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Original Article

A Study on Coastal Buildings - Cases of the Exterior Wall Tiling

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Abstract - *It is popular in Taiwan to use exterior wall tiles to decorate and protect buildings. In the tiling process, the pull-out tests of tiles must be carried out in accordance with the tensile strength regulations. However, factors such as poor construction, building locations (e.g., different distances from the coast in the coastal area) and material quality of tiles may affect the tiling performance. In order to ensure the quality and safety of all tiling projects, this study focuses on analyzing the tiling issues in the coastal area. Therefore, the study analyzes three tiling projects in the same coastal area. All the projects use similar quality tiles and are finished by the same construction team in a similar period, i.e., the only difference among the three projects is "distance from the coast." Results of the study show that building locations, i.e., distance from the coast, impact the outcome of tiles pull-out tests. For building projects in the coastal area, the closer the coast, the worse the tiling performance.*

Keywords - *Distance from the coast, Exterior wall tiles, Pull-out tests, Tensile strength.*

1. Introduction

Generally, the damage to the exterior wall tiles of the building is common, including contamination, whitening, cracking, peeling, bulging and many other situations. Taiwan belongs to island climate conditions in the subtropical region; earthquakes, temperature, and rain even easily degrade the exterior walls of buildings, etc. That will result in the peeling of the tiles and may cause public danger.

Among the elements that make up a building, the exterior wall is often the place that is most severely impacted by the external environment; moreover, the performance of exterior wall tiles is not only affected by the design, construction materials, construction quality and earthquakes, but also by the environment and climate conditions of site area.

Therefore, this study aims to explore the differences in tiling performance of building projects in the same area, however, with different distances from the coast in the coastal area in northern Taiwan. According to this study, tiling performance in the coastal area is analyzed, and some suggestions to overcome the issues of poor tiling performance are also given. With these analyses and suggestions, to reduce the incidence of tile peeling in the future, improve the safety and beauty of buildings, and reduce the loss of people's lives and properties.

2. Literature Review

The reviewed pieces of literature are categorized into "coastal constructions and climate issues" and "exterior wall tiling and its performance issues." First, literature related to coastal constructions and climate issues is summarized as follows.

Zviely and Klein (2003) studied the large-scale coastal construction in the Gaza Strip. They found the coastal erosion extending north of Gaza City to southern Israel. The proposed solution is beach nourishment and a sand bypass system, which would transfer the sand that accumulates south of the coastal construction to the affected areas in the north. Ferreira and Brito (2008) summarized the pathological situations that occur in coastal area construction are due to the conjugation of various elements: climatic agents, sea characteristics and the location of the buildings. There is a significant risk of service life reduction leading to adequate materials and constructive details to reduce the drawbacks concerning location. Their study showed the importance of applying appropriate materials for different construction sites in the corresponding environment.

Implementing effective mitigation and adaptation measures in coastal territories is important because they will be more directly affected by some possible effects of climate change. Gunawansa and Kua (2014) assessed and compared how Singapore, Miami-Dade and San Francisco implement climate change strategies in their construction industries. It was found that although mitigation has entered mainstream policymaking, adaptation still lags behind. Linwei et al. (2021) described green building projects in Dalian, a typical coastal city in a cold region of China. The research provided substantial guidance for the energy-saving design of green buildings and the application of appropriate technologies in cold coastal cities. Moreover, Alatrsh and Ilter (2022) found that environmental conditions impact the performance of building materials' lifespan.

Moreover, literature on exterior wall tiling and its performance issues are summarized as follows. Jiang (2009) concluded that general tile deterioration could mainly be divided into physical and epoch deterioration. Physical deterioration refers to the deterioration of structures, structures and equipment caused by factors such as natural force, wear, vibration and failure. In contrast, epochal deterioration refers to the reduction of the value of buildings due to factors such as technological innovation and increasing social demands. Similarly, Lu (2010) stated that human and natural environment factors mainly influence the damage to external wall tiles. The natural environment has many factors, such as atmospheric temperature or humidity, earthquakes, acid rain, etc. Furthermore, Lin et al. (2012) pointed out that since the exterior wall tiles are on the outermost layer of the building, they directly bear the changes of the external environment and provide protection for the reinforced concrete structure. Therefore, the considered durability factors such as sunlight, temperature and humidity changes, strong wind, rain, etc., may cause the deterioration of exterior wall tiles.

3. Methodology

In this study, "coefficient of variation (CV)" and "cluster analysis" are selected as numerical analysis tools. The analysis data is mainly obtained through self-inspection by the project contractor. The coefficient of variation is a measure of relative deviation, which is used to compare the dispersion of data with different units or the same unit but with large differences. When comparing the same unit or the same property, the absolute amount of variation can be used. However, when the units and properties of the two data are different, or when the units are the same, but the mean pairs are quite different from each other, the measure of relative variation must be used for comparison. Moreover, the coefficient of variation s can be calculated as Equation 1 (Ryan, 2007), where s is the standard deviation, and $\overline{x}$ is the mean of data.

$$CV = \frac{s}{\overline{X}} \times 100\% \tag{1}$$

The standard deviation can be regarded as the absolute value of the degree of dispersion. At the same time, the coefficient of variation is the relative value of the degree of dispersion to the mean (Warner, 2013.) Furthermore, since this study intends to deeply explore the detailed data distribution patterns of the pull-out test data of each building project, the coefficient of variation calculated from the overall sample data of each building project is still insufficient. Therefore, this study attempts to supplement the cluster analysis further to understand each project's internal data distribution status and to confirm whether the coefficient of variation analysis results are representative and sufficient to conclude that the results of the pull-out test of each project are different.

Cluster Analysis is not a statistical inference technique but an objective method to quantify the structural properties of a set of observations. Therefore, this method does not require any assumptions. For example, normality, linearity, and equality of variance requirements, which are very important in other methods, have little effect on cluster analysis (Warner, 2013.) However, multicollinearity does because those with multicollinearity variables will have a larger weight, and if there is a weighting process in multicollinearity, it will affect the results of the analysis. Using cluster analysis, relatively similar samples can be clustered together to form a cluster. If the distance is used as the basis for classification, the closer the relative distance is, the higher the degree of similarity will be (Verma, 2013.)

Moreover, after clustering, the differences within clusters can be small, and the differences between clusters are large. Furthermore, one of the popular hierarchical clustering methods is Ward's method, also known as the minimum variance method. Ward's method first treats each individual as a cluster and then merges the clusters in sequence. It depends on the size of the total internal variance, and the distance is calculated as Equation 2, where d is the distance, n is the data size, $\overline{x}$ is the respective average, and $\overline{\overline{x}}$ is the overall average (Stevens, 2009.)

$$d_{A,B} = n_A \left\| \overline{x_A} - \overline{\overline{x}} \right\|^2 + n_B \left\| \overline{x_B} - \overline{\overline{x}} \right\|^2 \tag{2}$$

Moreover, the non-hierarchical clustering method breaks up the original clusters and re-form new clusters in the clustering process at each stage. The K-Means method is the most commonly used non-hierarchical clustering technique. Regarding the above two types of clustering methods, the two-stage method can usually be used for cluster analysis to make the clustering more comprehensive. The so-called two-stage method combines the hierarchical and non-hierarchical clustering methods. In the first stage, the Ward method is used for clustering to determine the number of clusters. In the second stage, the K-Means method is used for cluster classification.

4. Projects Study

The Danhai New Town rezoning area is located in the northern end of Danshui District, New Taipei City, Taiwan. It is a residential rezoning area on the waterfront, with a maximum temperature of 37.9 degrees Celsius, and wet and cold weather in winter, with a minimum temperature of 4.8 degrees Celsius (Danhai New Town, Wikipedia). This study analyzes the recent project of three finished residential buildings. The location of the project is shown in Fig. 1.

Fig. 1 Projects location

Source: edited from Google Maps

To protect the privacy of the projects, the third row of projects from the coast is named Project A; the second row of projects is named Project B, and the project in the first row is named Project C. All three projects are constructed by the same contractor with similar tile materials and tiling process. The pull-out test data are collected from June 2017 to October 2018, as shown in Figures 2 and 3. Moreover, each with 60 pull-out test samples, the mean, standard deviation and CV of the data of the three projects were calculated, as shown in Table 1.

Fig. 2 Pull-out test for tiles (1)

Fig. 3 Pull-out test for tiles (2)

Table 1. Basic statistics

	Mean (kgf/cm^2)	Standard Deviation (kgf/cm^2)	Coefficient of Variation (CV)
Project A	8.1	1.942	0.236
Project B	7.1	1.677	0.235
Project C	5.0	1.466	0.293

From the basic statistical analysis of the three projects, it is known that project A has the best performance in terms of mean, standard deviation and coefficient of variation, project B is moderate, and project C has the worst performance. This result implies that the location of each project should have an impact on its pull-out test performance.

In addition, to further confirm the pull-out test performance of three projects. The statistics software SPSS V20 is used for cluster analysis to explore the patterns of the pull-out test performance of three projects. Firstly, the three projects were analyzed by the hierarchical cluster analysis method, and the number of suitable clusters obtained for each was two. Therefore, for each of the three projects, set the number of clusters as two, and then use the K-means clustering method to analyze again, and finally obtain the results as shown in Table 2 and Table 3:

Table 2. Initial cluster centers (Unit: kgf/cm2)

	Cluster	
	1	**2**
Project A	10.00	3.00
Project B	9.90	3.50
Project C	7.30	3.00

Table 3. Final cluster centers (Unit: kgf/cm²)

	Cluster	
	1	**2**
Project A	9.74	6.18
Project B	8.30	5.45
Project C	6.19	3.51

It can be found in Table 2 and Table 3 that the initial cluster center point and the final cluster center point in this study are divided into two clusters. To show the final result of the cluster more clearly, the data in Table 3 can be drawn, as shown in Figure 4. From the center point of the last cluster, it can be found that project C performs worst in both clusters with the lowest scores among the three projects, project B has the middle score, and project A performs better.

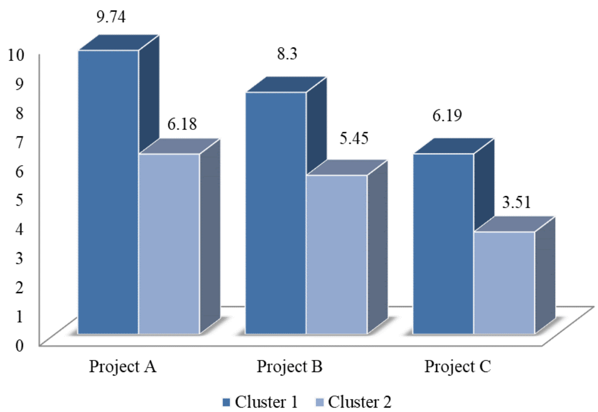

Fig. 4 The final cluster centers (unit: kgf/cm²)

Moreover, from the statistics of the final cluster center point in Figure 4, it is found that the sample data distribution patterns of the three projects are similar, and they can be named as two clusters of "high-level" and "low-level." If only the high-level clusters of each project are compared, the pull-out test results from best to worst are Project A, Project B, and Project C, respectively. The same results are obtained by comparing the low-level clusters of each project. So far, with the basic statistics and cluster analysis results, this study can conclude that project A performs better than project B, and project B is better than project C.

5. Conclusion

This study explores the quality of building tiling in the coastal area through the coefficient of variation and cluster analysis. The field pull-out tests show that project A has the best mean, standard deviation and coefficient of variation performance. Moreover, project B is moderate, and project C has the worst performance. Since these three projects are constructed in similar periods by the same contractor with similar quality of tiles, it can be concluded that the location, i.e., "distance from the coast" of the project, should have an important impact on the tiling performance.

Therefore, natural environmental factors such as ambient temperature and humidity at the coastal construction site considerably impact the building projects. For the future building project constructed like the case environment of this study, this study suggests that additional cost preparation for better tiles adhesives or the possibility of re-work is necessary. Moreover, more frequent maintenance actions may also be needed.

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