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EVALUATION OF THE STAIRCASES' VISIBILITY IN UMEDA UNDERGROUND STREET BY USING SPACE SYNTAX

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ABSTRACT: When an earthquake occurs, the tsunami caused by the earthquake can threaten people's lives. Especially for low-lying terrain and densely populated areas, it is necessary to evacuate people to a safe place as soon as possible. The predicted water level of the Osaka Umeda Underground Street during the tsunami flood will reach 0.5-1.0 meters. And people inside the underground street need to reach the ground through stairs or evacuate from the exits connected to the surrounding buildings. There are a large number of stairs distributed inside the Umeda Underground Street. This study uses spatial syntax theory and depthmapX software to quantitatively analyze and organize the visibility of the staircases, to evaluate whether the stairs at different locations are easy to be discovered by the crowd during evacuation. And then lay the foundation for further evacuation research. In this paper, the following conclusions can be drawn: The visibility of staircases under different radius restrictions is different. On the whole, the stairs near the integration center and the square nodes have better visibility, and those stairs which require multiple turns and have deeper visual depth are more difficult to find and use.

Keywords: Tsunami, Staircases, Visibility, Integration

1. INTRODUCTION

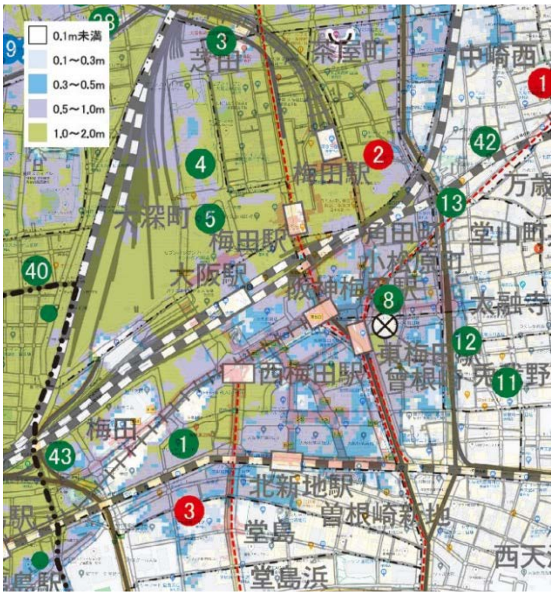

Fig. 1 Flooding in the Umeda area of Osaka at the time of the tsunami

When a huge earthquake occurs, the accompanying tsunamis often threaten the lives of people in the city. When a disaster occurs, people located in an underground shopping street need to use the shortest route to reach a safe place where they can evacuate as quickly as possible. According to the flood hazards issued by the Osaka City Hall, it can be seen that in the Umeda area, the depth of water caused by the tsunami was about 0.5-1.0 meters when the earthquake occurred (Fig. 1). And the tsunami refuge building directly connected to the underground street is only one, the Osaka Fukoku Life Hall (No. 8).[1]

Therefore, the most important thing during a disaster is to let people in the underground street find the nearest exit to the ground or the surrounding buildings. This leads to the analysis and evaluation of the staircases in the underground street.

Accessibility refers to how easy it is to reach a location in space. In 1980, William. H. Whyte described the relationship between the accessibility of urban space and the communication activities that occur in urban space in his book "The Social Life of Small Urban Spaces". Among them, accessibility is listed as the most important feature of a successful space. [2]

Firstly, accessibility has a visual meaning. At the level of visibility, only the "visible" space has the possibility of "reachable". Secondly, accessibility has spatial significance. Accessibility reflects the ease of communication between spaces and expresses the logical relationship between spaces. [3] In addition, accessibility is also affected by people's psychology, and the psychological guidance and hints to people in some spaces will also affect accessibility.

2. RESEARCH BACKGROUND PURPOSE AND SIGNIFICANCE

2.1 Research Background

As Japan is one of the countries with frequent earthquakes, disasters such as tsunamis caused by earthquakes have always been important issues for researchers. How to minimize the loss of people's lives and property caused by natural disasters is a task that researchers should continue to study and think about.

The 2011 earthquake of the Pacific coast of Tōhoku occurred on March 11, 2011, the magnitude of the earthquake reached 9.0 and was the fifth largest earthquake in history. The huge tsunami triggered by the earthquake caused devastating damage to the coastal areas of northeastern Japan and also caused heavy casualties. Now in 2021, 10 years have passed since this huge earthquake. While commemorating and mourning the victims of the earthquake, it’s also meaningful for us to take this as a topic to study the evacuation plan in the case of an earthquake or a tsunami, and to deal with similar problems in the future.

When a tsunami occurs, low-lying and densely populated areas are more susceptible to disasters and face greater evacuation pressure. Especially as the density of cities is increasing and the three-dimensional transportation system is greatly developed today, the commercial street around the underground station is the area where the evacuation problem should be addressed. The Umeda area in Osaka is one of such typical areas.

And in recent years, the Space Syntax theory proposed by Bill Hillier of the University of London has entered the vision of more people. As a new method of describing and analyzing space, Space Syntax believes that "space itself is not important, but more important is the relationship between spaces." [4] This theory, which studies space logic with mathematical methods, is gradually becoming widely used in the study of road systems in cities and neighborhoods.

2.2 The Purpose and Significance of The Research

The Umeda area is in danger of being damaged by floods due to its low altitude in the case of tsunamis. In addition, the Umeda Underground Street is connected to the subway system and there are also many shops located in the Umeda Underground Street. It can be imagined that there’s always a large number of people here. This research aims to evaluate and simulate the location of stairs and exits in the underground streets by analyzing the visual integration of the Umeda underground area and then finding the dangerous parts, thereby obtaining evacuation inspiration.

The significance of this research is to evaluate the distribution of the staircases by summarizing and analyzing the overall passable roads inside the Underground Street. To predict the stairs that are prone to be crowded in situations of disasters, and formulate targeted evacuation plans and response measures when necessary. It also lays the foundation for further research on disaster simulation.

3. RESEARCH OBJECTS AND METHODS

3.1 Research Object and Scope

The research area is located in the Umeda Underground Street, Kita Osaka, around JR Osaka Station and Hankyu Umeda Station. It mainly analyzes the visual accessibility of the underground passable parts except for stations and shops (Fig. 2). And it also analyzes the staircases and exits that can reach the ground or surrounding buildings.

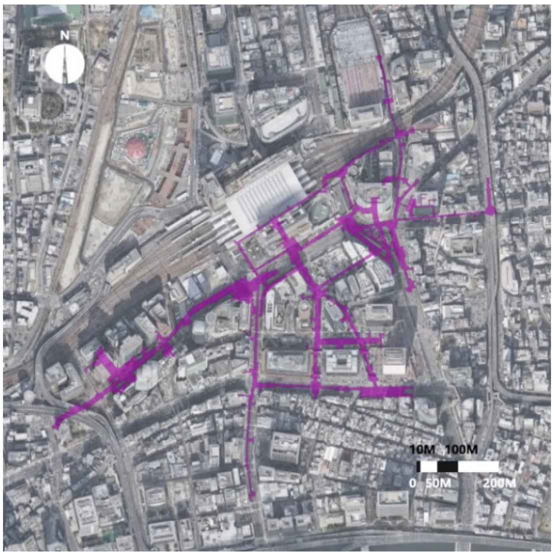

Fig. 2 The scope of the Umeda Underground Street of the research

In Fig.2, The purple part is the scope of research in this paper. In this research, I believe that within these parts of the underground street, the sight of people can travel through the space without obstruction theoretically. Therefore, the parts with a large height difference, which need to be traversed through multiple stairs, and the shop area with a clear sense of spatial separation are not considered as research objects.

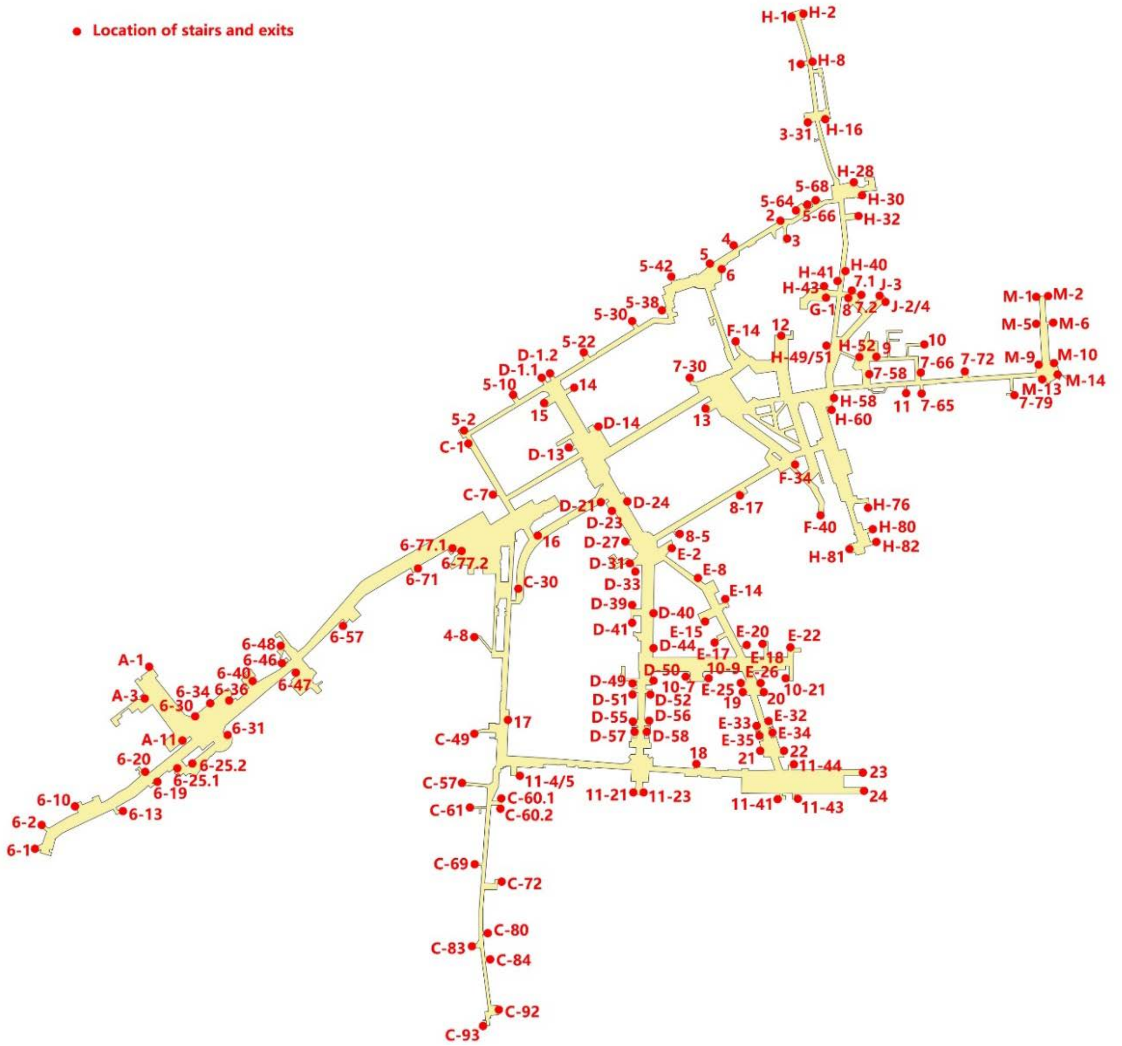

Fig. 3 The locations of all the stairs and exits

To study the visibility of stairs and exits in the entire underground street, and to compare and evaluate them, firstly mark all the stairs and exit positions inside the underground street to facilitate subsequent discussion. [5] (Fig. 3)

3.2 Space Syntax Theory

The space syntax theory was first proposed in the 1970s by Bill Hillier of UCL, England. Now a relatively complete and mature theoretical system and methodology, as well as technologies and software for spatial analysis, have been formed. Based on the analysis of spatial accessibility at the theoretical level, it is also further researching various indicators of spatial accessibility from a quantitative perspective.

In this article, depthmapX software is used to quantitatively analyze the research area from the aspect of visual reachability. Visual accessibility is the attribute of whether things can be seen in sight. It can be studied from the perspective of spatial connectivity and isovist area.

3.2.1 Depth of sight

The analysis of the visibility in the space is to examine the distribution of the depth of the sight in a space.

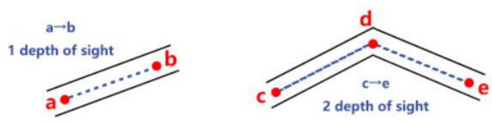

Fig. 4 Definition of the depth of sight

As for the definition of the depth of sight, we can set it on a straight street. If point b can be directly seen from point a, then from a to b is the distance of one depth of sight. However, when the street turns, point e cannot be seen directly from point c. If you want to reach point e from c, you must first go to point d. In this case, the distance between c and e is two sight depths. (Fig. 4)

Besides, we can also set the maximum distance that the sight can reach. For example, if the farthest visible distance in space is 150 meters, and the distance from a to b is already 200 meters, then a to b is already 2 sight depths distance.

3.2.2 Convex Map model

The convex map model is to understand the architectural space as a system composed of convex spaces. Convex space means that within a space, any two points can see each other. In the research and calculation of space syntax, we transform the space that is not convex space into a system composed of several convex spaces. The convex space involved in the calculation is the "element". In the following research, an infinitely subdivided square grid will be used to replace the original spatial system. [6]

4. RESULTS

The convex space analysis method is used to study the interior of the Umeda Underground Street, starting from the analysis of the connectivity, and further analyzing the isovist area. Then use the depthmapX software to compare the visual integration under different radius, and find out whether each staircase can be seen by the crowd under different visual ranges.

4.1 Result of Connectivity and Isovist Area

Use an infinitely subdivided convex space grid to replace the spatial plan. This is the first step "set grid" process. In this study, the grid-scale is set to 1000. And then set the farthest range of sight on this basis, I set 10 meters here. After the calculation is performed, the connectivity of the space will be obtained. (Fig. 5)

The connectivity generated based on the grid means that from a certain element in the space, a total value of several other elements can be seen is added up, and then fed back to that element. After each element has a value, these values are regarded as a sequence of numbers, and the interval of the sequence is a closed interval of [n_1, n_2]. Take $\frac{n_2-n_1}{10}$ as the width, divide this value segment into ten equal parts, and assign red to the highest value segment, blue to the lowest value segment, and the middle-value segment from top to bottom from warm to cold. It can be seen that the closer the position to the center of the wide space, the higher the connectivity value. These positions are usually similar to nodes and small squares in the space.

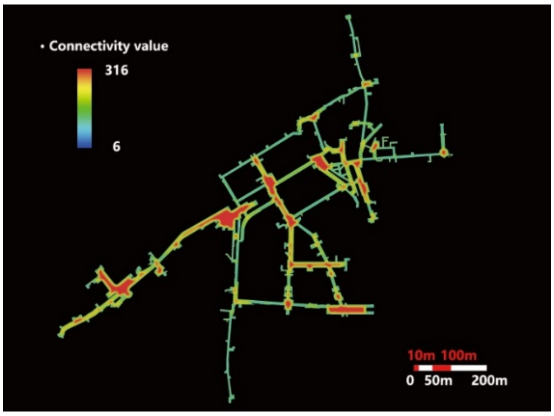

Fig. 5 Connectivity in the area

Based on the numerical feature distribution of connectivity, a spatial isovist feature map can be generated. The isovist map means that looking out from an element a, the value of the area that can be seen is fed back to a. At this time, if point b and point a are in different positions, but their value is in the same value range, then a and b will show the same color. (Fig. 6)

Fig. 6 Isovist area map

Because the Isovist area map calculates the visible area, the Umeda Underground Street we studied is greatly affected by the spatial shape and road width, and the results displayed by the Isovist area and connectivity are quite different. For squares and roads in a wider area, the visible range of sight in the isovist map tends to be wider.

4.2 Result of Visual Integration

Using the depthmapX software to analyze and calculate the spatial visibility relationship. In this study, the numerical distribution of the spatial sight integration degree is mainly calculated. Visual integration, that is, "accessibility of sight". It describes how many turns people need to make from one point to another. And in space designing and planning, the "shortest distance" is always one of the most meaningful contents to think about. That is why I choose the Visual Integration [HH] value to get the result.

Visual Integration [HH] means the global visual depth after removing all the influencing factors in topology. The higher the value, it means that this element only needs fewer turns to see other elements in the entire system. The lower the value, it indicates that starting from this element, if you want to see other elements, you need more turns. Simply say, the higher the value of Visual Integration [HH], the easier it is to attract people's attention, and the easier it is for people to use that place.

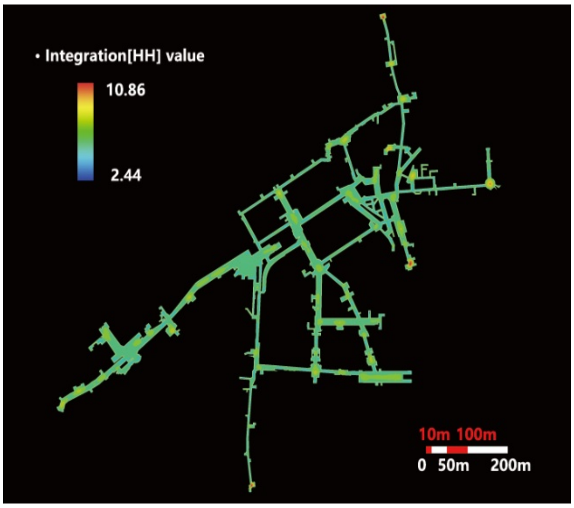

Fig. 7 Visual Integration [HH] R3

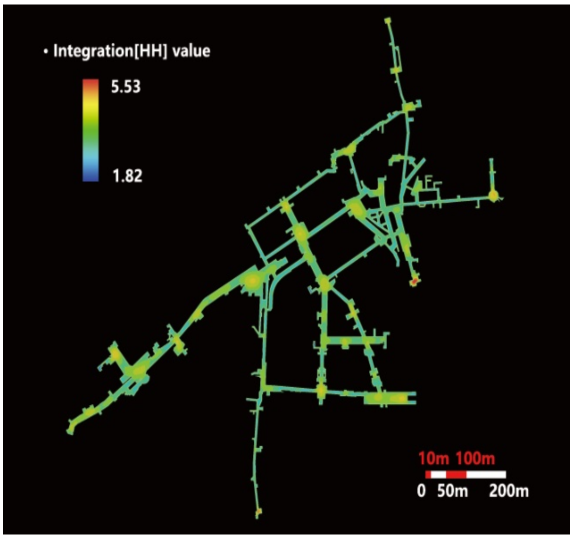

Fig. 8 Visual Integration [HH] R5

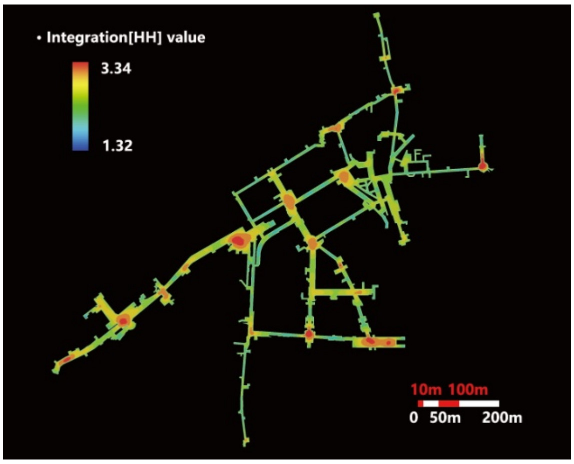

Fig. 9 Visual Integration [HH] R7

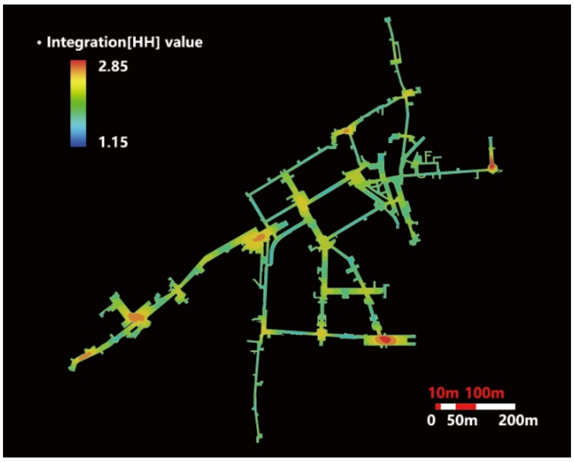

Fig. 10 Visual Integration [HH] R9

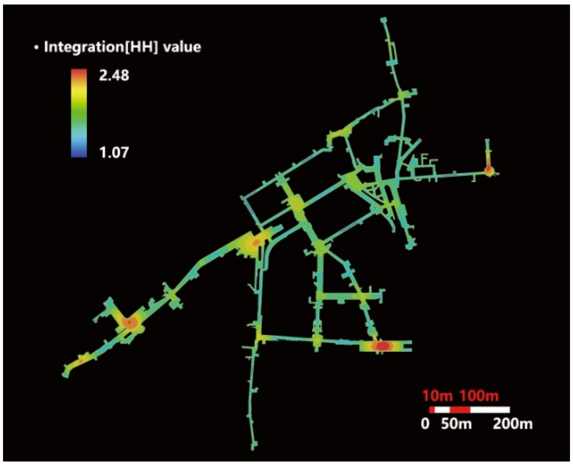

Fig. 11 Visual Integration [HH] R11

When analyzing, the first step is to set the radius of the analysis, that is, how many sight depths our analysis is limited to. For different space systems, the appropriate range is also different. Here I choose R3, R5, R7, R9, R11 (corresponding to the range of 30 meters, 50 meters, 70 meters, 90 meters, and 110 meters), these situations for analyzing. (Fig. 7-11)

It can be seen that under the conditions of different radius restrictions, the results obtained are not the same. From R3 to R11, with the gradual expansion of the radius, some nodes with better views in the space gradually become obvious, and the possibility of each staircase being discovered by people also changes.

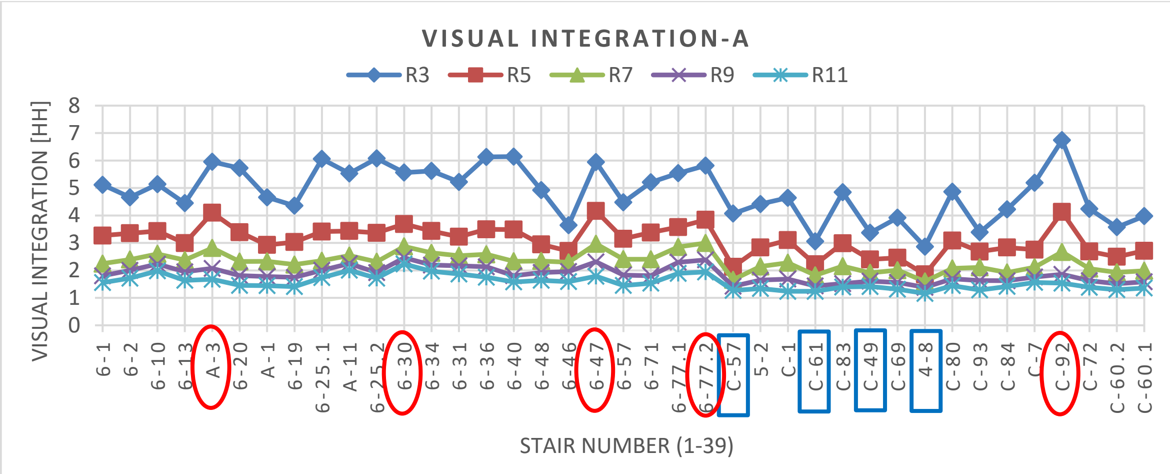

Fig. 12 Comparison of Visual Integration-Part A

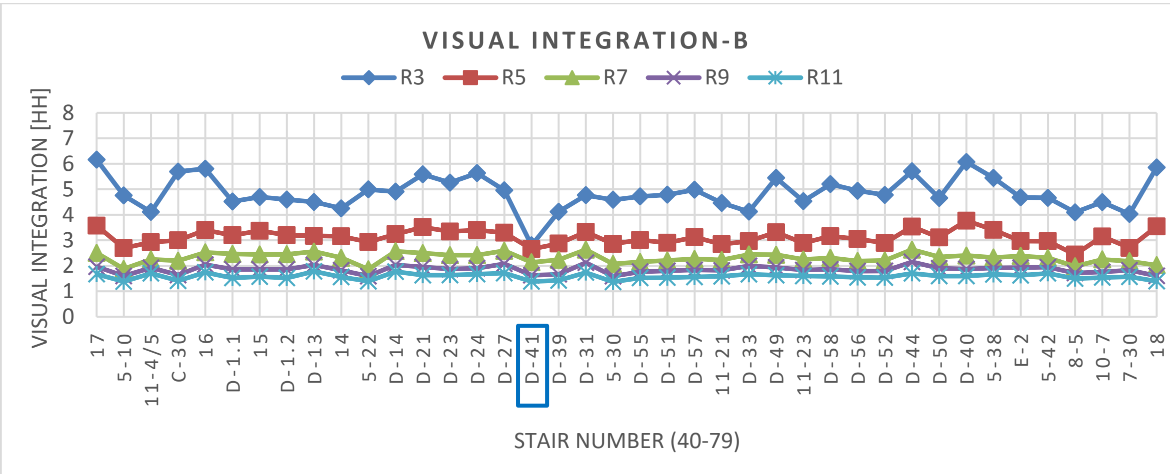

Fig. 13 Comparison of Visual Integration-Part B

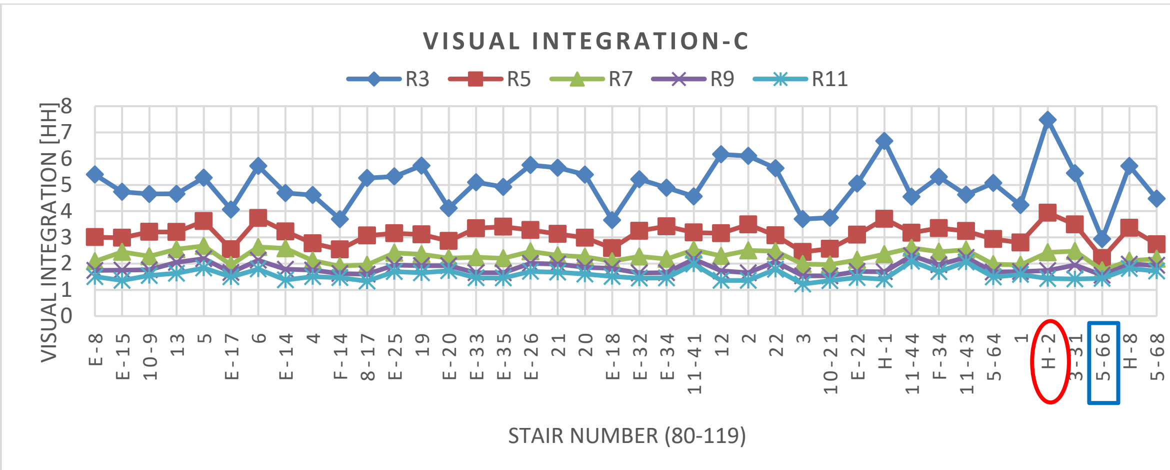

Fig. 14 Comparison of Visual Integration-Part C

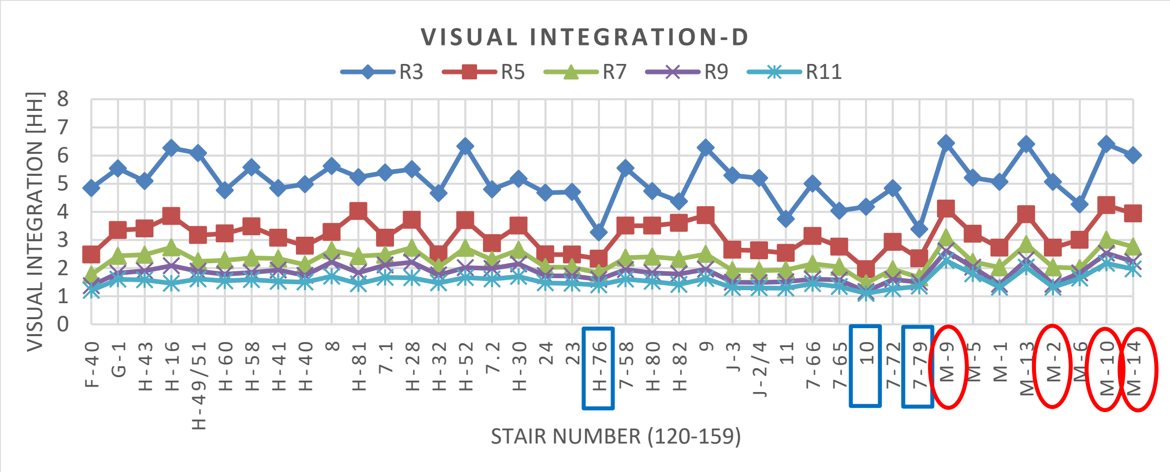

Fig. 15 Comparison of Visual Integration-Part D

Then count the visual integration value of all the stairs and exits. And draw charts and statistics on the results obtained. (Fig. 12-15)

On the whole, the visual integration value of the staircases decreases from R3 to R11, which also shows that the larger the range, the lower the probability that the stairs will be discovered by people. As a result, it is necessary to ensure that within a certain range, there are enough stairs to meet the evacuation needs.

From the overall trend, with the expansion of the sight radius, the trend of the integration value distribution of each staircase is gradually regular, however, under the radius of R3 (small range), the value of the integration degree of the staircases fluctuates greatly.

5. DISCUSSION

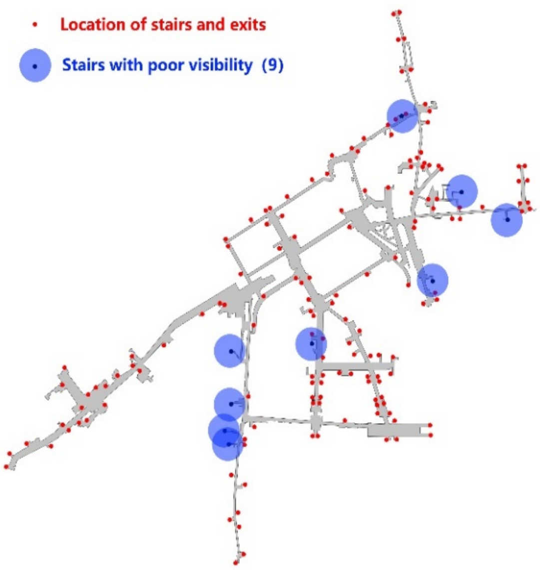

Fig. 16 Distribution of stairs with poor visibility

In addition, from the obtained data results, some distinctive staircase positions can also be found and show that it is necessary to pay attention to them.

Firstly, there are some stairs, even though they are within a radius of 30 meters, their visibility is still very low. It means that these stairs are still not easy to find in a small area. Inspecting its specific distribution location, it can be found that most of these stairs with poor visibility are located in branch roads with more turns from the main roads, such as stairs No. 4-8, C-61, 10, 5-66, 7-79, H-76, C-57, D-41, and C-49. (Fig. 16) This suggests that people are more prone to choose staircases that are easier to reach from the main road, for the reason that these stairs have better visibility.

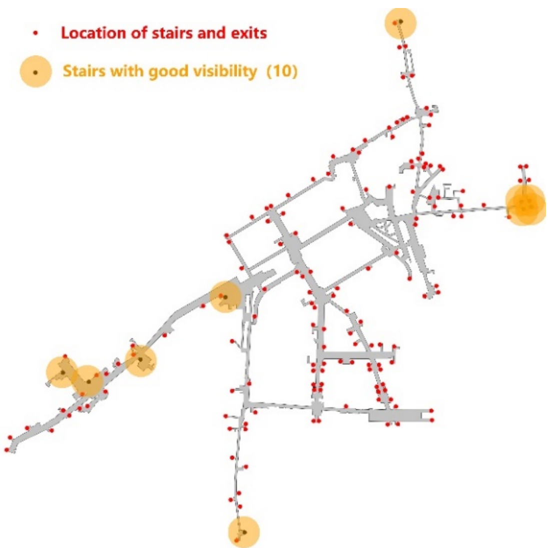

Fig. 17 Distribution of stairs with good visibility

Next, there are some stairs with higher integration values under different radius ranges, such as M-9, M-10, M-13, 6-47, H-2, 6-77.2, C-92, M-14, 6-30, A-3 (Fig. 17). By analyzing the map, the locations of these stairs are very close to the small centers of integration, such as the intersections or the vicinity of small squares. But correspondingly, it’s important to note that in the process of evacuation, it may be easier to cause congestion at the locations of these stairs.

6. CONCLUSION

This study analyzed the visibility of the staircases inside the Umeda Underground Street and got the following conclusions:

1. From the perspective of connectivity, the connectivity between open road intersections and square nodes is higher than that of narrow and terminal roads. Correspondingly, from the isovist area map, the value of connectivity plus the area value within the visual range of the location also shows that the area of sight on squares and wide roads is larger than that of narrow places, that is to say, narrow roads are not only more likely to be crowded but also more difficult to find safe exits within sight.

2. From the perspective of visual integration, under different limits of the radius, the visual integration center, and the visual integration value at the location of each staircase are different, but the overall integration center distribution trend is similar. With the enlargement of the sight radius, the center of integration becomes more obvious and concentrated.

3. Through the analysis of the specific values of the staircase locations, it is possible to find and locate some stairs that are difficult to find, and some stairs that are easier to be found - the stairs that are close to the square and nodes and can be reached without many turns are easier to use; and the stairs with many turns and far away from the main roads have low visibility in people's vision.

In general, most of the stairs’ visibility can be seen to be relatively average, and that guides me to do the simulation of the crowd to find more patterns in specific evacuation situations in future research.

7. ACKNOWLEDGMENTS

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