SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Appraisal of the Aetiology and Pathology of Soil Settlement-Related Building Defects and Failures

Md Azree Othuman Mydin[1,*], Nor Haslina Ja'afar[2], Norsafiah Norazman[1], Mohd Azian Zaidi[3], Mohd Nasrun Mohd Nawi[4]

[1] School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
[2] Department of Architecture and Built Environment, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[3] Building Surveying Program, College of Built Environment, Universiti Teknologi MARA, Malaysia
[4] School of Technology Management and Logistics, Universiti Utara Malaysia, Kedah, Sintok, 06010, Malaysia

ARTICLE INFO

Article history:
Received 3 February 2024
Received in revised form 15 June 2024
Accepted 15 July 2024
Available online 10 August 2024

Keywords:
Soil settlement; building defects; structural failures; sinkholes; rectification; foundation failure

ABSTRACT

A building defect refers to flaws or faults in the construction or design of a building, which may arise from errors in the design process or be caused by the impact of a natural disaster. These defects have the potential to reduce the lifespan of the building by compromising its structural integrity. The occurrence can be attributed to inadequate design, substandard workmanship, or non-compliance with the specified design standards. Deficiencies adversely affect the tenants' satisfaction and diminish the intrinsic worth and functionality of the structure. The deterioration of each component exacerbates when there are chemicals present in the environment that induce deterioration to the structure. Agents such as mechanical forces, electromagnetic radiation, thermal fluctuations, chemical reactions, biological processes, and natural catastrophes can induce alterations in building materials and components, ultimately impacting the structural integrity of the building. The aims of this study were to identify aetiology and pathology of soil settlement, analyze the elements that contribute to it, and examine the indicators of soil subsidence. The findings revealed that common types of soil settlements were immediate settlement, consolidation settlement, creep settlement, uniform settlement, differential settlement and curve settlement. The factors that led to such deficiencies were roots of trees, soil compositions and types, collapsing cavities, unstable foundations, drainage problems, insufficiently consolidated soil, effect of vibration and sinkholes. The most efficient method to maintain the structural integrity and long-term durability of your property is to promptly repair any foundation settlement issues. If the situation is not resolved, it will undoubtedly worsen, causing further damage.

1. Introduction

Buildings are architectural structures created and constructed to accommodate human residence, work, or recreational pursuits [1]. They exhibit variations in dimensions, form, and

* *Corresponding author.*
E-mail address: azree@usm.my

https://doi.org/10.37934/araset.50.1.286307

function, encompassing residential dwellings, commercial establishments, and industrial space facilities [2]. The process of constructing buildings entails the integration of architectural design, engineering principles, and material selection to produce spaces that are both practical and visually appealing for the people who use them [3]. Significantly, buildings can also be susceptible to diverse faults that might undermine their structural soundness, safety, and general efficiency [4]. These faults may result from inadequate construction procedures, design deficiencies, or insufficient maintenance, emphasizing the significance of frequent inspections and prompt repairs to guarantee the durability and safety of structures [5]. The importance of recognizing and rectifying construction faults [6]. An examination of prevalent categories of structural flaws and their possible origins can assist proprietors and supervisors in determining the order of importance for upkeep and repairs, so averting additional harm and guaranteeing the durability of the structure [7]. Periodic examinations conducted by certified experts can assist in promptly detecting flaws, enabling timely intervention to resolve difficulties before they grow into more severe complications.

For several decades, total quality management (TQM) has been one of the most essential components of exceptional performance for any organization, particularly in the building sector. Consequently, TQM practices are considered a critical administration perspective for the purpose of attaining corporate objectives and sustaining outstanding performance as far as building performance and defects management is concerned [8]. A building defect is a term used to describe imperfections or deficiencies in the construction or design of a structure [9]. These issues can result from errors made during the design phase or be triggered by natural disasters. These flaws have the potential to undermine the building's structural stability and potentially shorten its lifespan [10]. The cause of the occurrence might be ascribed to insufficient design, inferior craftsmanship, or failure to adhere to the prescribed design requirements. Deficiencies adversely affect the level of comfort enjoyed by the tenants and reduce the value and efficacy of the construction. The degradation of each constituent worsens in the presence of environmental pollutants that cause damage to the structure [11].

Various agents, including mechanical, electromagnetic, thermal, chemical, biological, and natural disasters, can cause alterations in building materials and components, which can have an effect on the overall structure of the building. Soil is a determinant of building damage. Soil with a weak structure has a substantial risk of collapsing or causing harm to structural components. This is primarily attributed to the overwhelming stress and the imposition of a substantial burden. Essentially, it will lead to the collapse of the primary load-bearing structure. It should be pointed out that liquefaction-induced ground failure is a major contributing factor to building failures resulting from major seismic events in loose, non-cohesive, water-saturated sandy conditions. Figure 1 illustrates the process of soil liquefaction prior to, during, and following an earthquake [12]. While Figure 2 illustrates the qualities of stable soil compared with those of liquefied soil.

The selection of foundation type and size can have an influence on the structural integrity, which may result in the occurrence of cracks and subsequent damage. Moreover, the condition of the ground might also be a contributing factor to the demise of a building. Foundation movement occurs because of substantial ground displacement [13]. Soil can experience either contraction, leading to settlement, or expansion, resulting in heave [14]. The compressed soil results in structural harm to the edifice, encompassing foundation fissures, internal wall impairment, and misalignment of entrances and apertures [15].

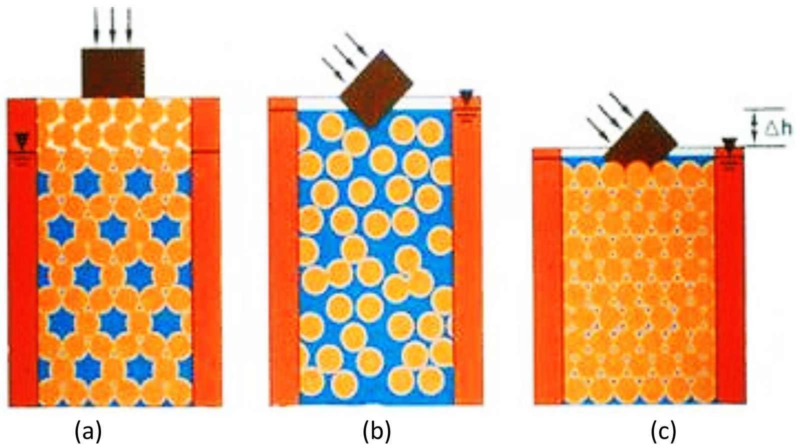


Fig. 1. Soil liquefaction mechanism [12] (a) Before earthquake (b) During earthquake (c) After earthquake

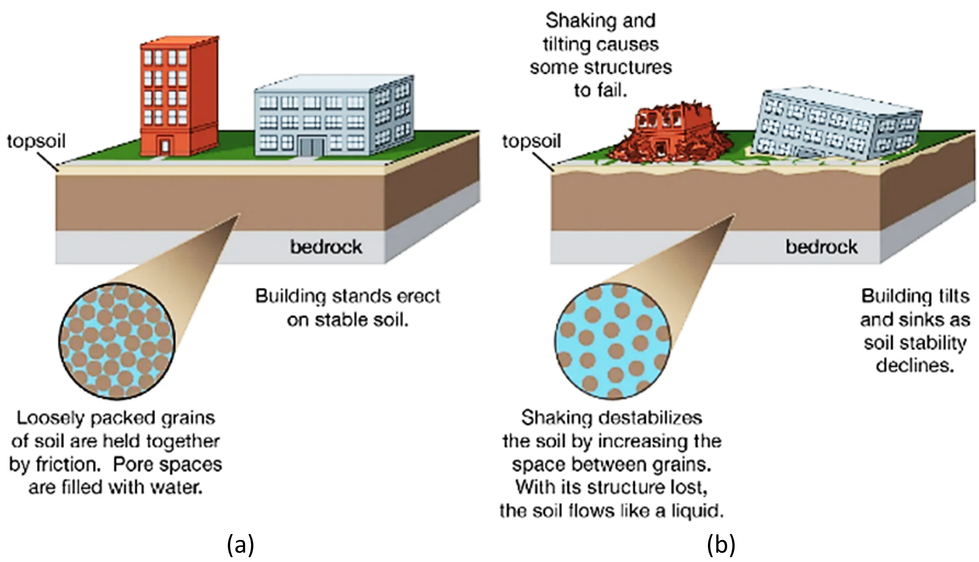


Fig. 2. The characteristics of stable soil in comparison to those of liquefied soil [13] (a) Stable soil (b) Liquefied soil

Table 1 summarized the criteria for settlement and differential settlement of structures. It is important to highlight that, while using the criteria listed in Table 1, we should consider any settlements that may have occurred before the development or placement of the item in question. If the issue pertains to structural finishes, then the evaluation should focus solely on settlements and differential settlements that are anticipated to take place after the finishes have been installed.

The presence of faults might be influenced by the soil composition of the site. The development and construction process can produce vibrations that may harm surrounding buildings, perhaps causing significant soil settling and disrupting the foundation of the affected structure [16]. The issue is predominantly attributed to land settlement, which has a significant impact on the ecological. To ensure the absence of any flaws, it is imperative to firmly fasten the apron parts to the ground beam [17]. Figure 3 shows the schematic illustration of angular distortion and deflection ratio for sagging and hogging profiles. Regular inspections are crucial for identifying and addressing building defects.

Table 1
Criteria for settlement and differential settlement of structures

Type of structure	Type of damage/concern	Criterion	Limiting value (s)
Framed buildings and reinforced load bearing walls	Structural damage	Angular distortion	1/150 - 1/250
	Cracking in walls and partitions	Angular distortion	1/500 (1/1000 - 1/1400) for end bays
	Visual appearance	Tilt	1/300
	Connection to services	Total settlement	50 - 70 mm (sands) 75 - 135 mm (clays)
Tall buildings	Operation of lifts and elevators	Tilt after lift installation	1/1200 (L/H=1)
Structures with unreinforced load bearing walls	Cracking by sagging	Deflection ratio	1/2500 (L/H=5)
		Deflection ratio	1/5000 (L/H=1)
	Cracking by hogging		1/2500 (L/H=5)
Bridges - general	Ride quality	Total settlement	100 mm
	Structural distress	Total settlement	63 mm
	Function	Horizontal movement	38 mm
Bridges - multiple span	Structural damage	Angular distortion	1/250
Bridges - single span	Structural damage	Angular distortion	1/200

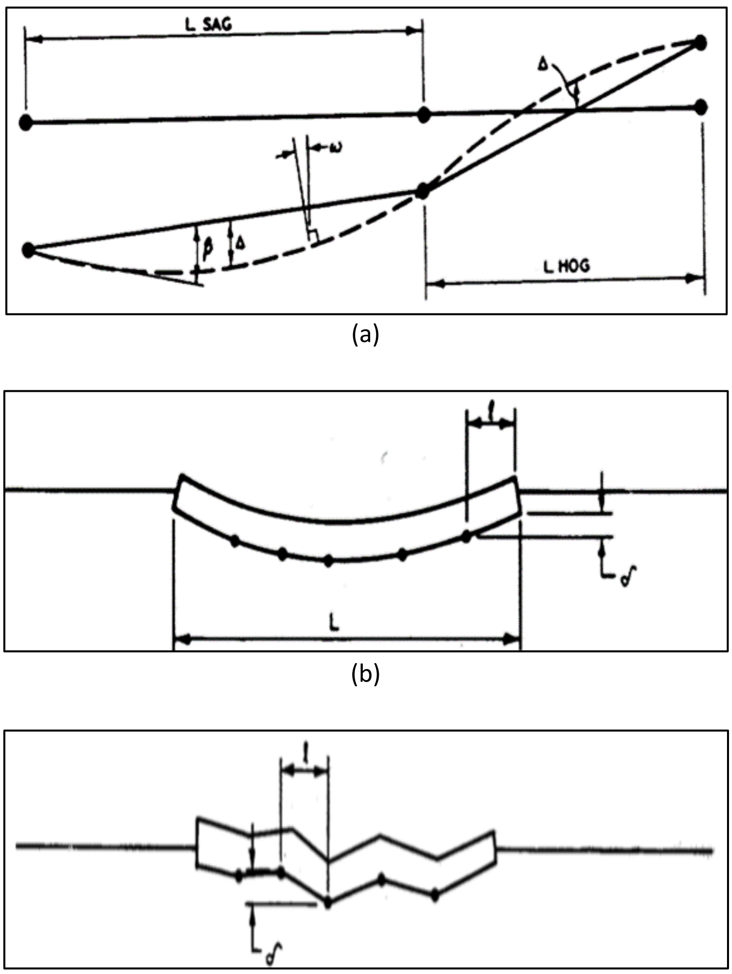


Fig. 3. Schematic representation of the deflection ratio and angular distortion for hogging and sagging profiles (a) Combination of sagging and hogging profile (b) Regular settlement (c) Irregular settlement

By conducting routine inspections, property owners have the ability to detect any concerns at an early stage, so preventing them from developing into significant problems that necessitate expensive repairs [18]. These inspections also ensure that the building remains safe and structurally sound, providing peace of mind to both occupants and owners. Hence this paper will emphasize the issue of soil settlement-related building defects and failures in the construction industry [19].

2. Methodology

There were 2 methods implemented to execute this investigation specifically case studies as well as literature survey.

2.1 Literature Survey

The literature survey will offer a thorough and all-encompassing summary of the most advanced and up-to-date knowledge in the aspect of soil settlement-related building defects and failures.

2.2 Case Studies

3. Differential Settlement

Naggar *et al.,* [2] state that differential settlement poses a significant risk to the structural integrity and capability of the development. The researcher stated that this settlement will result from various factors, such as fluctuations in moisture content, vibrations, and proximity to construction operations. This form of settlement typically exhibits a range of structural damage, ranging from cracks in the cladding to more severe damage that might compromise the structural integrity and durability of the building. Alternatively, differential settling refers to the situation where one portion of a building's foundation settles more or at a faster rate than another.

3.1 Case Study 1: Shop Lot

Figure 4 depicts an image of the building located in a commercial lot in Penang. Several studies have been conducted to determine the type of settlement based on careful examination of the defect. Empirical evidence indicates that the soil settlement seen is of the differential settlement type. Diverse solutions are those that exhibit structural fissures, lack of homogeneity, and protrusions where no fissures are evident. The fractures are characterized by their significant size and semi-horizontal orientation. They are typically seen in areas experiencing the greatest pressure and are commonly attributed to base shifting. Upon performing a site survey and visual examination, it has been determined that this store lot consists of two floors and is intended for commercial and business use. The likelihood of a crack occurring due to construction activity is minimal as there is no construction activity in the vicinity [20].

Figure 5 depicts a closer look at the cracks that form on the structure. The settlement of a building is influenced by various factors, including the type, material, and loadings of the building, the usability requirements, the integrity of the superstructure, the location of the structure in relation to other buildings, the rate at which settlement is occurring, and the distribution of settlement [2].

After making observations, the researcher makes measurements of the structure and any defects that occur (Figure 6). The width of the structure is 1.5 m. For the crack on the structure, the researcher estimates the crack is 15mm wide. This size of crack is required to open. Repointing the external brickwork might be needed, or in some cases, it might need to be replaced. The length of the crack that occurs is 1.2m from the actual width of the structure.

Fig. 4. Differential settlement at shop lot

Fig. 5. Crack on shop lot structure

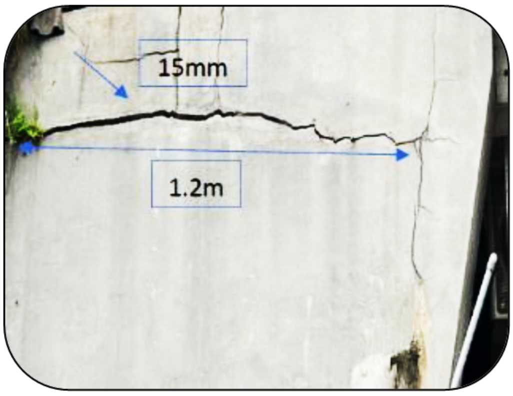


Fig. 6. Detail of defects

3.2 Case Study 2: Dormitory Residential Building

Figure 7 depicts a residential building specifically designed for dormitory purposes. The structure consists of four levels. This structure exerts a significant load and applies substantial pressure, resulting in stress on the earth. This investigation was carried out by visual examination in order to discover defects caused by soil subsidence. This problem can be identified as a form of differential settling. The building is situated in a gently undulating terrain and is near a lake. Due to its location within the school and in a student living neighborhood, no construction operations take place in this building.

Fig. 7. Dormitory residential building

Additionally, the building is situated far away from the major road with public transportation. Therefore, it is possible to prevent the occurrence of vibration caused by external activity. Figure 8 demonstrates the concrete fractures that occur due to soil settlement.

Observation and study reveal that natural factors, such as the earth's steep shape, contribute to this phenomenon. Inadequate drainage systems or unsuitable geological conditions can weaken the embankment's strength and stability. Furthermore, due to the seasonal climate, soil moisture in a liquid or gaseous state moves from hot to cold temperatures and accumulates, which destroys the embankment [21]. The presence of horizontal fissures in the building is attributed to soil movement produced by settlement of the ground. The diagram depicts apron fractures in the building's foundation caused by ground subsidence and the slope adjacent to the structure. The crack measures more than 2.0 m in length (Figure 9). The occurrence of concrete cracking in the curved section is attributed to ground displacement in the surrounding area. The crack has a width of 10 mm (Figure 10).

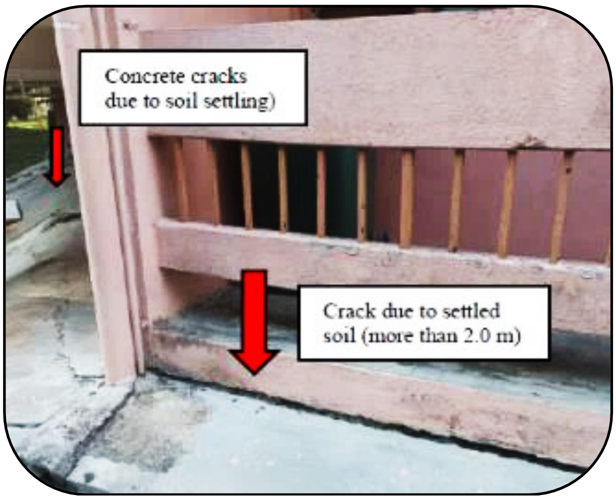


Fig. 8. Concrete cracks due to soil settelement

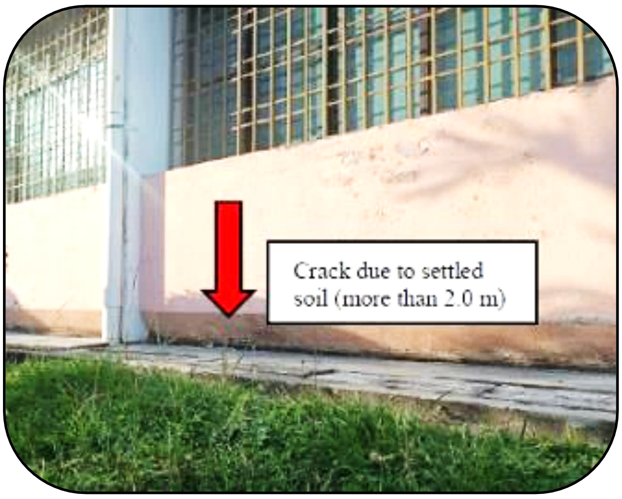


Fig. 9. Visible cracks at wall due to soil settelement

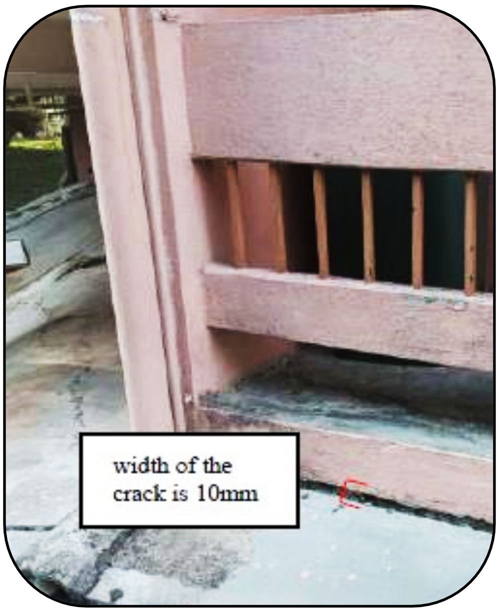


Fig. 10. Width of crack of approximately 10 mm

4. Uniform Settlement

When foundation subsidence occurs across the structure at the same rate and direction, it is referred to as uniform settlement [22]. When the weight of the building is distributed evenly and the soil conditions are constant throughout the foundation, this solution occurs. Although most damage from homogeneous solutions is not severe, when it does occur, it can result in leaks, cracked concrete patios, porches and sidewalks, and drainage problems. Uniform placement basically lowers the structure in place, whether straight or inclined. the structure (or road or railway) will fit the same amount along its length and no damage will occur, for example the least type of settlement [23].

4.1 Case Study: Flat

Figure 11 depicts an image of the building and structure of a flat building. This structure comprises a total of five levels, which encompass a designated area for parking vehicles. Upon examining the defects at the site, it is evident that the settling of the soil is consistent. This indicates that the ground subsidence is occurring evenly across the entire structure, without causing any cracks. Soil settlement within a building lead to ground subsidence because of underground displacement. The closeness of the building to the ditch region results in flooding during heavy rainfall. Strong currents during flooding can lead to soil erosion in the neighbourhood of buildings. This process of erosion can lead to the loosening or complete disappearance of the soil beneath the building, resulting in soil subsidence.

Fig. 11. External appearance of the flat

Figure 12 unambiguously illustrates the sinking of the ground beneath the building. The subsidence resulted from recurrent subterranean displacements caused by the extraction of water and mineral resources. Natural phenomena, such as soil compaction and the introduction of water to fine wind-deposited soil, can contribute to land subsidence. Ground sinking within a building can cause significant structural damage and jeopardize the overall stability of the structure. Consequently, this can lead to fissures in the walls, uneven flooring, and in extreme situations, complete structural failure. Promptly addressing ground subsidence issues is vital to maintain the safety and lifespan of the building. It should be pointed out that proper engineering methods can avoid or reduce ground sinking within the building. These methods may involve utilizing deep foundations to ensure sufficient support, performing routine inspections to detect any indications of subsidence, and employing soil stabilization procedures to enhance the strength and stability of the soil. In addition, the installation of monitoring systems can be implemented to identify any alterations in ground movement and promptly initiate appropriate measures to mitigate additional subsidence. During the observation, the researcher takes precise measurements of the structural characteristics of the building's foundation in relation to the ground. The researcher approximated the vertical distance from the foundation to the ground as 20 cm as depicted in Figure 12. Rectify obstructed air ducts or install a drainage system if further supplementation is required.

Fig. 12. Ground subsidence within the building

5. Categories of Soil Settlement

5.1 Immediate Settlement

Immediate Settlement pertains to the quick reaction of the soil when a contractor builds a base and a structure on its top. Soil typically undergoes compaction, irrespective of its type, but this settling is typically more pronounced in clay soils. Immediate settlement is a typical and anticipated occurrence. However, if the contractor ensures sufficient compaction of the soil in advance, the settlement ought to be modest.

5.2 Consolidation Settlement

Consolidation settlement is the phenomenon when soil particles are compacted and reorganized, leading to a reduction in size and a rise in concentration. Consolidation settlement arises when the water in the soil beneath the foundation is squeezed out, leading to further compaction. Consolidation settling commences promptly upon the pouring of the foundation and persists for a period of time even after the construction of the entire structure. With adequate ground preparation, the amount of consolidation settlement is supposed to be relatively small [24].

5.3 Creep Settlement

Creep settlement is the term used to describe the gradual horizontal movement of the foundation that happens once consolidation settlement has ceased to be a concern. The soil's properties and the weight carried by the structure above both affect creep settling. It is the primary factor responsible for the development of hairline cracks in foundations [25].

5.4 Uniform Settlement

Uniform settlement refers to the even and consistent sinking or movement of a structure or land over a period. Uniform settlement refers to any of the types of settlement that occur evenly across the entire foundation [26]. Uniform settlement seldom causes issues with structure as the whole foundation continues to receive consistent and level backing from beneath. Uniform settlement commonly arises beneath foundations and is typically unrelated to inadequate soil compaction or any soil problem.

5.5 Differential Settlement

Differential settlement is the term used to describe the uneven vertical displacement or settling of several components of a building or foundation. Differential settlement refers to the occurrence when a specific section of the foundation, typically a side or corner, experiences a loss of support from beneath and subsequently sinks into the earth, resulting in the formation of cracks that separate it from the rest of the foundation [26]. Differential settling sometimes leads to structural problems as it results in an uneven distribution of support beneath the structure. Differential settlement occurs when certain areas of a property experience uneven sinking due to issues such as inadequate drainage, decayed tree roots, or soil erosion, in contrast to uniform settlement.

5.6 Curve Settlement

Curve settlement refers to the process of resolving financial transactions related to the trading of interest rate derivatives on the Curve platform. Curve settlement, also known as differential settlement, refers to the uneven settling of a structure at varying speeds. It is possible to observe that one side of the foundation remains stable, while the middle section sinks at a more rapid pace, and the other side sinks at the most accelerated rate [27]. Curve settlement typically leads to structural damage and serves as an indication of an underlying issue, such as inadequate drainage or sinkholes.

6. Causes of Soil Settlement

6.1 Roots of Trees

Vegetation such as trees, plants, and bushes can have a negative impact on the stability and integrity of foundation as shown in Figure 13. Additionally, the presence of tree roots can result in structural damage to structures, including the formation of cracks as demonstrated in Figure 14. Large trees, in particular, are responsible for depleting moisture from the underlying soil beneath your foundation if they are planted near it. Plants require water for their survival, and their roots instinctively search for moisture. Shrinkable cohesive soils can cause excessive water withdrawal from the foundation by plants. This leads to soil shrinkage and foundation subsidence. It is predictable that various species have varying capacities for water absorption. Typically, when determining how far to plant trees from a property, it is advisable to consider both the length of the roots and the height of the tree, as they are usually similar [28].

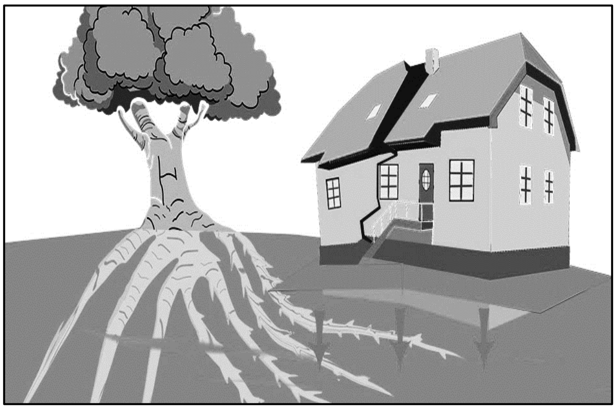


Fig. 13. Trees can negatively affect the stability and integrity of the foundation

Fig. 14. Root of trees can lead to cracks on buildings

6.2 Soil Compositions and Types

The soil composition plays a crucial role in comprehending subsidence. Cohesive soils are classified as soils that have properties such as clay and silt. This indicates that when exposed to moisture and dryness, they possess the ability to expand and contract. Structures constructed on such surfaces can experience fluctuations on a daily, monthly, and seasonal basis. Soils such as sand and gravel are classified as non-cohesive soils. This soil type does not experience any shrinkage or swelling [29]. Undesirably, they are not immune to subsidence. They consist of little particles that can gradually dissolve and be carried away by water. In addition, organic soils have the inherent ability to breakdown spontaneously as a result of their composition. Oxygen inherently causes particles to contract, leading to a reduced ability to withstand loads. Inadequate soil compositions and types can result in significant settlement, as illustrated in Figure 15. Uniform, tipping, and differential settlement are potential occurrences.

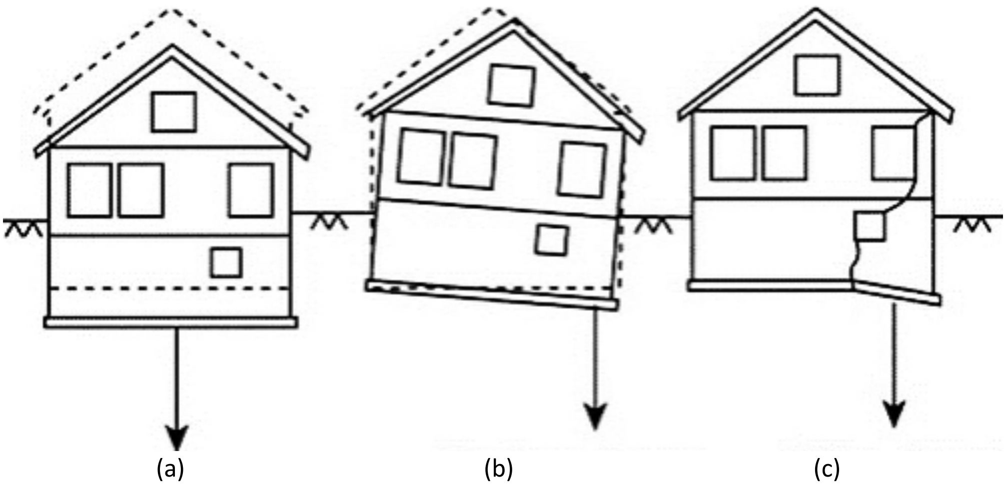


Fig. 15. Poor soil conditions settlements (a) uniform (b) Tipping (c) Differential

6.3 Collapsing Cavities

Occasionally, certain regions of the ground may experience a collapse. Severe reductions in groundwater levels frequently cause this specific form of localized collapse. Collapses are infrequent occurrences as they are typically linked to highly particular rock formations, such as salt or gypsum. These rock types exhibit higher solubility. Although approximately 35-40% of the underlying rocks are present, most of these rocks are deeply buried and provide less of a hazard for most regions. Cavity collapse entails the generation of significant swirling and a notable augmentation in volatility and the boundaries layer thicknesses as demonstrated in Figure 16. When vapor canals collapse, they create huge swirling currents, and at the same time, swirling patterns emerge in the area where the cavity closes, and the flowing liquid circulates.

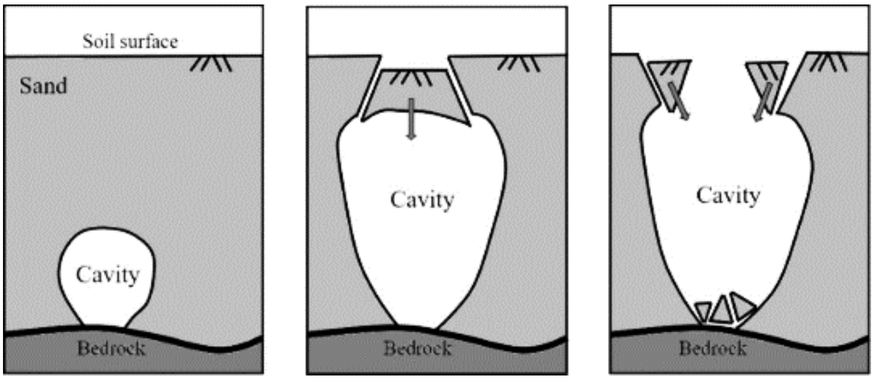


Fig. 16. Cavity collapse [30]

6.4 Unstable Foundations

Occasionally, structures may undergo settlement when the soil beneath the foundation decreases in volume. This phenomenon can be attributed to the cumulative load exerted on the building over time and inadequate soil preparation as indicated in Figure 17. Gradual foundation settlement is a natural occurrence that commonly happens over a period. The weight of the structure itself can cause soil compaction over time, leading to increased soil density [30]. The settlement amount often fluctuates depending on the soil composition beneath your residence. Soils with high salinity, low cohesion, gypsum content, silt, and clay can contribute to increased settlement. On the other hand, bedrock will experience significantly less settling.

Fig. 17. Inadequate soil preparation may lead to settlement

6.5 Drainage Problems

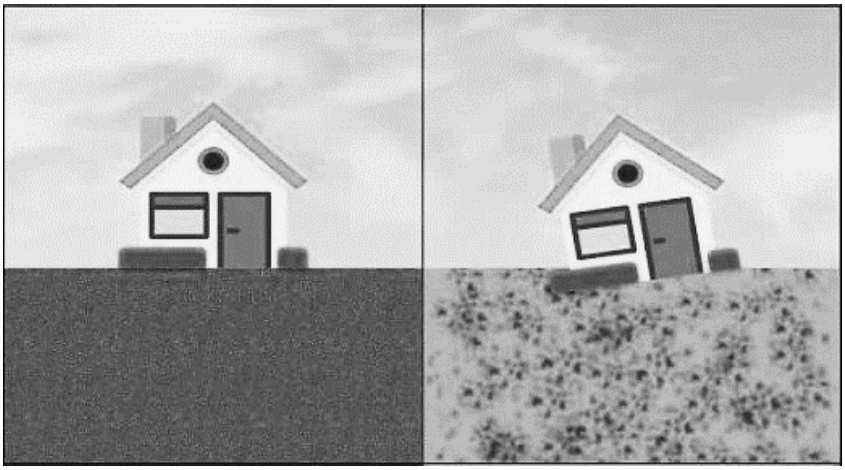
Subsidence problems sometimes arise due to leakage originating from pipes or sewers. Water can infiltrate and impact the foundations in one of two manners. Water can induce soil erosion, leading to a decrease in the soil's structural integrity. Consequently, the foundation begins to subside.

Alternatively, water can erode non-cohesive soil particles and cause the amount of soil to decrease, resulting in the sinking of bases [31]. Additionally, the poor drainage and road infrastructure may lead to serious ground settlement as shown in Figure 18.

Fig. 18. Improper drainage and roadways may result in ground settlement

6.6 Insufficiently Consolidated Soil

Lot preparation is a significant aspect of the home building process when constructing a new foundation. Good soil compaction (Figure 19(a)) is an essential aspect of land preparation, whether the builder is excavating to create a basement or crawl space or constructing a slab foundation with footings directly on the soil. Inadequate soil compaction (Figure 19(b)) by the builder might result in insufficient support for the foundation, hence causing settling problems.



(a) (b)

Fig. 19. (a) Good soil compaction (b) Poor soil compaction

6.7 Effect of Vibration

Seismic activity can induce soil vibration, leading to abrupt soil displacement around the foundation and potentially causing areas of the home to lack stability. Over time, the excessive load of the structure will result in the gradual subsidence of your foundation, causing it to reestablish contact with the underlying earth [32].

6.8 Sinkholes

If there are sinkholes beneath the ground (Figure 20), the support for the house's foundations can also be compromised. Sinkholes commonly form in regions characterized by a karst topography, where the underlying rock is mainly composed of limestone or dolomite. These minerals undergo degradation when exposed to groundwater, leading to the formation of channels or voids beneath houses. These cavities might collapse and result in unstable areas beneath the foundation. Over time, the foundation will gradually sink into the ground that has caved in [33].

Fig. 20. Sinkholes may lead to settlement

7. Indications of Soil Subsidence

7.1 Hairline Cracks

Hairline cracks (Figure 21) are the predominant indication of soil settlement, and they will manifest on the concrete flooring and/or wall structures regardless of whether the house has experienced typical, mild settlement or significant sinking problems. Hairline cracks are typically narrow, measuring roughly 0.125 inch in width, and exhibit equal alignment on the two sides [34-37]. Typically, one may include this into the usual base care routine to avoid the infiltration of dampness and eliminate any future concerns. These formations normally develop within the initial year or so following installation and do not increase in width or length as time passes.

Fig. 21. Hairline cracks

7.2 Foundation Cracks that are Not Uniform

If fractures in the base of the ground or sidewalls expand to a width of 0.125 inch or greater [38-40], or if one of the sides elevates higher than the other, it is probable that you are experiencing a more significant settlements issue that is not of an unforeseen nature as displayed in Figure 22. Because of their great heat retention concentration, they are the focus of attention and undergo the isothermal process throughout the phase of change [41]. To address this matter and the accompanying complications, it is advisable to seek the assistance of a foundation repair expert who can implement a lasting resolution, such as basement refurbishment, supporting, or another type of stability or waterproofing.

Fig. 22. Foundation cracks

7.3 Stair-Steps Fractures

Stair-step fractures on the wall (Figure 23) typically occur while a section of the wall experiences a loss of rigidity from beneath, leading to settling and sinking into the soil. Cracks such as these are frequently a sign of structural degradation and necessitate a comprehensive repair method known as underpinning [42].

Fig. 23. Stair-steps fractures

7.4 Sloping and Irregular Floors

If the house's foundation experiences settlement, it can cause the flooring in the living room to slide inward or become unequal or undulating due to a loss of stability [43-45]. Figure 24 illustrates the sloping floor, whereas One may observe pronounced displacement in your everyday activities, or one could be using a leveling instrument to ascertain irregularity that is often imperceptible [46-48]. Severe structural deteriorations may also result from exposure to heat and elevated temperatures [49, 50]. The behavior of different types of concrete will vary as a result of their distinct engineering features.

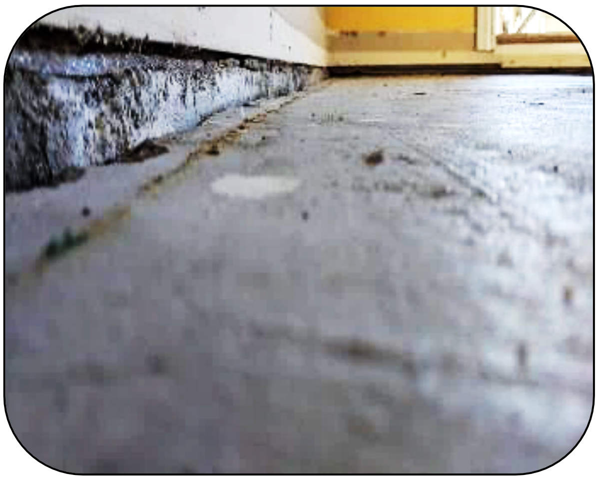


Fig. 24. Sloping floor

8. Soil Settlement and Consolidation Prevention Measures

8.1 Execute Proper Geotechnical Investigation

Prior to the design and construction of any structure, it is crucial to carry out a comprehensive soil study or geotechnical investigation as an initial and vital measure to avoid soil settlement and serious consolidation [51]. Geotechnical investigation entails the collection and examination of soil samples obtained from the site, followed by the assessment of their physical, chemical, and mechanical characteristics [52]. Geotechnical investigation is a crucial component of the construction process that aims to gather data on the physical properties of the soil and rock in the vicinity of a site. Subsurface exploration involves sampling and testing the layers of soil beneath the ground to determine their properties, which will have an impact on the construction project. This can assist in determining the soil's characteristics such as category, stacking, resilience, elasticity, permeation, and moisture content. It can also help evaluate the soil's appropriateness and load capacity for the desired construction [53]. Soil analysis can also assist in identifying possible issues, such as weak layers, organic matter, pollutants, or variations in groundwater, allowing for appropriate planning. These analyses serve as the foundation for the process of planning, designing, and constructing the structures. The functionality and efficiency of the structure rely on the precision and sufficiency of these studies.

The accuracy of the information in the geotechnical report significantly impacts the design, construction, project cost, and safety. Regrettably, a significant number of individuals fail to see the need to conduct a thorough geotechnical assessment during the initial stage of a project [54]. Inadequate understanding of soil conditions is a major contributing factor to foundation failure. There have been instances where attempts to reduce expenses on on-site inspections have led to disastrous consequences. Designing structures based on unreliable or insufficient data can result in enduring issues. It can also lead to fatalities and property damage, put residents at risk, harm nearby buildings, and generally make it unusable for its intended purpose. Soil studies yield the engineer valuable information on the underground conditions at the location of an engineering project. The software enables the engineer to calculate a secure and cost-effective design for a project and communicate to the construction engineer the materials and conditions they will experience on-site.

8.2 Soil Enhancement

Occasionally, the state of the soil at the site may be unsuitable or insufficient for the construction, necessitating improvements or modifications to avert soil settlement and consolidation. Soil enhancement is the deliberate effort to improve the soil's durability, rigidity, irrigation, or stabilization through the application of physical, chemical, or biological techniques. Typical soil enhancement procedures include compaction, grouting, drainage, reinforcing, stabilization, and preloading. Compaction is the act of decreasing the empty spaces in the soil by using mechanical force, such as vibration or rolling. Grouting is the act of injecting a fluid substance, such as cement or resin, into the soil to fill any empty spaces or fractures and enhance its cohesion [55]. Drainage refers to the procedure of eliminating surplus water from the soil in order to decrease its compressibility and consolidation. Reinforcement is the addition of external components, such as geotextiles or steel bars, to the soil in order to enhance its ability to withstand tension and resist deformation. Stabilization involves the incorporation of additions, such as lime or fly ash, into the soil to enhance its chemical characteristics and mitigate its tendency to shrink or swell. Preloading refers to the practice of subjecting the soil to a temporary load in order to promote settlement and consolidation before to erecting a structure. The load is subsequently removed to prevent any additional settlement and consolidation.

8.3 Selection of Foundation

To avoid soil settlement and major consolidation, it is crucial to choose the suitable foundations type and size for the construction. The choice of foundation is determined by various factors, including the nature and intensity of the loads, the characteristics of the soil, the amount of groundwater, the design specifications, and the available funds. In general, there are two primary categories of foundations: shallow and deep. Shallow foundations are positioned near the surface of the earth, so they directly transmit the stresses to the soil [56]. Deep foundations are installed at greater depths in the ground and are designed to transmit the loads to a more robust or stable stratum. The selection of foundation type can impact the magnitude and dispersion of settling and consolidation. Shallow foundations are susceptible to differential settlement, which refers to the unequal settling of different sections of a structure. In contrast, deep foundations can mitigate or eradicate this issue by achieving a consistent layer.

8.4 Inspection and Upkeep

Another crucial method for avoiding soil settlement and major consolidation is to constantly track and diligently maintain both the structure and the soil throughout and after the building process. Inspection and upkeep encompass the activities of assessing and observing the behavior and performance of the structure and the soil. It also involves recognizing and rectifying any indications of settlement and consolidation. Inspection and upkeep can be conducted using a range of devices, including surveying tools, settlement plates, inclinometers, piezometers, and strain gauges. These devices are used to measure and record changes in elevation, slope, pore water pressure, and strain in both the structure itself and the soil. Monitoring and maintenance can be conducted by the examination and repair of any fractures, leaks, or impairments in the structure and soil [57]. Additionally, mitigation measures such as waterproofing, drainage, or strengthening can be implemented to avert further degradation.

8.5 Structural Weight

Minimize the weight of the building. This will not only reduce the pressure exerted on the foundation, but also prevent soil displacement. Reducing weight also decreases the lateral seismic loads and so reduces eccentricity [58].

8.6 Consistent and Equal Distribution of Load Intensity

Strive for consistent distribution of both the weight of the building and any additional loads across the entire area and foundation of the construction. This will decrease the occurrence of differential settlement [59].

8.7 Strategic Planning

The functional layout and configuration of the horizontal plate of the building also contribute to its overall design. Eliminate sharp acute corners in the layout and position high-intensity activities at the lower level [60]. Attain balance in the design process to prevent the occurrence of arbitrary empty spaces in the slab plates.

8.8 Implement Construction Protocols

During the construction process, it is important to preserve the original structure. The foundation construction should involve excavating the foundation and ensuring that the new foundation has a greater bearing capacity than the original natural foundation. The construction sequence should be carefully planned, with simultaneous construction of the internal and external walls, and no unfinished areas should be left. The masonry construction of neighboring sections must not exhibit a significant disparity in height, with a maximum limit of three levels [61]. When there is an imbalance in the load distribution across different sections of the building, it is important to organize the construction process in a rational manner. Construct the weighty and elevated components initially, followed by the lightweight and lower components; commence with the primary section and subsequently assemble the subordinate sections. By capitalizing on the discrepancy in construction time, it is possible to proactively modify a portion of the settlement to minimize the disparity in settlement [62].

8.9 Safeguard Critical Components

The use of preventative measures to prolong the onset of fractures mostly involves safeguarding critical components. Based on the previous discussion, in addition to the requirements, to mitigate the negative effects of uneven settlement, it is crucial to have an adequate number of ring beams, core columns, and core columns. Simultaneously, enhance the stiffness of the foundation beams and closely monitor the subsidence of the home. Typically, the settlement is limited to 200mm. Create a robust foundation design to minimize differential settlement. To address the issue of soft soil foundation, it is recommended to either treat the foundation or use pile foundation. Additionally, it is advisable to utilize proper concrete to fill the window sill wall of the outer wall of the bottom layer and the masonry hole of the lower wall.

To address the issue of an uneven foundation, the bottom window sill wall is reinforced with steel spot welded mesh and window sill beams at the second and fourth ash seams. This reinforcement helps prevent the formation of vertical cracks [63]. By analyzing the resistance to ground deformation of unprotected dwellings, it is evident that window holes play a crucial role as a protection object. Therefore, it is imperative to implement protective measures. The window opening represents a significant alteration in the stiffness of the masonry structure, making it a susceptible place for experiencing elevated levels of stress [64]. The crucial factor in safeguarding the entire masonry house is to postpone the occurrence of cracks around the window opening.

9. Conclusions

Soil settlement and consolidation happen when the ground undergoes movement, causing the structure to slip downwards. This frequently occurs despite the building's long-standing construction. Nevertheless, the issue of soil settlement poses a significant threat, particularly to buildings, and can potentially jeopardize the safety of occupants. While little cracks may be considered commonplace in buildings, the occurrence of large cracks in walls, windows, and other vital structures can pose significant issues. Every construction project must thoroughly analyze and consider every aspect of the site to guarantee that the building is appropriate and well-suited for the location. Furthermore, it is crucial to prioritize the focus on building design and drainage to mitigate significant hazards. It is crucial to utilize construction materials of high quality that are appropriate for both the specific project and site. Natural phenomena like soil settling are uncontrollable, necessitating construction practices that adhere to proper norms. Promptly addressing a foundation that is settling is the most effective approach to preserving the structural soundness of your home and ensuring its long-term durability. Failing to resolve the issue will most certainly exacerbate it, resulting in additional harm.

Acknowledgement

The authors express their gratitude for the financial support received from the Ministry of Higher Education, Malaysia, which was rendered through the Fundamental Research Grant Scheme (FRGS); Ref. No. FRGS/1/2022/TK01/USM/02/3.

References

[1] Manaf, Nor Syahidah Che, and Tuan Norhayati Tuan Chik. "Relationship between cracks and structure settlement on residential building at Ayer Hitam." *Recent Trends in Civil Engineering and Built Environment* 4, no. 2 (2023): 46-56.

[2] El Naggar, A., M. A. Youssef, H. El Naggar, and A. M. El Ansary. "Differential settlement effect on RC framed structures." In *Canadian Society of Civil Engineering Annual Conference*, p. 683-694. Singapore: Springer Nature Singapore, 2021. https://doi.org/10.1007/978-981-19-1004-3_56

[3] Nawi, Mohd, Angela Lee, Md Azree Othman Mydin, Wan Nadzri Osman, and Mohamad Khadafi Rofie. "Supply chain management (SCM): disintegration team factors in Malaysian industrialised building system (IBS) construction projects." *International Journal of Supply Chain Management* 7, no. 1 (2018).

[4] Mydin, MA Othuman, A. F. Phius, N. Md Sani, and Norngainy Mohd Tawil. "Potential of green construction in Malaysia: industrialised building system (IBS) vs traditional construction method." In *E3S Web of Conferences* 3, p. 01009. EDP Sciences, 2014. https://doi.org/10.1051/e3sconf/20140301009

[5] Conyers, Lawrence B. "Ground-penetrating radar." In *Encyclopedia of Geoarchaeology*, pp. 1-12. Cham: Springer International Publishing, 2023. https://doi.org/10.1007/978-3-030-44600-0_167-1
[6] Mydin, MA Othuman, N. Md Sani, NA Agus Salim, and N. Mohamed Alias. "Assessment of influential causes of construction project delay in Malaysian private housing from developer's viewpoint." In *E3S Web of Conferences*, vol. 3, p. 01027. EDP Sciences, 2014. https://doi.org/10.1051/e3sconf/20140301027
[7] Nensok, Mohammed Hassan, Md Azree Othuman Mydin, and Hanizam Awang. "Investigation of thermal, mechanical and transport properties of ultra lightweight foamed concrete (ULFC) strengthened with alkali treated banana fibre." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 86, no. 1 (2021): 123-139.
[8] Hasim, Nur Aiman Hanis, Suriati Akmal, Sayed Kushairi Sayed Nordin, Ruzy Haryati Hambali, Mohd Fauzi Mamat, Abdulla Thamer Jumma Aldharif Alshamsi, and Supawi Pawenang. "Modelling total quality management in the Malaysian composite manufacturing industry." *Malaysian Journal on Composites Science and Manufacturing* 7, no. 1 (2022): 11-22. https://doi.org/10.37934/mjcsm.7.1.1122
[9] Strigin, Boris, and V. Fedorov. "Foundation reconstruction technology." In *IOP Conference Series: Materials Science and Engineering*, vol. 365, no. 6, p. 062043. IOP Publishing, 2018. https://doi.org/10.1088/1757-899X/365/6/062043
[10] Mydin, MA Othuman, N. Md Sani, and A. F. Phius. "Investigation of industrialised building system performance in comparison to conventional construction method." In *MATEC Web of Conferences*, vol. 10, p. 04001. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141004001
[11] Mydin, MA Othuman, J. C. Khor, and N. Md Sani. "Approaches to construction waste management in Malaysia." In *MATEC Web of Conferences*, vol. 17, p. 01014. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141701014
[12] Bansal, B. K., and S. K. Nath. "Seismic microzonation handbook, Geoscience divisions." *Ministry of Earth Sciences, Government of India* (2011).
[13] Rozli, Mohd Ikmal Fazlan, Juhaizad Ahmad, Mohd Asha'Ari Masrom, Syahrul Fithri Senin, and Abdul Samad Abdul Rahman. "The effect of fly ash and bottom ash pile in problematic soil due to liquefaction." In *Proceedings of the Second International Conference on the Future of ASEAN (ICoFA) 2017–Volume 2: Science and Technology*, pp. 807-815. Springer Singapore, 2018. https://doi.org/10.1007/978-981-10-8471-3_79
[14] Esruq-Labin, A. M. J., Adi Irfan Che-Ani, N. M. Tawil, Mohd Nasrun Mohd Nawi, and Othuman Mydin. "Criteria for affordable housing performance measurement: A review." In *E3S Web of Conferences* 3. EDP Sciences, 2014. http://dx.doi.org/10.1051/e3sconf/20140301003
[15] Tan, S. W., MA Othuman Mydin, N. Md Sani, and M. Z. Sulieman. "Investigation into common decay of educational buildings in Malaysia." In *MATEC Web Of Conferences*, vol. 10, p. 05001. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141005001
[16] Mydin, MA Othuman, N. A. Othman, and N. Md Sani. "A prospective study on building quality: Relationship between workmanship quality and common building defects of low-cost construction projects." In *MATEC Web of Conferences*, vol. 17, p. 01001. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141701001
[17] Jimenez, Rafael, and Nicholas Sitar. "The importance of distribution types on finite element analyses of foundation settlement." *Computers and Geotechnics* 36, no. 3 (2009): 474-483. https://doi.org/10.1016/j.compgeo.2008.05.003
[18] Al-Moadhen, M. M., M. M. Abdullah, and M. S. Oleiwi. "On the use of constrained modulus for soil settlement analysis." *Magazine of Civil Engineering* 17 no. 3 (2024): 12706. http://doi.org/10.34910/MCE.127.6
[19] Mydin, MA Othuman, NA Agus Salim, S. W. Tan, N. M. Tawil, and N. Md Ulang. "Assessment of significant causes to school building defects." In *E3S Web of Conferences* 3, p. 01002. EDP Sciences, 2014. https://doi.org/10.1051/e3sconf/20140301002
[20] Jing, Ting Siew, Md Azree Othuman Mydin, and Nangkula Utaberta. "Appraisal of moisture problem of inheritance building envelope assemblies via visible and infrared thermography methods." *Jurnal Teknologi* 75, no. 5 (2015). https://doi.org/10.11113/jt.v75.4951
[21] Mahli, M., A. I. Che-Ani, H. Yahaya, N. M. Tawil, and MA Othuman Mydin. "School building defect pattern." In *MATEC Web of Conferences*, 15, p. 01007. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141501007
[22] Grant, Rebecca, John T. Christian, and Erik H. Vanmarcke. "Differential settlement of buildings." *Journal of the Geotechnical Engineering Division* 100, no. 9 (1974): 973-991. https://doi.org/10.1061/AJGEB6.0000101
23] Chauhan, Dhananjay, Tanveer Khan, Devansh Tripathi, Devesh Mishra, and Anuj Singh. *Causes, Prevention & Repair of Cracks*. Babu Banarasi Das University, 2020.
[24] Mydin, Md Azree Othuman, Mohd Nasrun Mohd Nawi, and Muhammad Arkam Che Munaaim. "Assessment of waterproofing failures in concrete buildings and structures." *MCRJ Spec* 2 (2017): 166-179

[25] Mydin, Md Azree Othuman. "Building defects and failure of malay timber house: causes and symptoms." *Jurnal Teknologi* 78, no. 5 (2016). https://doi.org/10.11113/jt.v78.8350
[26] Sulieman, M. Z., N. N. Omar, and MA Othuman Mydin. "Structural component defects of low cost housing: A case study at Taman Bandar Perdana, Sungai Petani, Kedah, Malaysia." In *MATEC Web of Conferences*, 10, p. 05002. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141005002
[27] Hong, Chin Hang. "Investigation of defects in new buildings in Malaysia." PhD diss., UTAR, 2016.
[28] Tariku, Fitsum, Herman Kwok, and Ying Simpson. "Experimental investigation of moisture transfer between concrete foundation and sill plate." *Journal of Architectural Engineering* 22, no. 3 (2016): B4016003. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000208
[29] Dmochowski, Grzegorz, and Jerzy Szolomicki. "Technical and structural problems related to the interaction between a deep excavation and adjacent existing buildings." *Applied Sciences* 11, no. 2 (2021): 481. https://doi.org/10.3390/app11020481
[30] Keawsawasvong, Suraparb. "Limit analysis solutions for spherical cavities in sandy soils under overloading." *Innovative Infrastructure Solutions* 6, no. 1 (2021): 33. https://doi.org/10.1007/s41062-020-00398-5
[31] Hassan, Muhamad Hanif, Md Azree Othuman Mydin, and Nangkula Utaberta. "Study of rising dampness problem in housing area in Klang Valley, Malaysia." *Jurnal Teknologi* 75, no. 5 (2015). https://doi.org/10.11113/jt.v75.5080
[32] Salgiya, Disha, D. Jain, and Shruti Tongiya. "General building defects and cracks." *International Journal of Research in Engineering, Science and Management* 2, no. 10 (2019): 628-631.
[33] Mydin, MA Othuman, N. Md Sani, M. Taib, and N. Mohd Alias. "Imperative causes of delays in construction projects from developers' outlook." In *MATEC Web of Conferences*, vol. 10, p. 06005. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141006005
[34] Gizzi, Fabrizio Terenzio, and Giovanni Leucci. "Global research patterns on ground penetrating radar (GPR)." *Surveys in Geophysics* 39 (2018): 1039-1068. https://doi.org/10.1007/s10712-018-9475-1
[35] Maglad, Ahmed M., Md Azree Othuman Mydin, Shuvo Dip Datta, and Bassam A. Tayeh. "Assessing the mechanical, durability, thermal and microstructural properties of sea shell ash based lightweight foamed concrete." *Construction and Building Materials* 402 (2023): 133018. https://doi.org/10.1016/j.conbuildmat.2023.133018
[36] Traore, Yasmine Binta, Adamah Messan, Kinda Hannawi, Jean Gerard, William Prince, and Francois Tsobnang. "Effect of oil palm shell treatment on the physical and mechanical properties of lightweight concrete." *Construction and Building Materials* 161 (2018): 452-460. https://doi.org/10.1016/j.conbuildmat.2017.11.155
[37] Nensok, Mohammed Hassan, Md Azree Othuman Mydin, and Hanizam Awang. "Fresh state and mechanical properties of ultra-lightweight foamed concrete incorporating alkali treated banana fibre." *Jurnal Teknologi* 84, no. 1 (2022): 117-128. https://doi.org/10.11113/jurnalteknologi.v84.16892
[38] Mydin, M. A., N. Mohd Zamzani, and A. N. Ghani. "Effect of alkali-activated sodium hydroxide treatment of coconut fiber on mechanical properties of lightweight foamed concrete." In *AIP Conference Proceedings*, vol. 2016, no. 1. AIP Publishing, 2018. https://doi.org/10.1063/1.5055510
[39] Suhaili, Siti Shahirah, Md Azree Othuman Mydin, and Hanizam Awang. "Influence of mesocarp fibre inclusion on thermal properties of foamed concrete." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 87, no. 1 (2021): 1-11.
[40] Mydin, Md Azree Othuman, Mohd Nasrun Mohd Nawi, Muhammad Arkam Che Munaaim, Noridah Mohamad, Abdul Aziz Abdul Samad, and Izwan Johari. "Effect of steel fibre volume fraction on thermal performance of Lightweight Foamed Mortar (LFM) at ambient temperature." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 47, no. 1 (2018): 119-126.
[41] Tahsin, Sharzil Huda, Mostafa Kamal Fahad, Nowroze Farhan Ifraj, Md Shahporan Rimon, Fazlar Rahman, and Mohammad Rejaul Haque. "Experimental and numerical study of conical-shaped pin finned heat sink with PCM material." *Malaysian Journal on Composites Science and Manufacturing* 14, no. 1 (2024): 1-15. https://doi.org/10.37934/mjcsm.14.1.0115
[42] Maglad, Ahmed M., Md Azree Othuman Mydin, Shuvo Dip Datta, Imad Shakir Abbood, and Bassam A. Tayeh. "Impact of anionic surfactant-based foaming agents on the properties of lightweight foamed concrete." *Construction and Building Materials* 438 (2024): 137119. https://doi.org/10.1016/j.conbuildmat.2024.137119
[43] Alharthai, Mohammad, Md Azree Othuman Mydin, Rodrigue Cyriaque Kaze, Samadar S. Majeed, and Bassam A. Tayeh. "Properties of ultra lightweight foamed concrete utilizing agro waste ashes as an alkaline activated material." *Journal of Building Engineering* 90 (2024): 109347. https://doi.org/10.1016/j.jobe.2024.109347
[44] Maglad, Ahmed M., Md Azree Othuman Mydin, Samadar S. Majeed, Bassam A. Tayeh, and Sahar A. Mostafa. "Development of eco-friendly foamed concrete with waste glass sheet powder for mechanical, thermal, and

durability properties enhancement." *Journal of Building Engineering* 80 (2023): 107974. https://doi.org/10.1016/j.jobe.2023.107974

[45] Mydin, Md Azree Othuman, Nadhim Hamah Sor, Alireza Bahrami, Anmar Dulaimi, Yasin Onuralp Özkılıç, Fadi Althoey, P. Jagadesh, Haytham F. Isleem, and Taher A. Tawfik. "Residual durability, mechanical, and microstructural properties of foamed concrete subjected to various elevated temperatures." *Engineering Science and Technology, an International Journal* 55 (2024): 101725. https://doi.org/10.1016/j.jestch.2024.101725

[46] Alyami, Mana, Md Azree Othuman Mydin, Abdullah M. Zeyad, Samadar S. Majeed, and Bassam A. Tayeh. "Influence of wastepaper sludge ash as partial cement replacement on the properties of lightweight foamed concrete." *Journal of Building Engineering* 79 (2023): 107893. https://doi.org/10.1016/j.jobe.2023.107893

[47] Mydin, Md Azree Othuman, P. Jagadesh, Alireza Bahrami, Anmar Dulaimi, Yasin Onuralp Özkılıç, Mohd Mustafa Al Bakri Abdullah, and Ramadhansyah Putra Jaya. "Use of calcium carbonate nanoparticles in production of nano-engineered foamed concrete." *journal of materials research and technology* 26 (2023): 4405-4422. https://doi.org/10.1016/j.jmrt.2023.08.106

[48] Majeed, Samadar S., Md Azree Othuman Mydin, Alireza Bahrami, Anmar Dulaimi, Yasin Onuralp Özkılıç, Roshartini Omar, and P. Jagadesh. "Development of ultra-lightweight foamed concrete modified with silicon dioxide (SiO2) nanoparticles: Appraisal of transport, mechanical, thermal, and microstructural properties." *Journal of Materials Research and Technology* 30 (2024): 3308-3327. https://doi.org/10.1016/j.jmrt.2024.01.282

[49] Grondzik, Walter T., and Alison G. Kwok. *Mechanical and electrical equipment for buildings*. John wiley & sons, 2019.

[50] Douglas, James. *Building surveys and reports*. John Wiley & Sons, 2010.

[51] Habsya, Chundakus, Kuncoro Diharjo, Prabang Setyono, and Prasasto Satwiko. "Thermal conductivity of lightweight foamed concrete filled fly ash." In *IOP Conference Series: Materials Science and Engineering*, vol. 725, no. 1, p. 012033. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/725/1/012033

[52] Khan, Majid, Muhammad Shakeel, Khalid Khan, Saeed Akbar, and Adil Khan. "A review on fiber-reinforced foam concrete." *Engineering Proceedings* 22, no. 1 (2022): 13. https://doi.org/10.3390/engproc2022022013

[53] Eravan, Serri, Md Azree Othuman Mydin, and Mohd Zailan Suleiman. "Thermal properties of oil palm shell lightweight concrete with different mix designs." *Jurnal Teknologi: Sciences and Engineering* 70, no. 1 (2014): 155–159. https://doi.org/10.11113/jt.v70.2507

[54] Mydin, Md Azree Othuman, and Sara Soleimanzadeh. "Influence of high temperatures on flexural strength of foamed concrete containing fly ash and polypropylene fiber." *International Journal of Engineering, Transactions B: Applications* 26, no. 2 (2013): 117–126.

[55] Mydin, MA Othuman, N. Md Sani, and M. Taib. "Industrialised building system in Malaysia: A review." In *MATEC web of conferences* 10, p. 01002. EDP Sciences, 2014. https://doi.org/10.1051/matecconf/20141001002

[56] Mohamad, Noridah, Abdul Aziz Abdul Samad, Muhammad Tahir Lakhiar, Md Azree Othuman Mydin, Suriani Jusoh, A. Sofia, and Suaidi Azis Efendi. "Effects of incorporating banana skin powder (BSP) and palm oil fuel ash (POFA) on mechanical properties of lightweight foamed concrete." *International Journal of Integrated Engineering* 10, no. 9 (2018).

[57] Salim, NA Agus, M. A. O. Mydin, and NH Md Ulang. "Biomimetic architecture in building envelope maintenance (a literature)." In *E3S Web of Conferences*, vol. 3, p. 01007. EDP Sciences, 2014. https://doi.org/10.1051/e3sconf/20140301007

[58] Wong, Leong Sing, and Shamini Somanathan. "Analytical and numerical modelling of one-dimensional consolidation of stabilized peat." *Civil Engineering Journal* 5, no. 2 (2019): 398-411. http://dx.doi.org/10.28991/cej-2019-03091254

[59] Das, Braja M., and Nagaratnam Sivakugan. *Principles of foundation engineering*. Cengage learning, 2018.

[60] Knappett, Jonathan, and Robert F. Craig. *Craig's soil mechanics*. CRC press, 2019.

[61] Bowles, Joseph E., and Yingzhong Guo. *Foundation analysis and design*. Vol. 5. New York: McGraw-hill, 1996.

[62] Tomlinson, Michael John, and Roger Boorman. *Foundation design and construction*. Pearson education, 2001.

[63] Bowden, Robert K. "Compression behaviour and shear strength characteristics of a natural silty clay sedimented in the laboratory." PhD diss., University of Oxford, 1988.

[64] Chen, R. P., W. H. Zhou, and Y. M. Chen. "Influences of soil consolidation and pile load on the development of negative skin friction of a pile." *Computers and Geotechnics* 36, no. 8 (2009): 1265-1271. https://doi.org/10.1016/j.compgeo.2009.05.011