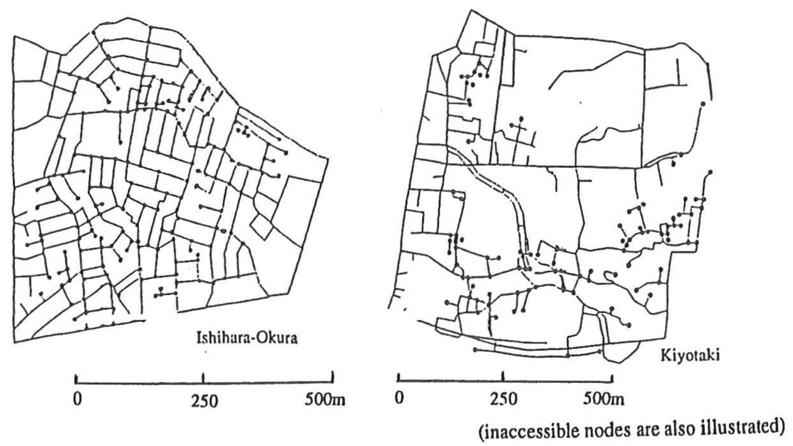

Fig. 11 - Present street network in Ishihara-Okura and Kiyotaki district

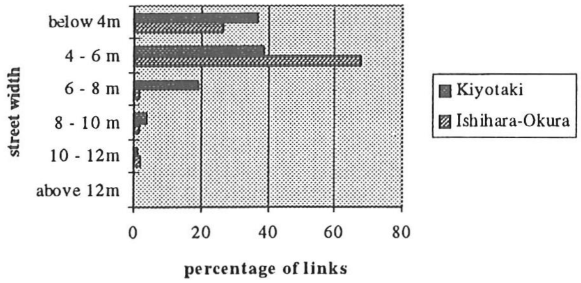

Figure 12 - Composition of street width in Ishihara-Okura and Kiyotaki district

Osaka City. Ishihara-Okura district was mostly developed during 1960s' and by the beginning of 1970s' the framework of the street network has been determined. Most of streets in this area consist of 4-meter wide streets without district and local distributors as shown in Figure 11. On the other hand, farmland still remains in Kiyotaki district whose present street network is also given in Figure 11. And the composition of street width is shown in Figure 12.

We have analysed the two areas mentioned before, from a viewpoint of accessibility of emergency vehicles (Tsukaguchi, 1995a, 1995b). Results show that 250-meter interval arrangement of district and local distributors is effective. Therefore, this study adopts 250 meter as an average interval of the streets. The networks chosen in this section are shown in Figure 13. Since it is difficult to construct 12-meter wide streets in sprawled districts, the width of district and local distributors is considered as 8 meter in Ishihara-Okura district. In the case of Kiyotaki district where district and local distributors will be constructed as a new development, 12 meter is mostly used but in some parts of the area 8-meter wide streets are used. The present percentages of wooden houses in both districts are 35.1% and 19.7% in the two districts respectively. This analysis adopts 20% wooden houses.

Results of the simulation are found in Figure 13 and Table 5. Here the model B has been used, because the classification of street width in the model A is not suitable for application to sprawled areas. There is no remarkable decrease of the inaccessible nodes in both districts. It means that the 250-meter interval arrangement of district and local distributors is not effective. It is difficult to evaluate sprawled areas using the same criterion as in the areas intentionally developed.

But we can see effects of arrangement of the distributors in these districts. Since a much higher standard is required to upgrade district and local distributors to 8 or 12-meter width considering their present condition, this analysis introduces another indicator. Here, networks composed of streets of 6 meter wide and up are taken into consideration. We assume that nodes located within 2 links from the network would be easy to access compared with other nodes, and these nodes are excluded from the inaccessible nodes, which we call it semi-accessible nodes. Such kind of nodes not far from 6-meter street network is comparatively accessible for emergency vehicles in ordinariness. Using this indicator, the percentage of semi-accessible nodes, the arrangement of district and local distributors in Kiyotaki district has a large effect on improvement of accessibility. However, in the case of Ishihara-Okura district, more than 30% of nodes remain isolated.

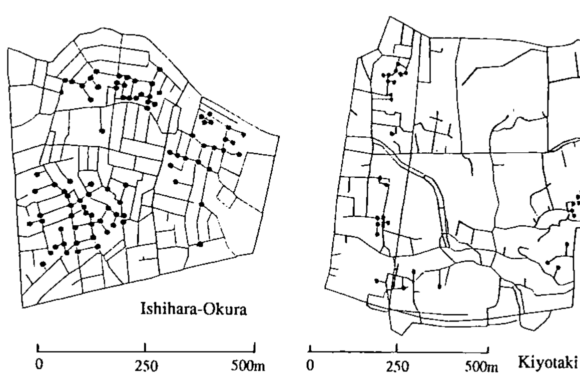

Figure 13 - Street network alternatives and inaccessible nodes

Table 5 - Percentage of accessible nodes in Ishihara-Okura and Kiyotaki district

		percentage of accessible nodes	percentage of semi-accessible nodes
Ishihara-Okura	present network	6.0 %	14.0 %
	improved network	21.8 %	42.1 %
Kiyotaki	present network	18.4 %	38.6 %
	improved network	33.3 %	51.1 %

Desirable residential street network

A case study in Roko district indicates that 12 meter wide street network by 200 meter interval or 8 meter wide street network by 200 meter interval accompanied with solidly built adjacent buildings are effective in decreasing the level of isolation during a natural disaster in intentionally developed districts. This study recommends a network of 12-meter wide district and local distributors at 200-meter intervals when land readjustment projects are carried out or new residential areas are developed. Needless to say, these findings suggest that there are other solutions with appropriate combination of street width and percentage of wooden houses. Therefore, the relation of street width and building structure has to be considered very carefully to recommend the most suitable solution for a particular district.

Since the discriminant model developed in Roko district is adapted to different districts, it is inappropriate to make general observations here. However, it can be said that district and local distributors, which is composed of 8 or 12 meter wide streets at 250 meter intervals, is not effective in decreasing the number of isolated nodes in sprawled areas. It is difficult to recommend the suitable solution for sprawled areas, and it is important to understand that it is necessary to renew the street network to a considerable extent at the same time as the renewal of the buildings in order to make them disaster-resilient urban areas.

CONCLUSION

A large earthquake with epicentre under an urbanised area is one of the most severe problems transport planners have to be concerned. There is not much research performed on reliability of residential streets, up to date, because the main objective of planning residential street network is to restrain through traffic from the area, ensure safe and comfortable condition for pedestrians and residential access requirements. From a point of view of disaster-resilient urban planning, this study demonstrates the need to consider the functional requirements of the surviving network during the rare event.

A characteristic of damage in residential street is the reduction of capacity, thus reducing network accessibility. Such closures of streets and the resulting inaccessibility of the network greatly endanger lives and increase property damage as disaster relief activities and search and rescue activities are delayed. These relief and rescue activities tend to be essential for about 72 hours after an earthquake. Damage of each street is not the main problem here, but it is the fragmentation of the area into isolated zones that pose immediate problems.

From this point of view, this study has proposed residential street network for two types of areas. One area is planned development such as one based on land readjustment project, and the other is unplanned development such as a sprawled area. Network standards are proposed for planned developments. A methodology for analysis is provided for sprawled developments.

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REFERENCES

Akasaki, K. (1989) Concept of "Chu-gairo" in Sprawled Areas; in **Planning of Residential Streets** (in Japanese), Kajima, Tokyo.

Li, Y. and Tsukaguchi, H. (1996) A Study on the Capability of Local Road Network Against the Great Hanshin-Awaji Earthquake Disaster, **International Conference on Urban Engineering in**

Asian Cities in the 21 Century, Bangkok, November, 1996.

Obase, R. (1983) A Study about the History of Forming the Streets network in Sprawled Area, **Papers of the Annual Conference of the City Planning Institute of Japan No.18**, 337-342 (in Japanese).

Obase, R. (1985) A Study about Road Network within Sprawled Area, **Papers of the Annual Conference of the City Planning Institute of Japan No.20**, 151-156 (in Japanese).

Takeuchi, D. (1986) A Planning Method of Residential Streets, **Infrastructure Planning Review, No. 3**, 1-22 (in Japanese).

Tsukaguchi, H. (1991) Planning of Residential Streets in Urban Sprawled Areas, **Papers on City Planning, No.26**, 235-240 (in Japanese).

Tsukaguchi, H. and Sano, S. (1995a) Planning of Local Distributors in Sprawled Areas and Analysis of Street Network, **Infrastructure Planning Review, No.12**, 549-558 (in Japanese).

Tsukaguchi, H., Sano, S., Tanaka, M.,and Kim, D. (1995b) A Study on Planning of Residential Streets in Sprawled Areas Based on an Analysis of Inhabitant's Awareness, **Proceedings of International Symposium City Planning 1995**, 141-151, Kwangju, November, 1995.

Tsukaguchi, H., Totani, T., and Nakatsuji, K. (1996) Study of Impassable Roads During the Great Hanshin-Awaji Earthquake, **IATSS Review Vol.22, No.2**, 101-111 (in Japanese).

Vandebona, U (1997) Modelling of Transport for Special Events, **Proceedings of the 19th Conference of Australian Institute of Transport research**, Melbourne, November, 1997.

Yamakawa, H. (1980) Formation of Streets and Standard for Planning in Newly Developed Area, **Papers of the 15th Scientific Research Meeting of the City Planning Institute of Japan**, 427-432 (in Japanese).

Yamakawa, H. (1981) Characteristics of Traffic in Residential Areas and Resident's Evaluation on Streets, **Papers of the 16th Scientific Research Meeting of the City Planning Institute of Japan**, 313-318 (in Japanese).

Yamanaka, H. and Yoshikawa, K. (1993) Analysis System for Local Street Network in Old Development Areas in Japan, **Selected Proceedings for the 6th WCTR, Vol.1**, 183-193.

Yamanaka, H., Nagashima, N. and Mitani,N. (1994) Evaluation Method of Streets Network Improvement Plans for Spread Residential Areas Considering Resident's Sense, **Papers on City Planning, No.29**, 271-276 (in Japanese).