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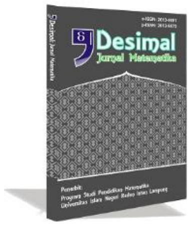

Selection of foundation type of hospital building using analytical hierarchy process

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ABSTRACT

In order to develop the Ministry of Defense Hospital dr. Suyoto in Bintaro, South Jakarta, a new 27-storey building will be built on the south side of the hospital complex. This study aims to select the type of foundation that is able to support the building above it, but with minimal disturbance due to vibration, noise, mud, and excavation, because the hospital must continue to operate, and relates to aspects of cost, time, and scope. The method used is the Analytical Hierarchy Process (AHP) involving five respondents who are considered construction experts from the Construction Center (Puskon) officers, planning consultants, supervisory consultants, and contractors. The results of the study found that concrete pile foundations with Hydraulic Static Pile Drivers (HSPD) were the most suitable for new building foundations from the five criteria and four alternative choices of foundations. In the detailed design process by the planning consultant, several pile caps were found that coincide with each other so it was decided to combine them into a large pile cap which also functions as a raft foundation. So that in its implementation, a combination of concrete piles with HSPD and raft foundations is used.

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INTRODUCTION

Ministry of Defense Hospital dr. Suyoto in Bintaro, Pesanggrahan District, South Jakarta (hereinafter referred to as the Kemhan Hospital) is the only Level II (Type B) hospital and serves as a referral center within the Ministry of Defense (Kementerian Pertahanan – Kemhan) as well as a rehabilitation center for members of the Indonesian National Armed Forces (Tentara Nasional Indonesia – TNI) experience disabilities from all areas of the Republic of Indonesia. In addition, with the implementation of the Social Security Organizing Body (Badan Penyelenggara Jaminan Sosial – BPJS) system, the Kemhan Hospital has been designated as a provider of medical services to members of the National Health Insurance (Jaminan Kesehatan Nasional – JKN) managed by BPJS. The Kemhan Hospital is a referral hospital for officials and all Kemhan personnel and their families.

In order to realize the mission of the Kemhan Hospital and in particular to improve health services that exceed accreditation standards, the Kemhan Hospital intends to carry out the development of existing health service facilities and infrastructure by constructing new hospital buildings and supporting buildings related to the hospital development plan of 174 beds to ±500 beds (Puskon, 2021). The concept of developing the planned hospital area also accommodates three functions at once, namely a general hospital, a teaching hospital and also a TNI rehabilitation center.

Figure 1. Illustration of the new hospital building
Source: Geotechnical Engineering Consultant (2022)

The Construction Center (Pusat Konstruksi – Puskon), which is one of the organizations under the Defense Facilities Agency (Badan Sarana Pertahanan – Baranahan) of the Kemhan with the duties and functions of carrying out construction planning, construction procurement, and controlling and supervising defense facilities construction work, was appointed to realize the development of the hospital. The readiness of the Kemhan Hospital must always be considered, improved and updated to be able to respond to these dynamics. This policy is in line with the country's development plan policies in the context of strengthening economic resilience, reducing inequality, increasing human resources and their competitiveness, developing basic services, increasing disaster resilience and strengthening political, legal, defense and security stability.

In general, the scope of activities for the development of the Kemhan Hospital are: (1) The main building of the hospital, 27 floors high, floor area of ±56,000 m2, capacity of ±504 beds can be seen/shown in Figure 1; (2) Rehabilitation Facilities/Mess Building with 10 floors, ±12,960 m2 area and mosque area ±616 m2; (3) Parking Building, has 7 floors (6 parking floors and 1 hall floor) with an area of ±11,000 m2 (Puskon, 2021).

In this study, we will discuss the construction of the 27-floor main hospital building on the south side of the hospital area. The building is included in the category of high rise building, so that the construction planning needs to be designed to be more reliable in all aspects including the strength of the building structure, including the foundation. Engineering planning for building construction including aspects of architecture, structure, mechanical, electrical, plumbing, and environmental arrangement is carried out by a Planning Consultant who is contractually appointed by Puskon.

The building construction consists of two parts, namely the upper structure and the lower structure. The force from the upper structure is transmitted to the lower structure, which is then transmitted to the ground supporting the building. Pile foundation is part of the lower structure that is used to receive and transmit forces from the upper structure to the supporting soil at a certain depth based on the results of soil investigations.

Structural analysis is carried out on all types of foundations, where the foundation must be able to serve all working forces ranging from dead loads, live loads, wind loads, earthquake loads, rainwater loads, etc. that occur on the upper structure. The consideration for choosing the type of foundation is the Project Triangle, which consists of cost, scope, and time, plus the disturbances caused by construction activities. There are several choices in the design, namely bored-pile foundations, pile foundations, raft foundations, or a combination thereof.

There are various types of foundations, but in this study we will discuss bored-pile foundations, concrete pile foundations which are distinguished from the way they are penetrated into the soil, namely by diesel hammer and with Hydraulic Static Pile Drivers (HSPD).

Bored Pile Foundation

Bored-Pile foundation is a pile foundation whose installation is done by drilling the ground first (I Wayan Jawat et al., 2020). Bored pile foundation work begins with drilling soil with a certain diameter and depth, then the drilled hole is filled with reinforcement that has been arranged above, then the hole containing the series of reinforcement is casted with concrete. The productivity of bored pile foundation work based on research by Mubarak, Bulba, & Yunita (2014) is 3.14 m^3/hour (I Wayan Jawat et al., 2020).

Some of the advantages of using bored pile foundations (I Wayan Jawat et al., 2020) are as follows: (1) Installation does not cause sound and vibration disturbances that endanger the surrounding buildings; (2) Reducing the need for concrete and dowel reinforcement on the pile cap. The column can be directly placed on the top of the bored pile; (3) Pile depth can be varied; (4) Soil can be checked and matched with laboratory data; (5) Bored piles can be installed through the rock, while the piles will have difficulty if the piles penetrate the rock layers; (6) The diameter of the pile may be made large, if necessary, the lower end of the pile can be made larger in order to increase its bearing capacity; (7) There is no risk of land level rise.

Pile Foundation With Diesel Hammer

Piling the foundation with a diesel hammer is driving with a self-propelled ram with a diesel engine without the need for external resources such as compressors and boilers (Fitrianti et al., 2014). This hammer is simple and easy to move from one location to another. The diesel hammer pile consists of a vertical cylinder, ram, anvil beam and a fuel injection system. Beaters of this type are generally small, light and driven by using fuel oil. The total driving energy produced is the number of impacts from the ram plus the resulting energy from the explosion (Abu, 2020). Some of the advantages of using Diesel Hammer are: (1) Economical in use; (2) Easy to use in remote areas; (3) Works very well in cold areas; (4) Easy to maintain. While the disadvantages of Diesel Hammer are:

(1) Difficulty in determining energy/ blow; (2) Difficult to work on soft soil (Abu, 2020). Several previous studies have shown that the driving productivity with Diesel Hammer is 17.98 m/hour (Yuliana et al., 2021); 0.67 meters/minute or the equivalent of 40.2 meters/hour (Puspita, 2016); 0.75 meters/minute or the equivalent of 45 meters/hour (Fitrianti et al., 2014).

Pile Foundation With Hydraulic Static Pile Drivers (HSPD)

Pile foundation with Hydraulic Static Pile Drivers (HSPD) is a type of foundation that uses a jack-in pile system where the pile is pressed into the ground using a hydraulic jack that is given a counter weight so that the pile is not lifted and helps drive the pile up to the design carrying capacity is achieved (Primaswari et al., 2022). The jack-in pile system is very suitable for use in projects with densely populated locations because it does not cause vibration and noise (Primaswari et al., 2022). HSPD is able to pile sizes ranging from 200x200 mm to 500x500 mm or spun piles with a diameter of 300 mm to 600 mm (Limanto, 2009). Some of the advantages of using HSPD related to environmental issues include that it is suitable for project sites in densely populated areas and buildings, because it is almost vibration-free and less noise compared to other piling systems, and allows the pile to be installed near pre-existing structures without interfering with human activities. (Hakim & Akbar, 2018). While the advantages of HSPD with regard to technical issues are faster construction rates; more efficient than other piling methods; the driving quality is guaranteed similar to the pile test; The compressive force of the jack or the carrying capacity of the pile can be read directly through a manometer so that the pile compressive force can be known every time it reaches a certain depth (Hakim & Akbar, 2018). According to Lutfiansyah & Akhsan (Lutfiansyah & Akhsan, 2019), foundation work using the concrete spun pile method is more effective and efficient than the bored pile method based on the implementation method, time and cost.

Productivity is difficult to measure accurately but can only be done through an approach, because many factors influence it. The lowest productivity of HSPD equipment is 0.225 meters/minute or equivalent to 13.5 meters/hour and the highest production value is 1.364 meters/minute or equivalent to 82 meters/hour (Hakim & Akbar, 2018). Meanwhile, other studies show the highest productivity is 1.337 meters/minute or equivalent to 80.22 meters/hour, the lowest productivity is 0.990 meters/minute or equivalent to 59.4 meters/hour, and the average productivity is 1.143 meters/minute or equivalent to 68.58 meters/hour (Primaswari et al., 2022); other studies mention 0.906 meters/minute or the equivalent of 54.36 meters/hour (Fitrianti et al., 2014). Some of the results of these studies mention various numbers but in general the driving time is faster using HSPD than diesel hammers, but in terms of cost, diesel hammers are more efficient than HSPD (Fitrianti et al., 2014).

Raft Foundation

Raft Foundation is a concrete slab-shaped foundation used to unite one or more columns in several rows. In the case of the total foundation area reaching half the building area, the raft foundation is more economical than a single foot foundation (Saputra & Edy, 2000).

Like a construction project, the triple constraint of project management or Project Management Triangle, Iron Triangle, and Project Triangle applies, which consists of cost, scope, and time. The cost concerns the project budget, the scope concerns the construction activities needed to achieve the objectives, the time concerns the project schedule for completion. However, because this project is adjacent to an operational hospital, environmental factors are also one of the criteria that need to be anticipated, in this case noise or vibration disturbances due to the project and other physical disturbances.

The problem faced by the Kemhan Hospital is that the hospital as a whole must continue to operate in carrying out health services. Meanwhile, the problem faced by Puskon is that the 27-storey building must be completed with cost, time, and scope.

The problem or need related to the title being raised is that it requires a type of foundation that is able to support the building above it, but with the smallest possible disturbance, both caused by vibrations that can cause noise to crack the existing building, as well as other disturbances such as mud, waste, excavation, but also associated with The Project Triangle is cost, time, and scope.

This study aims to discuss the selection of the type of foundation associated with the function of its structural ability, with the smallest possible vibration, noise, mud, and excavation, and associated with aspects of cost, time, and scope with the Analytical Hierarchy Process (AHP) method. The AHP is a theory of measurement through pairwise comparisons and relies on expert judgment to derive priorities (Saaty, 2008). The benefits of research results can be used in other projects by changing according to the criteria.

METHOD

This study uses a descriptive method with a case study. The data collection technique used is by filling out questionnaires by five respondents who are construction officers at the Puskon, planning consultants, contractors, and supervisory consultants who are active in the Puskon. The types of data used in this study are primary data and secondary data. Primary data is data obtained from the results of filling out questionnaires by five respondents who are considered professionals in the construction field. While secondary data obtained from literature studies, scientific journals, reference books, and the internet. The data collected was analyzed using the AHP which was processed with the MS Excel 2016 computer program.

According to Saaty (Saaty, 2008), the first step is to perform decomposition to break down the problem that has been defined into its elements into several levels or hierarchies. Furthermore, assessing the relative importance of two elements at a level in the context of the level above it so that a pairwise comparison matrix is produced. Factors that influence the selection of foundations are noise (BG), considering the position of the project is close to existing hospital activities, as well as vibration (GT) which can affect existing buildings and buildings in hospitals and their environment, cleanliness (BS) related to dirt, mud which can interfere with hospital activities. Another influential factor is cost (BY) and time (WU), which are generic criteria in the construction world.

The next step is the preparation of a scale of importance consisting of which elements are more important (important/liked/ possible/...) and how many times more (important/liked/possible/…). In filling out the importance scale, it is necessary to have a thorough understanding of the elements being compared and their relevance to the criteria or objectives of the study. The basic scale of importance according to Saaty can be seen in Table 1.

Table 1. Fundamental scale of AHP

Intensity	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
	Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Source: Saaty (Saaty, 2008).

Next is to create logical consistency, where similar objects are grouped based on uniformity and relevance, then determine the level of relationship between objects with certain criteria. The flow chart for the use of AHP can be seen in Figure 2.

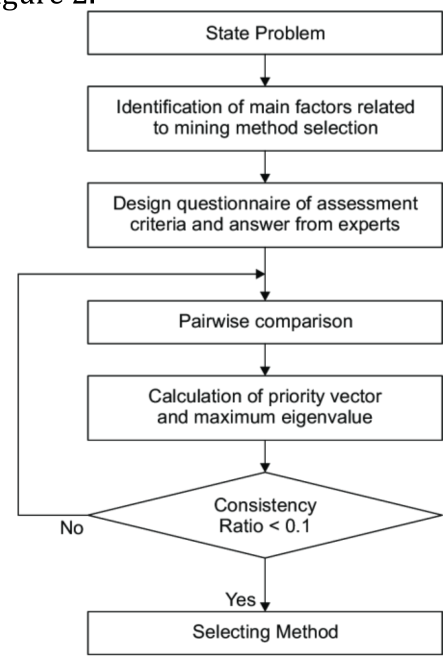

Figure 2. Flow chart of AHP method
Source: Wang, Liu, Li, Yu, & Liu (Wang, Liu, Li, Yu, & Liu, 2021)

The formula used in solving problems with AHP is as follows:

VE_i (Eigen vector)= $\sqrt[n]{\sum_{j=1}^{n} a_{ij}}$,

$i = 1, 2, \ldots\ldots, n$

VP_i (Priority Vector) $= \frac{VE_i}{\sum_{i=1}^{n} VE}$

VA (Vector Antara) $= a_{ij}(row) \times VP$

VB (Eigen values) $= \frac{VA}{VP}$

$\lambda maks$ (Eigen valuesmax)= $\frac{\sum VB}{n}$

CI (Consistency Index) $= \frac{\lambda_{max} - n}{n-1}$

CR (Consistency Ratio) $= \frac{CI}{RI}$

RI = Random Consistency Index, RI value can be seen in Table 2.

Table 2. Random Consistency Index (RI)

Matrix size	Random consistency index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Source: Saaty (1980) in (Ammarapala et al., 2018).

RESULTS AND DISCUSSION

Hierarchy Creation

Based on the literature study, three hierarchical levels were created, level 1 is the goal to be achieved, namely choosing the type of foundation for the hospital building project in Bintaro, South Jakarta; level 2 is the criteria for noise (BG), vibration (GT), cleanliness (BS), cost (BY), and time (WU); level 3 is an alternative choice of foundation, namely bored-pile foundation (BP), pile foundation using diesel hammer (DH), pile foundation using HSPD (HSPD) and raft foundation (PR).

The hierarchy of the strategy for choosing the type of foundation for the hospital building project in Bintaro, South Jakarta is as shown in Figure 3. The lines connecting the boxes between levels are relationships that need to be measured by pairwise comparisons with directions to a higher level (Teknomo et al., 1999).

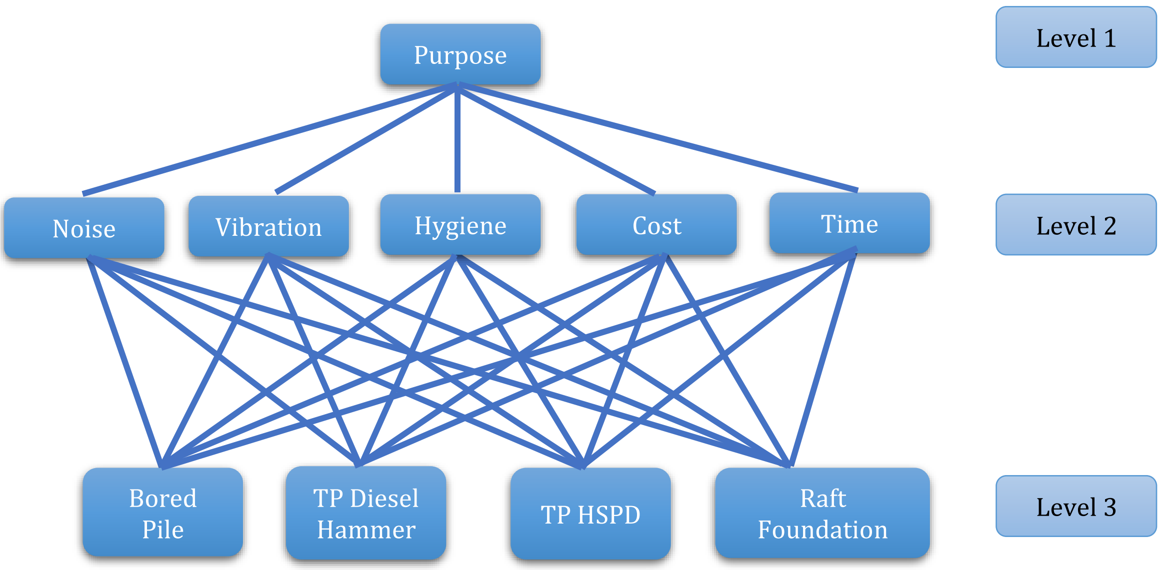

Figure 3. Hierarchical Structure

Preparation and Filling of Questionnaires

Based on the hierarchy that has been made, it is continued with the preparation of a questionnaire that aims to assess the relative importance of two elements at a certain level in relation to the level above it, with five respondents who were asked to compare the level of influence of each factor in the questionnaire table vertically and horizontally on the objectives. to be achieved. The results of the comparison are stated in the basic scale of importance. After filling in the opinions on the available questionnaire matrix, calculations are carried out automatically with the MS Excel program to determine the consistency of each respondent.

Prioritizing Foundation Choice

Based on primary data from the five respondents which was processed automatically with the MS Excel program, a combined matrix of foundation type selection can be obtained as well as obtaining the weight of the criteria and their ranking, and the value of each type of foundation on each criterion and its ranking.

The most important criteria in selecting the type of foundation in the hospital is vibration (GT) with a value of 0.27, followed by the time criterion (WU) with a value of 0.23, cost (BY) with a value of 0.23, noise (BG) with a value of 0 .15, and cleanliness (BS) with a value of 0.12.

For noise criteria, the foundations that cause the least environmental disturbances are piles with the HSPD tool with a value of 0.47, followed by raft foundations with a value of 0.29, bored piles with a value of 0.15, and hammered piles with a value of 0.09, the most noisy and disturbing environment.

For the vibration criteria, the foundations that cause the least environmental disturbances are piles with the HSPD tool with a value of 0.41, followed by raft foundations with a value of 0.33, bored piles with a value of 0.18, and hammered piles with a value of 0.08 which causes the most vibrations and disturbs the environment.

For the criteria of cleanliness, the foundation that causes the least disturbance to environmental cleanliness is the pile with the HSPD tool with a value of 0.46, followed by the diesel hammer pile with a value of 0.34, the raft foundation with a value of 0.12, and bored pile with a value of 0, 08 which causes the most dirt, in this case the mud from the drilling of the soil that disturbs the environment.

For the cost criteria, the most economical foundation is the raft foundation with a value of 0.39, followed by piles using the HSPD tool with a value of 0.25, bored piles with a value of 0.23, and diesel hammer piles with a value of 0.13 the most expensive.

For the time criterion, the fastest foundation in implementation is the pile using the HSPD tool with a value of 0.44, followed by the diesel hammer pile with a value of 0.33, the raft foundation with a value of 0.12, and bored pile with a value of 0.11 which longest processing time.

Based on the available criteria and alternatives, and the calculation of individual matrices and combined matrices, the selected foundation is the pile foundation with HSPD with a value of 0.3952, another alternative with a value below it is a raft foundation with a value of 0.2627, piles pile with a diesel hammer with a value of 0.1821, while the bored-pile foundation is the last alternative with the lowest value of 0.16.

From the results of the structural analysis, a pile cap plan is obtained according to Figure 4 where some of the pile caps collide with each other, based on these considerations it was decided to merge into a large pile cap which also functions as a raft foundation according to Figure 5 (Geotechnical Engineering Consultant, 2022). Based on the data information from the soil investigation, the type of foundation recommended by the Planning Consultant is a pile foundation with a length of 20 m to 26 m, where the pile is driven to a depth of hard soil. The dimensions of the proposed foundation are 500mm x 500mm (Geotechnical Engineering Consultant, 2022).

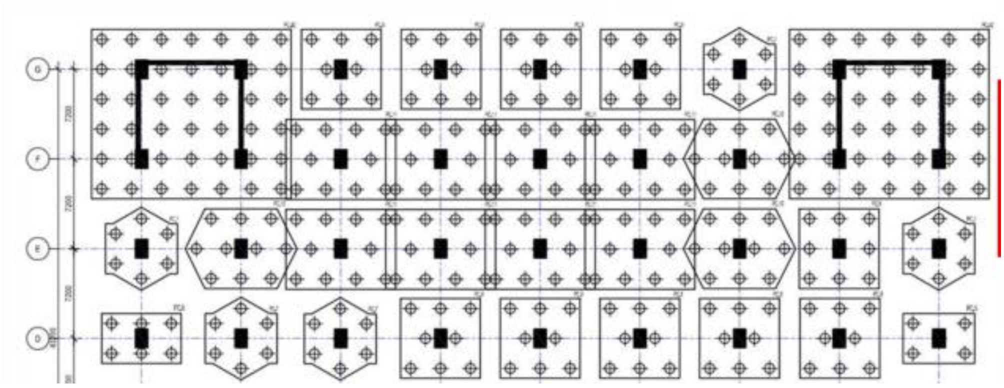

Figure 4. Pile-Cap Foundation Plan
Source: Geotechnical Engineering Consultant (2022)

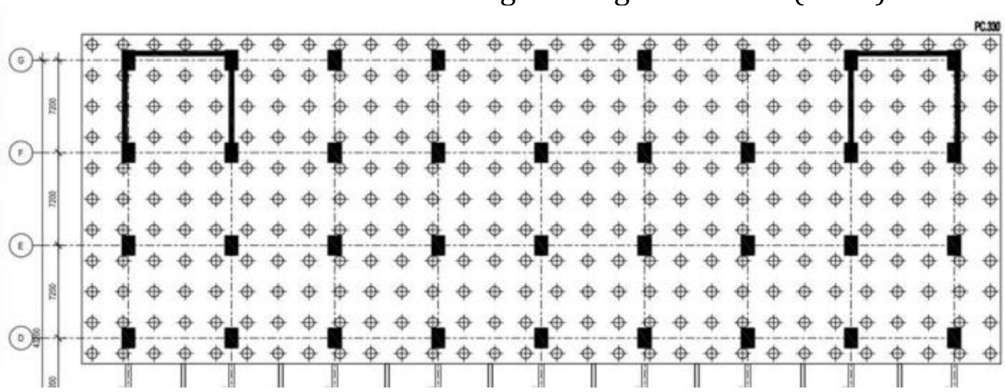

Figure 5. Raft Foundation Plan
Source: Geotechnical Engineering Consultant (2022)

CONCLUSIONS AND SUGGESTIONS

Based on the results of the AHP calculation, the most important criterion in selecting the type of foundation in the hospital is vibration, so that the most appropriate foundation to choose is piles with HSPD which have the smallest vibration impact, the smallest noise, the cleanest, and the fastest processing time.This is in accordance with what was recommended by the Planning Consultant based on the data from the soil investigation, namely the pile foundation with a length of 20 m to 26 m, driven to a depth of hard soil, with dimensions of 500mm x 500mm, with a allowable bearing capacity of 120 tons for axial compression, 25 tons for axial tension, and 5 tons for lateral.

The research results, especially Excel program files, can be used for other projects with the weighting of the criteria depending on the needs of each project and can differ from one another. A project located in an environment where no vibration, noise, and cleanliness is required would recommend a diesel hammer pile foundation.

REFERENCES

Abu, D. L. (2020). *Tinjauan pelaksanaan produktivitas pemancangan dengan menggunakan metode diesel hammer*.

Ammarapala, V., Chinda, T., Pongsayaporn, P., Ratanachot, W., Punthutaecha, K., & Janmonta, K. (2018). Cross-border shipment route selection utilizing analytic hierarchy process (AHP) method. *Songklanakarin Journal of Science and Technology*, *40*(1), 31–37. https://doi.org/10.14456/sjst-psu.2018.3

Fitrianti, N. L. D., Ratnaningsih, A., & Soetjipto, J. W. (2014). Perbandingan efisiensi kerja alat diesel hammer dengan hydraulic hammer pada pekerjaan pondasi tiang pancang dari segi waktu dan biaya (Studi kasus : Proyek pembangunan Jember Sport Center). *Artikel Ilmiah Hasil Penelitian Mahasiswa*.

Geotechnical Engineering Consultant. (2022). *Final report desain dan analisis geoteknik RS dr. Suyoto Jakarta Selatan approval No. 01/D 220040/21-01/ADM/PR* (Issue July).

Hakim, A. R., & Akbar, A. (2018). Analisis produktivitas hydraulic static pile driver pada pembangunan apartemen Victoria Square Tower B Tangerang Banten. *Jurnal Teknik Sipil*, *25*(2), 103. https://doi.org/10.5614/jts.2018.25.2.3

I Wayan Jawat, Putu Panji Tresna Gita, & I Made Satria Dharmayoga. (2020). Kajian metoda pelaksanaan pekerjaan pondasi bored pile pada tahap perencanaan pelaksanaan. *PADURAKSA: Jurnal Teknik Sipil Universitas Warmadewa*, *9*(2), 126–142. https://doi.org/10.22225/pd.9.2.1830.126-142

Limanto, S. (2009). Analisis produktivitas pemancangan tiang pancang pada bangunan tinggi apartemen. *Seminar Nasional 2009 Jurusan Teknik Sipil, FT-UKM*, *15 Agustus 2009*, 293–305.

Lutfiansyah, Y., & Akhsan, M. (2019). Comparative analysis method of work, time and cost of concrete spun pile work with bored pile on construction of the Light Rail Transit (LRT). *Journal of Applied Science, Engineering, Technology, and Education*, *1*(1), 63–72. https://doi.org/10.35877/454ri.asci1137

Primaswari, G., Bhakti Utama, A., Taurano, G. A., Program, D., Teknologi, S., Jalan, K., Jembatan, D., Umum, P., Konstruksi, S. T., Gedung, B., Soedarto, J. H., & Semarang, S. T. (2022). Produktivitas hydraulic static pile driver pada proyek pembangunan workshop di Semarang. *Orbith: Majalah Ilmiah Pengembangan …*, *18*(1), 11–21.

Puskon. (2021). *Kerangka acuan kerja pembangunan rumah sakit dr. Suyoto Pusrehab Kemhan*.

Puspita, D. A. (2016). *Analisa produktivitas alat berat diesel hammer dan hydraulic hammer pada pemasangan pondasi tiang pancang di proyek pembangunan gedung 2 SMK 1 MUHAMMADIYAH Kepanjen Kabupaten Malang*.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *Int. J. Services Sciences*, *1*(1), 83–98. https://doi.org/10.1108/JMTM-03-2014-0020

Saputra, R., & Edy, D. W. (2000). *Analisis perkuatan daya dukung pondasi rakit (raft foundation) dengan geotekstil pada tanah lempung*. Jurusan Teknik Sipil Faklltas Teknik Sipil Dan Perencanaan, Universitas Islam Indonesia.

Teknomo, K., Siswanto, H., & Yudhanto, S. A. (1999). Penggunaan metode analytic hierarchy process dalam menganalisa faktor-faktor yang mempengaruhi pemilihan moda ke kampus. *Civil Engineering Dimension*, *1*(1), 31–39.

Wang, Q., Liu, S., Li, C., Yu, C., & Liu, Y. (2021). AHP based evaluation model of energy efficiency for energy internet. *E3S Web of Conferences*, *233*. https://doi.org/10.1051/e3sconf/202123301031

Yuliana, C., Hapsari, R., & Dewi, E. P. (2021). Analisis perbandingan efisiensi alat pancang diesel hammer dan drop hammer pada pekerjaan pondasi tiang pancang di lahan (comparative analysis of efficiency of diesel hammer and drop hammer pieces on pile). *Jurnal Infrastruktur*, *7*(2), 87–92.