Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 2 (2023) 046-056

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Relationship Between Crack and Structure Settlement on Residential Building at Ayer Hitam

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DOI: https://doi.org/10.30880/rtcebe.2023.04.02.006
Received 16 January 2022; Accepted 15 January 2023; Available online 20 July 2023

Abstract: Building construction on soft soil including on peat has many challenges and difficulties. Building cracks and soil settlement are the most frequent issue in any area surrounded by peat soil. Therefore, this study is conducted to determine the effect and types of cracking which might be influenced by soil settlement together to propose the relationship between cracking and settlement. The location of the study being carried out in a residential building at Kompleks Penghulu Mukim Ayer Hitam, Muar. The visual inspection technique using specific measuring equipment such as taper gauge (measure crack) and triangle ruler (measure settlement) will be used to gain the data in conducting observation to the building. The building inspections were divided into two parts; the first part covers the investigation into measuring cracks, and the second part covers the investigation into measuring soil settlement. The length and width of the cracks were noted at the beginning of the study and monitoring activities were carried out on a regular basis to check whether these two parameters grew over time or not. A new formulation will be made to check on those parameters either directly proportional or not. A new formulation will be made to check on those parameters either directly proportional or not. Therefore, preventive measures can be set forth to avoid repetitive structural problems in the Ayer Hitam, Muar area in years to come. The results of the study found that the two parameters do not show a change directly proportional with time to each other but have proven the theory that cracking will only occur if there is a change in settlement.

Keywords: Surface Crack, Settlement

1. Introduction

Building failure is a common occurrence for residential buildings in Muar district, Johor state, since the location is surrounded by peat soil type. Construction of infrastructures on peat land is very challenging due to its properties of very high moisture content, high compressibility and very low shear strength [1]. Cracking is one of the factors that contributed to the failure of the building. Cracks will affect the artistic appearance of the building, as well as destroying the wall integrity, affecting the safety of the structure, and even reducing the structure's durability [2]. To examine the causes of building cracks, it

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is required to evaluate their position, pattern, width, length, depth, age, whether they are active or not, how catastrophic they are, and how to fix them. [3]. In practice, soil with weak strength is risky to withstand because of the massive and high load press on its surface that results in common failure in foundation bearing structures [4]. The wrong selection of foundation types and sizes in the building can be one of the reasons affecting the strength of the structure such that it can lead to cracking damage. On peat soil, specified building standards are introduced to ensure that constructed buildings meet the minimum health and safety requirements. The research would be precisely in West Johor on the following geography map, which is located in Kompleks Penghulu Mukim Ayer Hitam, Muar. Previous investigations have revealed the significant buildup of peat soil in the indicated area in Figure 1. Building inspection was carried out in this study by measuring the width, length, and orientation of cracks and settlement.

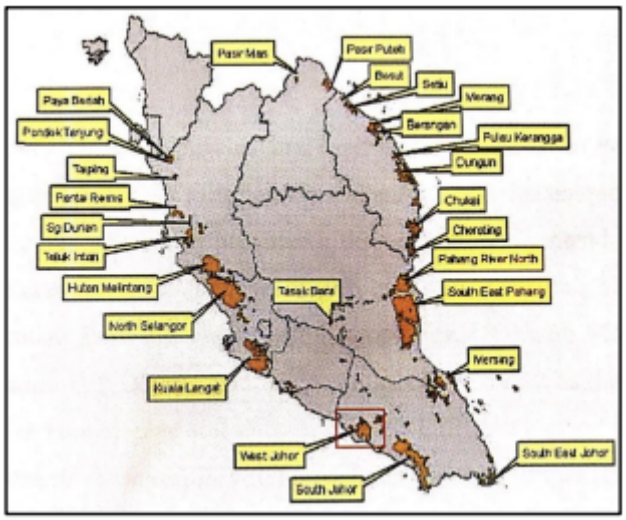


Figure 1: Peat concentration and accumulation at Peninsular Malaysia [5]

All the interpreted and analyzed data will be tabulated in a table form showing type of problems, date of data taken, value measured by measuring tape, and locations where problems occurred. These data can be used to relate its symptoms with the causes of the problem to ensure that solutions and preventive measures can be proposed to avoid repetitive problems in the future. It is hoped that the information obtained from this study can be used as a preliminary reference for the construction industry to carry out any construction or maintenance works on the future prospects of the Malaysian construction industry. Therefore, this paper is written for the objective as to measure the width of building crack and structure settlement and evaluate the crack pattern which might induced by settlement width.

2. Literature review

There are two types of failure that will be discussed which is cracking and settlement. The occurrence of different crack patterns in the structure during construction or after completion when exposed to super imposed load or throughout service life is a frequent phenomenon. Many factors could be responsible for building failure such as foundation movement. Foundation failure in a building can be attributed to several things. Most commonly foundation failure is caused by the movement of expansive and highly plastic soils beneath different sections of the foundation footings. This movement of soil can be in the form of shrinkage, which causes settlement, or expansion, which causes heave. In addition. In addition, when the tension in a building component exceeds its strength, the cracks will develop. Stress in a building component may be produced by externally applied forces such as dead, live, wind, or seismic loads, foundation settlement, and others or it can be induced internally owing to temperature movements, moisture changes, elastic deformation, and chemical action [6]. Therefore, in general cracks in concrete can be divided into two types which are structural cracks and non-structural cracks. Random cracks in concrete are normally innocuous unless they are created by fire or chemical

activity [7]. Cracks develop when a component of the structure is moved from its location without any change in the size of material. Settling may create cracks in a structure's foundation and internal walls, as well as uneven settling of doors and windows [8]. Other signs of settlement include leaning chimneys, external stairs that tilt or sink, bulging walls, seeping through holes and sunken slabs. Since soil settlement tends to be slow, cracks due to settlement tend to be bigger at the top, reducing to practically nothing at the bottom. Crack and settlement classification is based on its width as shown in Table 1 and Table 2.

Table 1: Classification of cracks based on crack width [9]

Crack Width	Category	Classification
Less than 2mm	Very Slight	Aesthetic
2mm to 5mm	Slight	Aesthetic
5mm to 15mm	Moderate	Serviceability
15mm to 25mm	Severe	Serviceability
Over 25mm	Very severe	Stability

Table 2: Category of settlement based on settlement [10]

Settlement width	Category
Less than 1mm	Very slight
Less than 5mm	Slight
5mm to 15mm	Moderate
15mm to 25mm	Severe
Over 25mm	Very severe

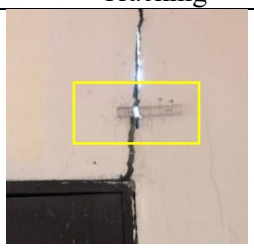
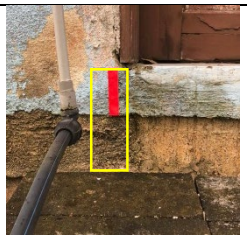
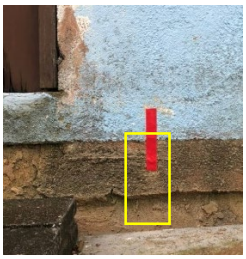
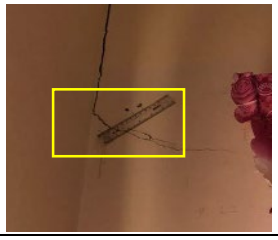
3. Methodology

The study focuses on the types of cracking that occur in residential buildings at Kompleks Penghulu Mukim Ayer Hitam, Muar which is likely due to the weakness of peat soil, which has a high moisture content, low bearing capacity, high organic content , high compressibility and mostly high in water table. The width, length and orientation of the cracks and soil settlement were measured during the building inspection. Therefore, at the beginning of the inspection the width and length were marked and monitoring activities were carried out on a regular basis to observe whether these two parameters increased with time or not. Based on a previous study, the monitoring activity of the cracks revealed that the cracks in the building are active cracks since there is some measure equipment which has already marked on the ruler which is used as a crack gauge. Because of peat soil settlement, these structures are rapidly expanding in width and length.

There were three different locations selected for analysis. The location is selected based on a selection of criteria where cracking and settlement are parallel to each other. As shown in Table 3, example for location A, the cracking position is above the settlement position. That is meant by parallel location. These criteria were chosen to see whether the settlement would affect the extent of the cracking.

There are 10 readings to be taken throughout the analysis of the residential building. Readings were taken only once per week to see if there is a movement on the building. The purpose of the readings taken every week is to make sure if there are any improvements to the building even in a short period so as not to be left behind. The purpose of the 10 readings obtained is to guarantee that the pattern of change in the structure seems parallel and orderly. Additionally, if the readings taken are less than 10 readings, for example like once every two weeks, the change in readings that happens will extend the distance between readings and if there is a significant change, the average reading per week is difficult to analyze.

Table 3: Marking of location in Kompleks Penghulu Mukim residential building

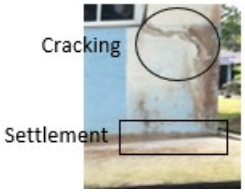
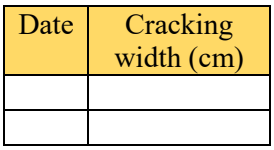
Location	Cracking	Settlement
A		
B		
C		

3.1 Measuring cracking

In this study, the easiest way to measure the cracking without using any sophisticated instruments was by using taper gauge. Taper gauge is working by filling the gap between two surfaces which is cracking on the wall. This is due to the fact that the taper gauge is a simpler and less expensive instrument to use as well as can last for a long time and does not cost a lot of money. The crack width measured along the middle of 15 cm of each specimen. Cracking width readings are also easy to read in the presence of scale readings provided on the taper gauge. The crack widths were taken at discrete times (once every week) during the cracking process until the inspection ended. Table 4 shows the procedure for measuring cracking and for the second steps show how the taper gauge is attached to the wall.

The crack width data will be determined according to a predetermined time. The time it takes to retrieve data is once in a week for several months. Based on the previous study, the cracking width always changes from time to time. However, it also took quite some time to see the change on the crack. That is why the data will be collected once every week. After obtaining the width value for each position, the category for cracks based on the crack width will be determined for the types of cracks that occur in the area.

Table 4: Procedure on measuring cracking

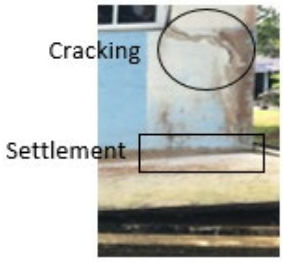
	Steps	Description
1		Determine the location of the cracking where there is settlement beneath it.
2		Place the measuring equipment which is taper gauge on the cracked area to get the width reading. The ruler is already have on it due to the past inspection of the building.
3		Fill in the results of the cracking width value into the table based on the specified date.

3.2 Measuring settlement

Settlement is a type of failure that occurs due to the movement of structures underground. Settlement can be measured in several ways by using equipment that is specifically designed for measuring settlement. However, in order to reduce costs as well as labor, triangle ruler and tape were used to measure the settlement in the building by attaching the triangle ruler to the wall where the settlement line was showing. The purpose of the taped tape is to identify the location and as a benchmark to always take readings at the same place each week. The time taken to measure settlement is the same with the time taken to measure cracking and the data is recorded the same day with cracking record data. Table 5 shows the procedure for measure settlement.

It is feasible to identify soil deformation if the ground surface surcharge causes a stress change in the soil or in the currently constructed earth structure. The settlement is the vertical component of soil deformation that is normally sloped. Settlement on the apron and surrounding column outside of the houses that occurs at the position where cracking occurs will also be retrieved data at the same time the cracking data is retrieved. This is to see whether the settlement width is directly proportional to the cracking value or not. Data for settlement will be collected once a week, therefore the appearance of changes in the value of settlement will change from time to time.

Table 5: Procedure on measuring settlement

Steps	Description
1 	Determine the location of the settlement where there is a cracking failure on it.
2 	Place the tape on selected location to ensure the location is not exchange for the future reading
3 	Place the triangle ruler to the wall in 90 degree condition to ensure that the reading are more accurate since the condition of the sidewalk is not in a perpendicular condition to the wall.
4 <table><tr><th>Date</th><th>Settlement width (cm)</th></tr><tr><td></td><td></td></tr><tr><td></td><td></td></tr></table>	Fill in the results of the cracking settlement value into the Table based on the specified date.

3.3 Correlation of cracking and settlement

Since desiring to observe the changes that have occurred to the crack and settlement, the time required has played a part in assessing those improvements. The time is taken every two weeks. Maaddawy [11] stated that cracking and settlement that occur according to the change of time will determine whether these two perimeters are directly proportional to each other or not through the equation given as below.

$$C = mt + c \quad Eq.1$$
$$S = mt + c \quad Eq.\ 2$$

Where C is the cracking width, S is the settlement width and t is the total of time until the data is taken. m is slope to determine the gradient of the graph and c stands for intercept at y-axes.

From this equation, it can determine whether the crack width and settlement are either directly proportional or inversely proportional. Using the aforementioned equation, the width of the crack and settlement will be able to determine if these two parameters are proportional to each other or not. The amount of time taken to determine the status of failures is important to ensure both parameters will change. To determine whether they are directly proportional or not, the crack width and settlement must be the same. If the width distances are not equal or in other words are valued in nearly equal multiples,

they are identified as directly proportional. Moreover, if the width value is not equal or is not within the appropriate multiple value, it is inversely proportional.

4. Results and Discussion

4.1 Analysis at location A

Location A shows the change for both two parameters which are cracking and settlement as shown in Figure 2. The value of the change that occurs in the crack is starting in the sixth week while for settlement it starts to show the change starting in the fifth week. Basically, settlement must take place before cracking occurs. This is because when the settlement occurs first, the cracks affected by the settlement will still occur in the end. Changes in the cracks continued to occur until the last week as well as the settlement that had taken place.

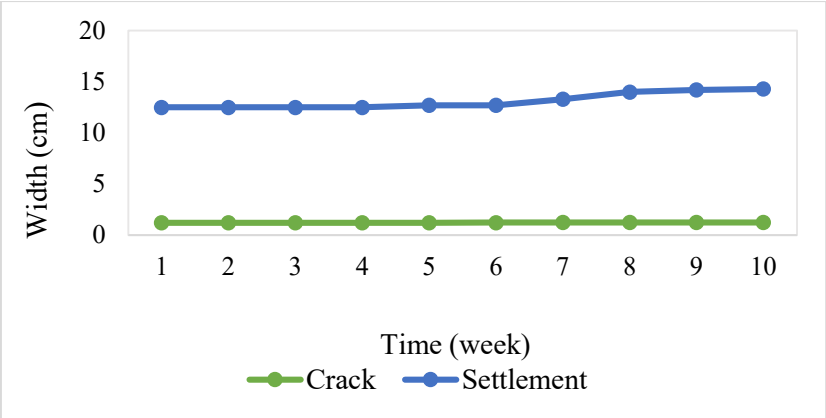


Figure 2: Graph of change in crack and settlement width versus time at Location A

1. Crack

$$C = 0.0033\ t + 1.1967 \quad Eq.3$$

Based on equation 3, the value of slope is 0.0033 which indicates that if the slope value is small it means less change in cracking.

2. Settlement

$$S = 0.2\ t + 12.3 \quad Eq.4$$

On equation 4 shows the slope is 0.2 and this proves that the change that occurs in the settlement is greater than cracking since the value of the slope for settlement is 0.2. Moreover, based on equations 3 and 4, the two parameters are not directly proportional to each other with time. This is because, if these two parameters are directly proportional the value of the slope must be the same or the difference in value is close.

4.2 Analysis at location B

Location B only showed a change in the fifth week for settlement as shown in Figure 3. For the fifth reading, settlement is changed from 19.5 cm to 19.7 cm. The width for settlement in location B is the largest among the sizes for the other two locations. While for cracking, it does not show any change since the first reading until seventh week it began to show change. It was changed from 0.6 cm to 0.63 and still showed a change until last reading with a value of 0.66. The change that occurs at location B indicates the rational reason that the change in cracking will occur after the change in the settlement.

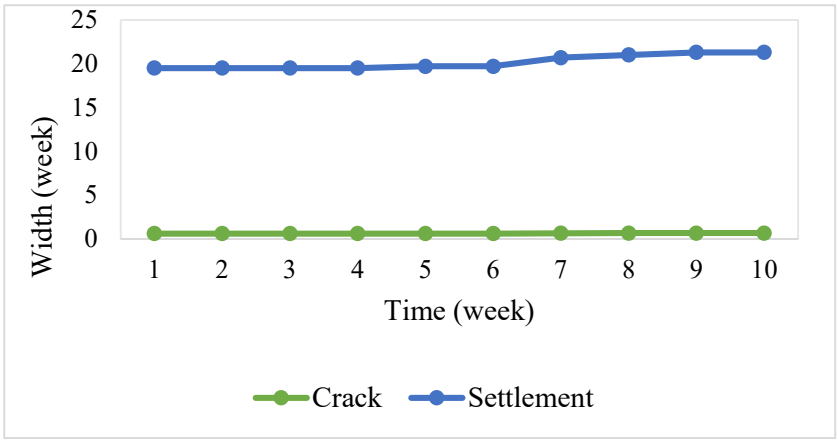


Figure 3: Graph of change in crack and settlement width versus time at Location B

1. Crack

$$C = 0.0067\ t + 0.5933 \qquad Eq.5$$

Based on equation 5, the value of slope is 0.0067 and implies that the slope value is too small and has the implication of less change in the cracked surface.

2. Settlement

$$S = 0.2\ t + 19.3 \qquad Eq.6$$

According to equation 6, the slope is 0.2, and this demonstrates that the change that happens in settlement is higher than the change that occurs in cracking, as shown by the value of the slope for settlement being 0.2. Furthermore, according to equations 5 and 6, the two parameters are not directly proportional to each other as time progresses, as previously stated. This is due to the fact that if these two parameters are exactly proportional, the value of the slope must be the same or the difference in value must be a little difference in value.

3.1 Analysis at location C

Location C showed the performance where there was a change in the seventh week for settlement parameter as in Figure 4. The seventh reading for settlement is 3.9 cm and continues to increase until the last reading with a maximum reading of 5.5 cm. While for the cracking reading is maintain 0.3 cm from the beginning of the investigation. The width reading for settlement in location C is the smallest among the other two locations. Although there is a significant change in the settlement, the cracking value still remains the same possibly because the change factor in the settlement is not as large as in locations A and B.

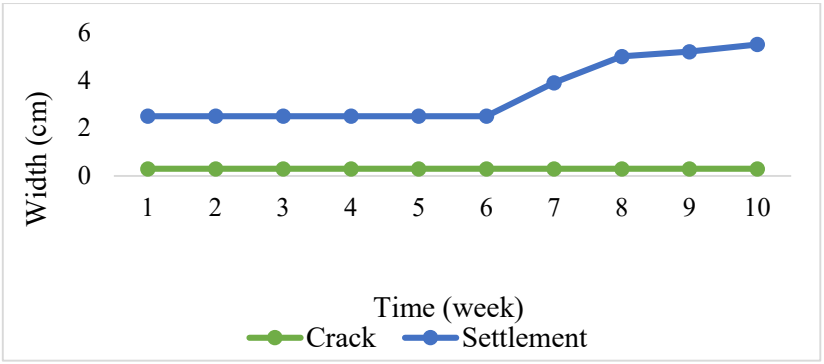


Figure 4: Graph of change in crack and settlement width versus time at Location C

1. Crack

$$C = 0.3 \qquad Eq.7$$

Based on equation 7, there was no slope on the cracking happen because the value maintained at 0.3 from the beginning of the investigation.

2. Settlement

$$S = 0.3333\ t + 2.1667 \qquad Eq.8$$

Equation 8 shows the slope is 0.3333 and this demonstrates that the change that happens in the settlement is enormous while in cracking there is no change in the slope. Additionally, based on equations 7 and 8, the two parameters are not directly proportional to each other with time. This is because, if these two parameters are exactly proportionate the value of the slope must be the same or the difference in value is near.

3.2 Analysis on crack and settlement width category

For the analysis for the crack and settlement category, the reading value in the last week which is the 10th week will be taken since the last week shows the change in the maximum crack and settlement. The results of previous studies made are the category of cracks based on crack width explained by [9] and category of settlement based on settlement width by [10]. In addition, for crack analysis, additions in terms of crack pattern analysis will also be analysed. The crack pattern is analysed based on the position and shape of the crack occurs for example whether vertical, horizontal or diagonal. While for the settlement analysis, the settlement pattern is not taken into account because the settlement that occurs does not show any pattern but only the line of decline of the building structure is visible. Based on Table 6 shows the analysis that has been made for cracking in the 10th week at each location. For all three locations, location A showed the width value for the largest crack while location C showed the lowest value and was in the slight category with a value of 3 mm (0.3 cm). Table 7 shows the analysis that has been made on the settlement that took place in all three locations. The category for the three locations is very severe. It means that the settlement that took place in all three locations is too bad because it is approaching a very large value. This is associated with the condition of the soil in the area which has peat soil type soil and is the cause of the maximum severity of the settlement that occurs.

Table 6: Analysis of crack based on crack classification

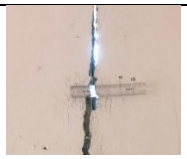
Location	Shape	Crack Width (mm)	Category
	Vertical crack	12.3	Moderate
	Horizontal crack	6.6	Moderate
	Diagonal crack	3	Slight

Table 7: Analysis of settlement based on settlement classification

Location	Settlement Width (mm)	Category
	143	Very severe
	213	Very severe
	55	Very severe

4. Conclusion

For the conclusion of the whole analysis that has been made, the condition of the building is still showing changes in terms of cracking and settlement. The settlement that applies is more changeable when compared to cracking. This can be attributed to cracking which will only occur when there is a change in settlement. The findings shown at locations A, B and C indicate that the settlement will make changes before cracking. It has proven the theory that cracking will only occur with a change in settlement. Other than that, the results of the study findings for the three locations do not show that the changes that occur are not directly proportional to each other. It means, based on the computational analysis that the slope for cracking and settlement show significant difference values from each other. If the two values of the slope are close, then it can be categorized that they are directly proportional to each other. But theoretically, the relationship between these two parameters has shown the result that cracking will only change if there is a change in the settlement. It can be concluded that the relationship between these two parameters is successful.

Acknowledgement

The authors would like to thank the Faculty of Civil Engineering and Built Environment, UniversitiTun Hussein Onn Malaysia for its support.

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