Study on Exterior Wall Tile Degradation Conditions of
High-rise Buildings in Taoyuan City

Chu-Tsen Liao*1

Abstract

In recent years in Taiwan, pedestrians have been injured by external wall tiles falling from high-rise buildings. In numerous cases, exposure to temperature and/or seismic behavior caused the tiles to fall off. This is now treated as a public safety threat. Therefore, in 2015, the Office of Building Administration of the Taoyuan City Government started inspecting buildings that were eleven stories or higher and constructed before 1996. From 2015 to 2016, the authors inspected 298 high-rise buildings for external wall tile failures in the city as contract research. We put building risk into Levels from A to E. Levels D and E accounted for 41.6% of the 298 buildings. These were dangerous buildings that needed to be repaired immediately. Additionally, we analyzed our data based on building age, number of stories, exterior materials, the directions walls faced, and city districts. Of the buildings inspected, 84% were between 20 and 25 years old. Approximately 74% were 11 to 15 stories high. Moreover, 74.5% used tiles such as mosaic, square brick, Nikogake, or half of Nikogake. Also, 44.3% of degraded buildings were in Taoyuan District. The authors hope that the research results are a useful reference for inspection systems and that they will lead to periodic inspections.

Keywords: external wall tiles; Taoyuan city; public safety; degradation condition; periodic inspection

1. Introduction

In recent years in Taiwan, some pedestrians have been injured by falling external wall tiles. One Taipei resident was killed by tiles from the United Daily News building in March 2015. In addition, Taiwan had the lowest temperatures in 10 years in late January 2016, until the temperature suddenly rose 12.5 degrees on January 26. This caused a large number of building tiles to fall off.1 Moreover, on February 6, 2016, in Meinung Town, an earthquake with a magnitude of 6.6 on the Richter scale caused a large number of building tiles to fall off. There have been numerous other cases where exposure to temperature and/or seismic behavior caused exterior wall tiles to fall to the ground. This issue is now treated as a threat to public safety. Consequently, the Taiwan government began paying attention to exterior wall problems and conducting visual inspections for signs of deterioration.

In line with this, the Office of Building Administration of the Taoyuan City Government started inspecting exterior walls of high-rise buildings eleven stories or higher and constructed before 1996 in the city. Until recently, Taipei City, New Taipei City, Taoyuan, Taizhong, Tainan, and Kaohsiung were the municipalities directly under the jurisdiction of the Central Government. According to the provisions of the Local System Act, these are areas with more than 1.25 million people and where there are special needs regarding politics, economics, culture, and other metropolitan affairs. Taoyuan City was added to the above municipalities in 2014.

The current study was a continuation of contracted research.2 Our team inspected 298 high-rise buildings in Taoyuan City for the city government from September 2015 to May 2016. All the buildings in this study were selected randomly. The exterior finish of 74.5% of the inspected buildings was tile. Our report includes data from 1980 to 2015 in the "Account and Residence Census Report" published by the Directorate-General of Budget, Accounting and Statistics of Taiwan and the Construction and Planning Agency in the Ministry of the Interior. According to this "Account and Residence Census Report", the number of householders from 1983 to 2015 in Taoyuan City had two peaks. One was 27,362 householders in 1995; and the other was 23,122 householders in 2006 (Fig.1.). Most buildings built during the peak of 1995 were in poor condition. For this reason, we also conducted research on buildings constructed in Taoyuan City before 1996 that had eleven or more stories. How to maintain and manage existing old buildings has become an important issue.

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Tile is one of the most popular materials for the finish of exterior walls for housing in Taiwan, especially for reinforced concrete and steel-reinforced-concrete structures. In the current survey, 74.5% of the buildings studied used tiles in Taoyuan City. The types of tiles included mosaic, square brick, Nikogake, and half of Nikogake.

Tile adhesion failure can be caused by a number of factors, including adhesive deformation, improper workmanship, and humidity. We collected data using nondestructive visual inspection of exterior wall tiles. The purpose of the study was to determine the relationships between degradation conditions and building ages, number of stories, exterior materials, directions that walls face, and city districts.

It is hoped that this study will be a very useful reference for inspection systems as well as provide important ideas on approaches to and implementation of periodic inspections.

2. Background on the Study and Our Methods

Our team inspected the external walls of 298 high-rise buildings from September 2015 to May 2016. Each building had eleven or more stories and was constructed before 1996 in Taoyuan City. There are thirteen districts in the city. Sixty buildings were surveyed monthly from October 2015 to January 2016. We were also responsible for responding to "1999" emergency notifications, which came in through a 24-hour City Hall hotline. If there was a notification about falling tiles, we had to arrive at the scene within two hours and inspect the exterior wall immediately.

Our team consisted of a university professor, three architects, two civil engineers, and three students seeking master's degrees. We used the naked eye, binoculars, and high-powered single-lens cameras to inspect the buildings and record the deterioration of their external walls at the sites.

2.1 Risk Classifications: Levels A, B, C, D, and E

The six municipalities started inspecting the exterior walls of high-rise buildings in 2015, 2016, and 2017. Each building had eleven or more stories and was constructed before 1996 in Taoyuan City. There are thirteen districts in the city. Sixty buildings were surveyed monthly from October 2015 to January 2016. We were also responsible for responding to "1999" emergency notifications, which came in through a 24-hour City Hall hotline. If there was a notification about falling tiles, we had to arrive at the scene within two hours and inspect the exterior wall immediately.

Our team consisted of a university professor, three architects, two civil engineers, and three students seeking master's degrees. We used the naked eye, binoculars, and high-powered single-lens cameras to inspect the buildings and record the deterioration of their external walls at the sites.

2.2 Survey Form

Three architects and two civil engineers were responsible for the main inspections. First, they held discussions with a community management committee and residents. Then, they reported on those discussions to professors at the University of Kaohsiung. After that, the professors integrated the information with city government information to create the survey form. The inspectors had to complete the form each time they examined a building.

The following are the items on the form.

- **Item 1. Building information:** Address, license, type of construction (e.g., reinforced concrete), number of structures, usage, and filing code.
Item 2. Inspectors, contract institution, and building-visit information: All the architects and civil engineers, the University of Kaohsiung, and the community management committee had to sign and date the form.

Item 3. Evaluation of walls and attached objects: The building risk classifications were Level A (Nonexistent), B (Caution required), C (Improvements recommended), D (Potentially dangerous, meaning moving to temporary facilities is recommended), and E (Dangerous, meaning a warning belt is necessary around the building and evacuation to temporary facilities is recommended).

The evaluations factored in the material used for the exterior walls (tile, stone, compacted light pebbles, monolithic finish, etc.) and attached objects (railings, air conditioning equipment, eaves, iron windows, etc.).

Item 4. Recommendation for use of safe temporary facilities

Item 5. The damage status of each floor

Item 6. Photos showing current conditions

Item 7. Drawings showing building and street status

Figs. 3 and 4. illustrate Items 6 and 7, respectively, on a survey form for a Level E building.

3. Basic Building Information

In this section, we explain the basic building information, i.e., the year of construction, number of stories, and types of exterior wall finishes.
less than 11 stories high, and 6% over 20 stories. Table 2. shows the relationships between the number of floors and the building risk level.

### 3.3 Tile Sizes and Exterior Wall Types

Table 3. lists common tile sizes in Taiwan. Right after that, Fig.7. shows the types of exterior wall finishes for the buildings inspected. Approximately 5% of the buildings used mosaic, 45% were square brick, 20% were Nikogake, and 5% were half of Nikogake. Therefore, 75% of them used tiles. The others were compacted light pebbles, monolithic finish, stone, curtain wall, and decorative plate.

#### 4. The Degradation Conditions of the Exterior Wall Tiles

In this section, we show the relationships between the deterioration of the inspected buildings and the building ages, the number of stories, the exterior materials, the direction each wall was facing, and the Taoyuan City districts.

**4.1 The Degradation Condition in Taoyuan City**

The relationships between the deterioration of the buildings and their exterior wall types, wall directions, and districts are shown in Tables 4., 5., and 6., respectively. We made several significant discoveries through our statistical data.

1. Of the inspected buildings, 84% were 20 to 25 years old, and most of them were rated as Levels C, E, or D.
2. In terms of height, 73.5% of the buildings were 11 to 15 stories high, most of which were rated as Level C or E.
3. The tile materials among 74.5% of the buildings were mosaic, square brick, Nikogake, and half of Nikogake. The square brick was the most commonly used material at 44.8% among all the buildings.
4. The degradations were the most common when a wall was facing east (15%), northeast (14.3%), or south (14.1%).
5. Regarding districts, 44.3% of the degraded buildings were in the Taoyuan District, with 26.5% in the Zhongli District.

Among our structures, Fig.8. shows a 12-story reinforced-concrete building (filing code: 10410-2). It was constructed in 1989. The building's square bricks were the most common type of tile used from 1985 to 1995.

#### Table 2. The Relationships between Building Heights and Risk Level

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Number of building floors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

#### Table 3. Common Tile Sizes in Taiwan

<table>
<thead>
<tr>
<th>Types of tiles</th>
<th>Size (mm)</th>
<th>When common</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosaic</td>
<td>18 x 18 / 24 x 24 / 50 x 50 / 55 x 55 / 60 x 120</td>
<td>1970 - 1985</td>
</tr>
<tr>
<td></td>
<td>x 55 / 60 x 120</td>
<td>1985</td>
</tr>
<tr>
<td>Square brick</td>
<td>78 x 78 / 80 x 80 / 90 x 90 / 95 x 95 / 100 x 100</td>
<td>1985 - 1995</td>
</tr>
<tr>
<td>Nikogake</td>
<td>230 x 60 / 230 x 50 / 210 x 55 / 227 x 60 / 240 x 52</td>
<td>1985 - present</td>
</tr>
<tr>
<td>Half of Nikogake</td>
<td>173 x 40 / 190 x 40 / 195 x 35 / 200 x 32</td>
<td>1985 - present</td>
</tr>
</tbody>
</table>

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Fig.6. The Number of Floors of All the Buildings Inspected

Fig.7. The Types of Exterior Wall Finishes

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45% Mosaic
40% Square brick
10% Nikogake
5% Half of Nikogake
5% Compacted light pebbles
10% Monolithic finish
20% Stone
7% Curtain wall
5% Decorative plates

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4.2 The Degradation Conditions of Level E Buildings

Level E structures accounted for 26% of the 298 buildings inspected. We were therefore able to create additional analysis with respect to the relationships between the Level E buildings and their stories, exterior wall types, directions, and districts.

Level E buildings had the following characteristics.

1. The ages of 81% of the buildings were 20 to 25 years old. In addition, 11% of them were 26 to 30 years old.
2. In terms of height, 71% of the buildings were 11 to 15 stories high, while 23% were 16 to 20 stories high.
3. Fig.10. shows that 84% of the buildings’ tile materials included mosaic (8%), square brick (49%), Nikogake (20%), and half of Nikogake (7%). Clearly, the square brick was the most common tile material in our study.
4. Most of the degraded walls were on the eastern and southeastern sides of buildings.
5. By district, 54% of the degraded buildings were in the Taoyuan District. The Zhongli District had 24% of them.

4.3 The Degradation Conditions of the Level E Buildings in the Zhongli District

Because 24% of the degraded buildings were in the Zhongli District, we have additional analysis regarding the relationships between the Level E buildings and their stories, exterior wall types, and directions there.

1. We observed that 88% of the inspected buildings were 20 to 25 years old. None of the buildings were 26 to 30 years, but 12% were 31 to 35 years old.
2. In terms of height, 71% of the buildings were 11 to 15 stories high, while 23% were 16 to 20 stories high.
3. We found that 92% of the buildings had tile materials, including mosaic (8%), square brick (52%), Nikogake (28%), and half of Nikogake (4%). Again, the square brick was the most common tile material that we found.
4. Most of the degradations were located on the southwest (22%), east (18%), and west (18%) sides of the buildings.
In Fig. 13, we can see that 98% of the buildings had tile materials, including mosaic (18%), square brick (44%), Nikogake (29%), and half of Nikogake (7%). Again, the square brick was the most common tile material.

Most degradation directions were southeast (19%), northeast (17%), and southwest (16%).

Table 4. The Relationships between the Deterioration of Inspected Buildings and Exterior Wall Types

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Mosaic</th>
<th>Square brick</th>
<th>Nikogake</th>
<th>Half of Nikogake</th>
<th>Compacted light pebbles</th>
<th>Monolithic finish</th>
<th>Stone</th>
<th>Curtain wall</th>
<th>Decorative plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.7%</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>12.6%</td>
<td>2</td>
<td>16</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>C</td>
<td>38.1%</td>
<td>4</td>
<td>66</td>
<td>26</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>12.2%</td>
<td>3</td>
<td>25</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>E</td>
<td>26.5%</td>
<td>7</td>
<td>45</td>
<td>18</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>4.7%</td>
<td>44.8%</td>
<td>20.3%</td>
<td>4.7%</td>
<td>1.5%</td>
<td>1.7%</td>
<td>7.3%</td>
<td>10.5%</td>
</tr>
</tbody>
</table>

Table 5. The Relationships between the Deterioration of Inspected Buildings and Wall Directions

<table>
<thead>
<tr>
<th>Risk level</th>
<th>North</th>
<th>South</th>
<th>East</th>
<th>West</th>
<th>Northeast</th>
<th>Southwest</th>
<th>Southeast</th>
<th>Northwest</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.4%</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>6.8%</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>39.4%</td>
<td>20</td>
<td>26</td>
<td>21</td>
<td>24</td>
<td>28</td>
<td>22</td>
<td>9</td>
</tr>
<tr>
<td>D</td>
<td>19.5%</td>
<td>8</td>
<td>15</td>
<td>11</td>
<td>15</td>
<td>11</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>E</td>
<td>32.9%</td>
<td>18</td>
<td>18</td>
<td>22</td>
<td>15</td>
<td>18</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>11.7%</td>
<td>14.1%</td>
<td>15%</td>
<td>13.8%</td>
<td>14.3%</td>
<td>12.4%</td>
<td>9.9%</td>
</tr>
</tbody>
</table>

Table 6. The Relationships between the Deterioration of Inspected Buildings and the Districts They were in

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Percentage</th>
<th>Tao-yuan</th>
<th>Zhong-li</th>
<th>Lu-zhu</th>
<th>Long-tan</th>
<th>Ping-zhen</th>
<th>Daxi</th>
<th>Yang-mei</th>
<th>Guan-yin</th>
<th>Bade</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.7%</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>16.1%</td>
<td>14</td>
<td>12</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>36.6%</td>
<td>47</td>
<td>30</td>
<td>9</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>15.8%</td>
<td>21</td>
<td>18</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>25.8%</td>
<td>41</td>
<td>18</td>
<td>4</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>44.3%</td>
<td>26.5%</td>
<td>7.7%</td>
<td>0.7%</td>
<td>6.7%</td>
<td>1%</td>
<td>0.7%</td>
<td>6.7%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

(3) In Fig.13., we can see that 98% of the buildings had tile materials, including mosaic (18%), square brick (44%), Nikogake (29%), and half of Nikogake (7%). Again, the square brick was the most common tile material.

(4) Most of degradation directions were southeast (19%), northeast (17%), and southwest (16%).
5. Conclusions
The Construction and Planning Agency in the Ministry of the Interior announced regulations for the public safety verification of buildings in 1996 and strengthened them in 2000 and 2010. The regulations state that fire prevention facilities and safety equipment need to be checked to help ensure safety. However, the condition of exterior walls has never been regulated. To protect pedestrians from exterior wall tiles that fall off, the walls should be listed in the near future as an item to check to determine safety. How to maintain and manage exterior wall tiles of existing buildings has become an important issue.

In this study, our team inspected exterior walls of high-rise buildings that were eleven or more stories high and constructed in or before 1995 in Taoyuan City. Of those buildings, 16% were rated as Level D and 26% of them were Level E. In addition, 84% of the buildings were between 20 and 25 years old. Also, 74% of the buildings were 11 to 15 stories high, and 17% of them were 16 to 20 stories high. Moreover, 74.5% of the buildings used tiles in Taoyuan City, such as mosaic, square brick, Nikogake, and half of Nikogake. Additionally, 44.3% of the degraded buildings were in the Taoyuan District.

Citizens who live on the 11th to 15th floors of buildings that use square brick and are twenty years old or older in the Taoyuan District should have the external walls checked. The government should also establish an inspection system for these buildings to prevent accidents involving falling tiles.

The features of the degraded buildings are below, with two considerations for actions to take in Paragraph (2).

(1) The degraded buildings' ages and stories:
As stated earlier, the number of householders from 1983 to 2015 in Taoyuan City had two peaks. One was 27,362 householders in 1995, and the other was 23,122 in 2006. Most of the buildings at the peak in 1995 are in poor condition now. Approximately 85% of the inspected buildings were 20 to 25 years old, and 11% were 26 to 30 years old. About 74% of the buildings were 11 to 15 stories high, and 17% were 16 to 20 stories high. Based on our Level E data, cases at 26 to 30 years old accounted for 22.2% of the total. In addition, those 31 to 35 years old and 36 to 40 years old made up 42.9% and 66.7%, respectively. Therefore, a higher housing age means a higher percentage of dangerous deterioration. Citizens should be concerned about buildings that correspond to these conditions.

(2) The tile materials of the exterior walls:
Of the inspected buildings, 74.5% had tile materials on the exterior walls, with square brick being the most common. In the Taoyuan District, we found that 84% of the buildings used tile, including mosaic (8%), square brick (49%), Nikogake (20%), and half of Nikogake (7%). Clearly, the square brick was the most common tile material in our study. In fact, it was the most commonly used tile type from 1985 to 1995. Construction workers often used cement mortar made with powdered seaweed as the tile adhesive up to 1995. Consequently, the material ratio and the amount of time the adhesive was in proper condition were not easy to control. Moreover, underdeveloped construction skills and tile unit areas that were too large caused a large percentage of square brick spalling. Therefore, implementing laws for regular tile inspections and maintaining these existing buildings with advanced housing age have become important issues.

(3) Degradation directions:
Degradations are most common when walls in Taoyuan face east (15%), northeast (14.3%), and south (14.1%). In addition, the locations of openings such as doors and windows affect the deterioration of the tiles. To avoid excess exposure to relatively hot western sunlight and cold wind, there should be fewer openings on the north and west. Therefore, the openings should be in other directions, resulting in most tile spalling on the eastern and southern sides. In this study, openings on the east, northeast, and south also affected the tile deterioration.

(4) Level D and E buildings:
We classified the risk of building degradation into five categories: Levels A to E. Level D and E accounted for 41.6% of the 298 buildings inspected. These are regarded as dangerous buildings that should be repaired immediately, especially those at Level E. Our ratings showed that 16% of the buildings were at Level D and 26% at Level E. This means that 42% of the buildings need to be repaired.

In the case of Level E buildings, 81% of them were 20 to 25 years old. We also found that 68% of the buildings had 11 to 15 floors. In addition, we learned that 84% of the buildings had tile materials. The square brick was the most common type. Additionally, most of the degradations were at the eastern and southeastern sides of the buildings.

(5) Degradation conditions of Level E buildings in the Taoyuan District:
A significant 44.3% of the degraded buildings were found to be in the Taoyuan District because this district was developed earlier and its population was about double that of the other districts.

Level E structures are regarded as dangerous buildings that should be repaired immediately. Our team teaches repair methods for exterior walls to the community management committee.
There are several notable features of Level E buildings in the Taoyuan District. We observed that 74% of them were 20 to 25 years old. Additionally, 68% of them were 11 to 15 stories high. In addition, 98% of the buildings had tile materials. Moreover, it again became clear that the square brick (44%) was the most common tile material. Finally, most degradations were on the southeastern side (19%) of the buildings.

Acknowledgement
This study was funded by the Office of Building Administration of the Taoyuan City Government. We highly appreciate the assistance that we received from the local architects.

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