PLANNING MALAYSIA:
Journal of the Malaysian Institute of Planners
VOLUME 22 ISSUE 3 (2024), Page 209 – 223

GEOMETRICAL STUDY OF SUSTAINABLE POLYMER PILES WITH BUCKLING ANALYSIS

Yee Yong Lee[1], Chee Khoon Ng[2], Yeong Huei Lee[3], Sim Nee Ting[4], Hoo Tien Nicholas Kuan[5]

[1.2.4]*Department of Civil Engineering, Faculty of Engineering,*
UNIVERSITI MALAYSIA SARAWAK
[5]*Department of Mechanical and Manufacturing Engineering,*
Faculty of Engineering,
UNIVERSITI MALAYSIA SARAWAK
[3]*Department of Civil and Construction Engineering,*
Faculty of Engineering and Science,
CURTIN UNIVERSITY MALAYSIA

Abstract

Bakau piling is commonly used to support lightweight structures, such as drains, manholes, road, raft foundations and box culverts in construction, aside from its ability to sustain the deterioration of high-water table areas. Consequently, from the high demands, it is leading to mangrove deforestation. On the other hand, the alarming consent of environmental problems is that plastic products generated and becoming waste is increasing every year in Malaysia. Plastic products, mostly from polymer, require a long degradation period of about 1,000 years. Mangrove deforestation and the non-biodegradable nature of polymer waste have become environmental and global issues that leading to the innovative motive in this research by introducing polymer as a new material to the pile manufacturing, an alternative substitute for the bakau pile. This study aimed to optimise the polymer piles in relation to their structural behaviour under compressive stresses. Based on the developed numerical models, the optimum cross-sectional area of the polymer pile by using the buckling analysis is very much depending on the shape and size, specifically second moment of area and slenderness ratio. In preventing of torsional buckling, doubly symmetrical sections are the predominant consideration in the pile design. It found out that, the optimum polymer piles with 1.90 cm2 of cross-sectional area could be suggested for H shape pile, and the proposed material is the high-density polyethylene (HDPE) with virgin to recycle ratio of 50% (VR 50). While serving the environmental issues of mangroves and waste management, polymer pile is a feasible alternative for sustainable construction.

Keywords: Bakau pile, polymer, polymer pile, cross sectional area, buckling

[1] Senior Lecturer at Universiti Malaysia Sarawak. Email: yylee@unimas.my

INTRODUCTION

Bakau (Rhizophora) is a common types of mangrove tree from Rhizophorace family. Bakau wood is used extensively for piling in Borneo and South East Asia to support small and medium structures. It is commonly used to support drains, manholes, raft foundations and box culverts in construction, especially on peats and soft soils. In constructing activities in peats and weak soils, instability and large settlement are significant problems (Rahardjo, 2005). However, uncontrol usage of the bakau pile could cause mangrove destruction. Mangrove is very important to the ecosystem. It prevents coastal erosion. Mangrove forests play a primary role in keeping a hold of the sedimentation from the wave force. Mangroves avoid erosions of coastline along the coastline. Mangrove is also a source of livelihood. Mangroves provide people with various types of invertebrates, fishes, reptiles, amphibians, birds, and mammals. Mangrove forests have been recognised on its importance and prioritised the preservation of forests through many policies and practices (Abdul Latip et al., 2022). This is because the mangrove forest has plenty of microorganisms and algae as a food web for the invertebrates and fishes. It is also a breeding ground for all animals and fisheries that hold economic importance.

The impacts of mangrove destruction are at the expense of ecosystem sustainability and cause climate change impacts. Mangrove destruction causes habitat destruction and biodiversity loss, exacerbating ecosystem degradation. Destruction of mangroves contributes to coastal tidal erosion. Destroyed mangroves will cause more carbon to be retained in the atmosphere, leading to global warming. Many people depend heavily on mangrove forests for their livelihoods.

Therefore, a replacement for the bakau pile is a must to ensure the sustainability of the mangrove area. Bakau piles can be replaced with an alternative material, such as reinforced concrete or steel pipe piles, or with new age material, such as polymer piles. Thus, the usage of bakau pile on supporting embarkment, pile raft system on peats and soft soils, coastal revetment, short bridge approach, stability of excavation in soft clay (Rahardjo, 2005). Also, pile support for infrastructure structures, such as sewerage manhole, drains, walkways, septic tank, water tank plinth, pipeline and road raft foundation base will have other pile material options.

As a new age material, the polymer material is widely used daily. The polymer has become an essential item. Many products are made from polymer. The surge of polymer products in daily human life causes polymer waste management concerns. Polymer, or others known as plastic, is a petroleum-based synthetic organic material. There are a few types of polymers in the market, such as polyvinyl chloride (PVC), polyethene (PE), polycarbonate (PC), polyethene terephthalate (PET) and polypropylene (PP). Their qualities and characteristics make them appropriate for various industries, including home, construction, packaging, goods, vehicle, electronics equipment, and agriculture. A million tonnes of plastic waste are in landfills or the natural environment. In 2015, 79% of complete plastic waste was accumulated in landfills/open dumps or lost to the natural environment (Geyer et al., 2017). In addition, assessments indicate that an annual influx of plastic waste ranging from 1.15 to 2.41 million tonnes is entering the ocean through rivers (Syed Alwi et al., 2023). Synthetic polymers pose a significant challenge on land as they are often discarded in landfills. It persists for centuries and slowly releases toxins into the soil over time. Due to their biodegradability, new landfill sites are always needed as the use of synthetic polymers continues and expands. Moreover, polymer degradation is another polymer issue as it can take up to 1000 years to degrade in a landfill. Given the slow degradation of polymers, they could potentially find reuse in long-term applications like piling, where materials endure extended periods underground.

Both mangrove forest and polymer waste management hold enormous economic and ecological importance. Mangroves harbour unique biodiversity. Protecting mangroves can help save the planet from increasing pollution and polymer recycling. Therefore, a study is required to look into the possibilities of recycling polymers to replace mangrove products. One of the examples is creating a polymer pile. The polymer has the potential to be used as a pile due to its diversified polymer properties. Recycled polymer piles are a potential technological solution to environmental, construction and waste disposal challenges. This research will investigate the structural behaviour of various polymer piles strengths, shapes, and sizes through modelling software. The research outcome expects to determine the relationship between the structural behaviour of polymer piles. It aims to give the most optimum strength, shape, and size of polymer pile against cost. This research will provide an alternative deep foundation for small and low-loading structures in civil works.

MODEL DEVELOPMENT

The polymer pile materials utilized for theoretical and numerical analysis include polyethylene (PE – HDPE), polypropylene (PP), and polyvinyl chloride (PVC). The polymer material is further categorized into 100% pure polymer, referred to as virgin, 50% pure with 50% recycled polymer, known as VR-50, and 100% recycled polymer, known as recycled. In comparison, polyvinyl chloride (PVC) was analyzed both as 100% pure polymer and 100% recycled polymer. The material properties are listed in Table 1.

A total of 144 samples of various shapes, sizes, and polymer materials were simulated using analytical and numerical models. The selected forms for this analysis were limited to circular hollow sections, square hollow sections, and H sections. The sizes varied from 100 mm to 400 mm in diameter or length, tailored to match the practical sizes of Bakau piles. The pile size analysis was based on a 1-tonne working load with a safety factor of 1.3, i.e., the pile capacity was 1,300 kN. The thickness of the hollow section was set as thin as 1 mm up to a maximum thickness of 72 mm. The length of the polymer pile was fixed at 3 meters for all the analyses. The 3-meter length was chosen as Bakau piles are typically available in lengths ranging from 1.5 meters to 3 meters. Other parameters, such as area, moment of inertia, and volume, were calculated based on the given dimensions and sizes.

Table 1. Properties of studied materials

Material		**Young's modulus, MPa**	**Poisson ratio**	**Density, kg/m^3**
HDPE	HDPE	240	0.46	970
	VR-50-HDPE	182		
	Recycled HDPE	211		
PP	PP	728	0.43	946
	VR-50-PP	544		
	Recycled PP	303		
PVC	PVC	728	0.40	1330
	Recycled PVC	638		

Analytical Model

The structural design of piles can be simplified to short columns by assuming that the columns are laterally retained unless bending moments are negligible (gravity loads only) and the soil is very soft. One of the column criteria is buckling. The buckling load is given as Euler's critical load:

$$P_{cr} = \frac{\pi^2 EI}{L_{eff}^2} \text{Equation 1}$$

where,
Pcr = Critical or maximum axial load on the pile just before it begins to buckle
E = Modulus of elasticity for the polymer material
I = Least moment of inertia for the polymer pile cross-sectional area
L^2_{eff} = Unsupported length of the polymer pile

Finite Element Models

Finite element models were developed in this study. Figure 1 and Figure 2 describe the typical meshing and boundary conditions of the developed models. The verified modelling technique was applied in further model development.

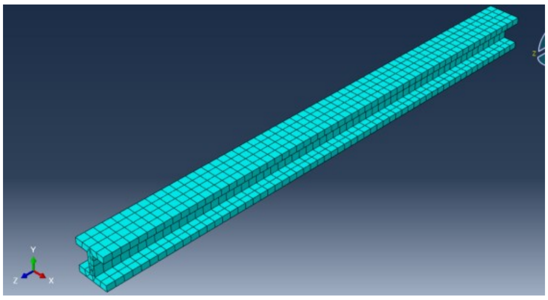

Figure. 1. Meshing of the model

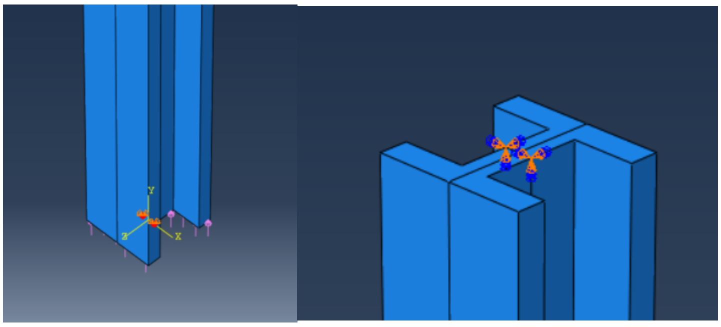

Figure 2. Assigned boundary conditions

Finite Element Analysis

Circular Hollow Section (CHS) piles

Forty-eight sample cases were analysed in circular hollow section shapes. The outer diameters (OD) were set at a minimum of 135 mm to 191 mm for solid circular and 200 mm, 250 mm, 300 mm, 350 mm and 400 mm for circular hollow sections. The inner diameters (ID) were in the range of 128 mm to 398 mm diameter. Typical failures are shown in Figure 3 and Figure 4. Results are tabulated in Table 2.

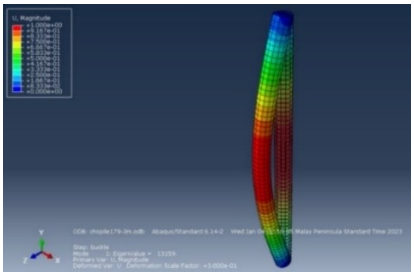

Figure 3. Typical deformation contour for solid circular section

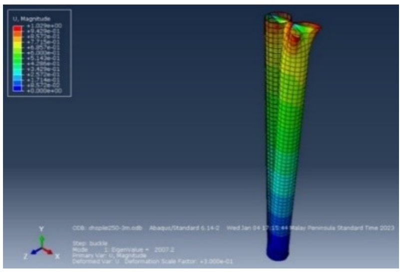

Figure 4. Typical deformation contour for CHS section

Square Hollow Section (SHS) piles

Forty-eight specimens were analysed in square hollow shape. The dimensions were studied in a range of 118 mm to 168 mm for solid square and 200 mm to 400 mm for square hollow sections. The wall thicknesses were ranged from 1 mm to 16 mm. Typical failure are shown in Figure 5 and 6. Results are tabulated in Table 3.

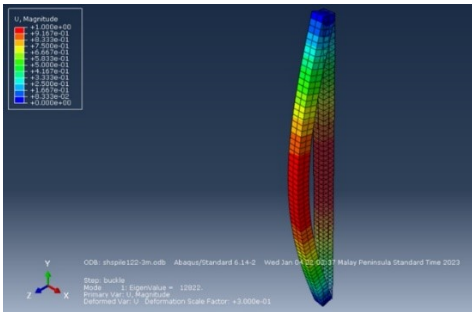

Figure. 5. Typical deformation contour for solid square section

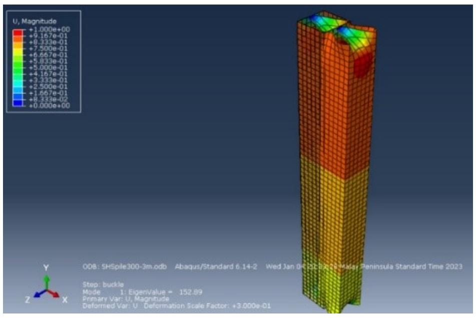

Figure. 6. Typical deformation contour for SHS section

H-section piles

Another forty-eight samples were analysed in the H section shapes. The H dimensions were like those of square shape. The web and flange thicknesses were set at a range from 2 mm to 48 mm. Typical failures are shown in Figure 7. Results are tabulated in Table 4.

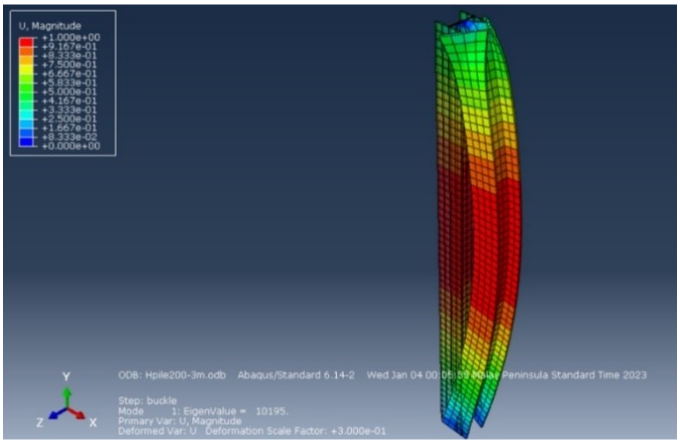

Figure. 7. Typical deformation contour for H- section

Table 2. Eigenvalues for CHS section with finite element analysis

HDPE				**VR50-HDPE**			
OD, mm	ID, mm	Thickness, mm	Eigenvalue, N	OD, mm	ID, mm	Thickness, mm	Eigenvalue, N
179	-	Solid	13150	191	-	Solid	12918
200	159	41	21763	200	128	72	12834
250	232	18	7530.7	250	225	25	12049
300	290	10	1780.1	300	287	13	2425.8
350	344	6	516.53	350	342	8	738.45
400	396	4	203.86	400	395	5	250.97
100% recycled HDPE							
OD, mm	ID, mm	Thickness, mm	Eigenvalue, N				
184	162	22	12910				
200	146	54	12774				
250	225	25	13969				
300	289	11	1934.6				
350	343	7	637.25				
400	395	5	250.97				

Table 3. Eigenvalues for SHS section with finite element analysis

HDPE				**VR50-HDPE**			
OD, mm	ID, mm	Thickness, mm	Eigenvalue, N	OD, mm	ID, mm	Thickness, mm	Eigenvalue, N
156	-	Solid	12890	168	-	Solid	13128
200	-	11	6998.1	200	-	16	12898
250	-	5	741.71	250	-	7	6998.1
300	-	3	123.98	300	-	4	209.70
350	-	2	33.869	350	-	3	81.303
400	-	2	27.261	400	-	2	20.673
PP				**VR50-PP**			
118	-	Solid	12854	128	-	Solid	13289
200	-	4	1319.9	200	-	5	1800.5
250	-	2	189.91	250	-	3	419.69
300	-	1	16.299	300	-	2	87.313
350	-	1	13.759	350	-	1	10.282
400	-	1	11.236	400	-	1	-20.55
PVC				**100% recycled PVC**			
122	-	Solid	12822	132	-	Solid	13231
200	-	4	1133.8	200	-	5	1558.2
250	-	2	160.48	250	-	3	358.63
300	-	2	100.39	300	-	2	75.371
350	-	1	11.786	350	-	1	7.8441
400	-	1	9.3605	400	-	1	7.0277
100% recycled HDPE				**100% recycled PP**			
162	-	Solid	13170	148	-	Solid	13207
200	-	13	9689.0	200	-	9	5002.8

100% recycled HDPE				**100% recycled PP**			
250	-	6	1057.0	250	-	4	502.14
300	-	4	243.11	300	-	2	152.89
350	-	2	29.776	350	-	2	41.682
400	-	2	23.967	400	-	1	4.5406

Table 4. Eigenvalues for H-section with finite element analysis

HDPE				**VR50-HDPE**			
OD, mm	ID, mm	Thickness, mm	Eigenvalue, N	OD, mm	ID, mm	Thickness, mm	Eigenvalue, N
156	-	Solid	12745	168	-	Solid	13128
200	-	37	10195	200	-	37	12003
250	-	19	2128.8	250	-	25	12009
300	-	11	313.47	300	-	15	3562.7
350	-	7	116.39	350	-	9	870.49
400	-	5	30.837	400	-	6	184.03
PP				**VR50-PP**			
118	-	Solid	12854	128	-	Solid	13289
200	-	12	10195	200	-	16	12003
250	-	7	2128.8	250	-	8	2327.7
300	-	4	313.47	300	-	5	446.01
350	-	3	116.39	350	-	3	85.733
400	-	2	30.837	400	-	2	22.554
PVC				**100% recycled PVC**			
122	-	Solid	12869	132	-	Solid	13231
200	-	14	11722	200	-	19	12979
250	-	7	1851.9	250	-	10	3840.1
300	-	4	271.90	300	-	6	659.95
350	-	3	100.80	350	-	4	197.53
400	-	2	26.008	400	-	3	63.538
100% recycled HDPE				**100% recycled PP**			
162	-	Solid	13170	148	-	Solid	13207
200	-	42	13661	200	-	29	13151
250	-	22	11590	250	-	15	8144.8
300	-	13	2744	300	-	9	1357.0
350	-	8	580.92	350	-	6	359.69
400	-	6	213.35	400	-	4	359.69

ANALYSIS AND DISCUSSION

Distribution of pile size and pile cross-sectional area's selection

The pile size and cross-sectional area selection in this study can be seen from Figure 8 to Figure 10, according to each type of material. The distribution of pile size and cross-sectional area is much broader and separated. The analysis will be a wider spectrum of understanding the structural behaviour and impact of shape and material in this study. The graph shows that the larger the pile dimension, the less the cross-sectional area.

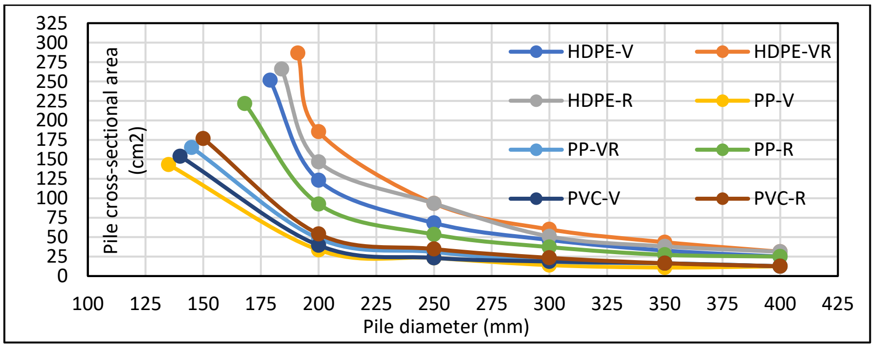

Figure. 8. Distribution of sample for circular hollow section (CHS) graph

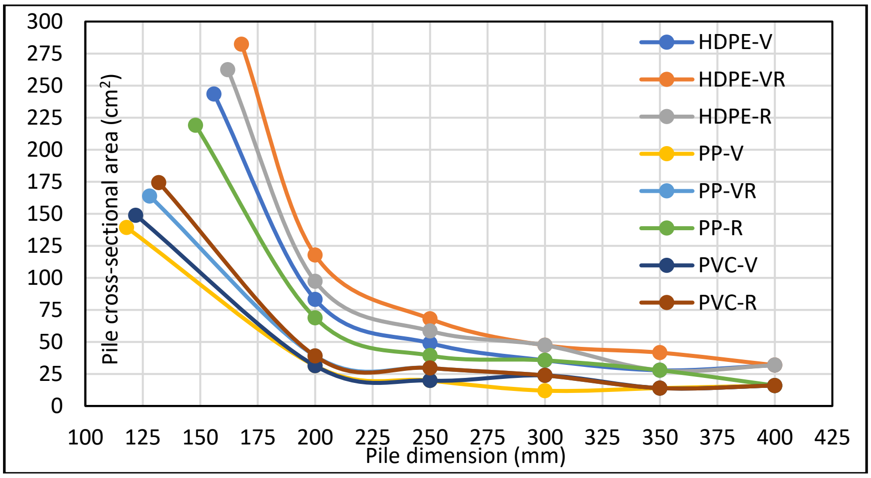

Figure. 9. Distribution of sample for square hollow section (SHS) graph

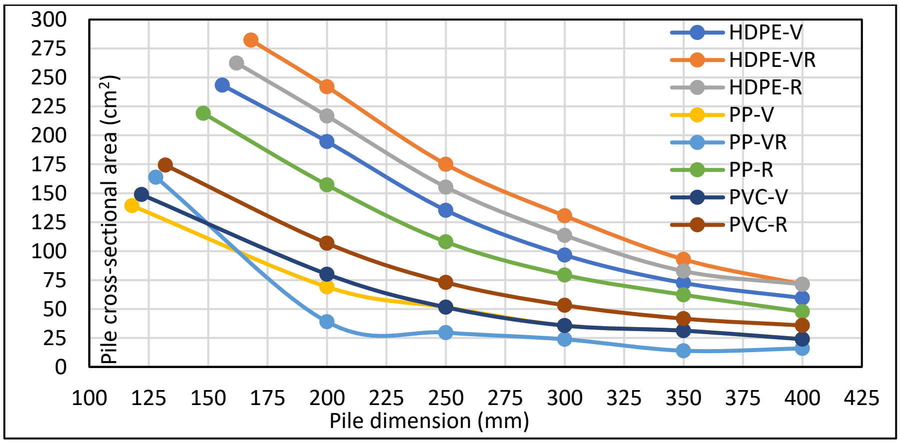

Figure. 10. Distribution of sample for H section (H Section) graph

Distribution of pile size selection

Figure. 11 to Figure 13 show graphs of the distribution of pile cross-section against Eigenvalue. The highest Eigenvalue was 13,644 N from polypropylene (PP-VR-50) in 128 mm solid square size, and the lowest Eigenvalue was -20.55 N, which is also from polypropylene (PP-VR-50) in 128 mm square hollow section with 1 mm wall thickness. The negative value may be caused by a modelling error or is often associated with a loss of stiffness or solution uniqueness, either in the form of a material instability or the application of loading beyond a bifurcation point. Young's modulus also plays a role in affecting the buckling criteria. The greater the Young' modulus, the stiffer the material.

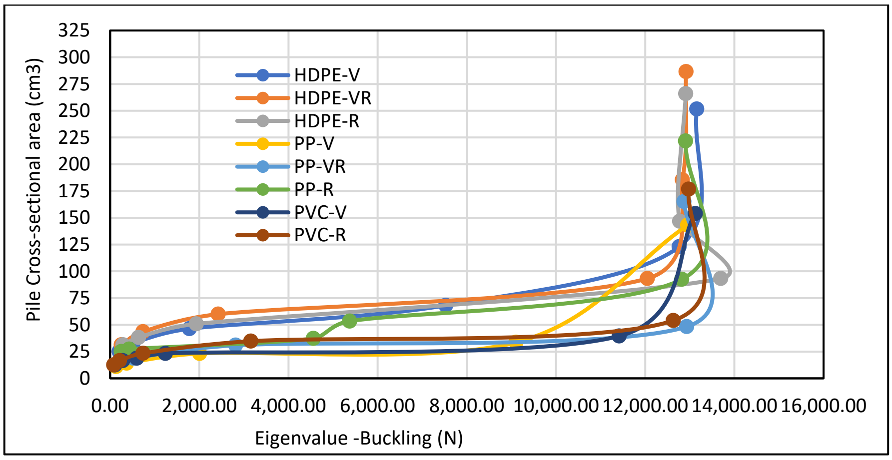

Figure. 11. Cross-sectional area vs eigenvalue of Circular Hollow Section

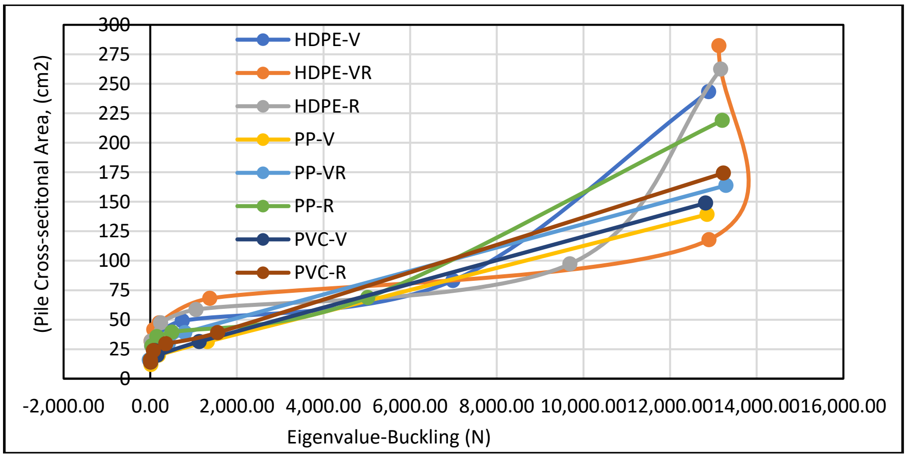

Figure. 12. Cross-sectional area vs eigenvalue of Square Hollow Section

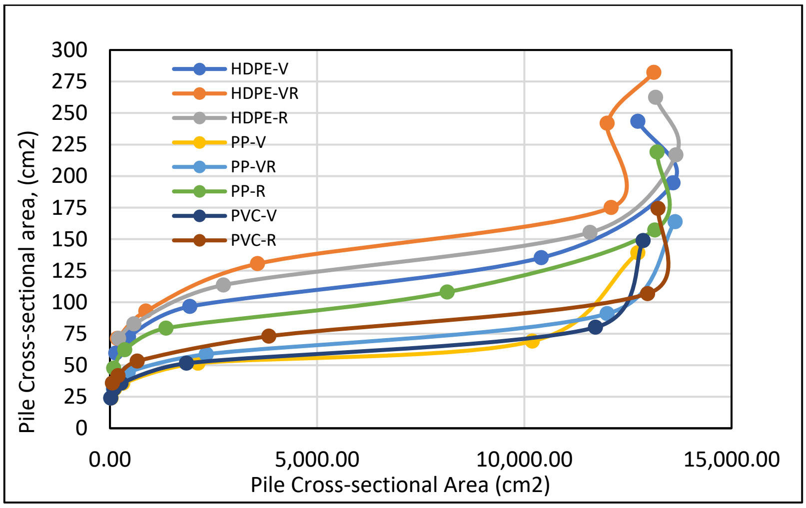

Figure. 13. Cross-sectional area vs eigenvalue of H Section

Determination of optimum pile

A three-dimensional graph plotted on which Eigenvalue is plotted together with cross-sectional and pile dimensions. The intersection of the pile cross-sectional curve with the pile dimension curve is recorded as the optimum cross-section and dimension for the maximum Eigenvalue. For example, HDPE – Virgin as shown in Figure 14.

Where, point A for the H-section is read as;
Eigenvalue= 12,100 N
Pile cross-sectional = 1.60 cm^2
Pile dimension= 205 mm

The finding of the optimum cross-sectional area of the polymer pile by using the numerical modelling method utilising buckling analysis much depends on the shape and size. The Young's modulus and Poisson ratio used in the modelling is almost similar for all polymer materials. Therefore, it does not affect the modelling.

Many models have encountered early failure. The main factor of premature failure is the selection of model thickness. A model of at least 25 mm thick could give a more reliable buckling analysis than below 25 mm thickness. The model with thickness below 25 mm had failed before the element could reach its maximum load, as predicted in the calculated buckling load. The expected buckling failure deformation changed from flexural buckling to another buckling failure (local, distortional, lateral-torsional buckling). Thus, the shape selection and thickness will ultimately enable the modelling to be tested in the best condition. From the analysis, the solid shapes were better represented by the Eigenvalue against calculated critical load.

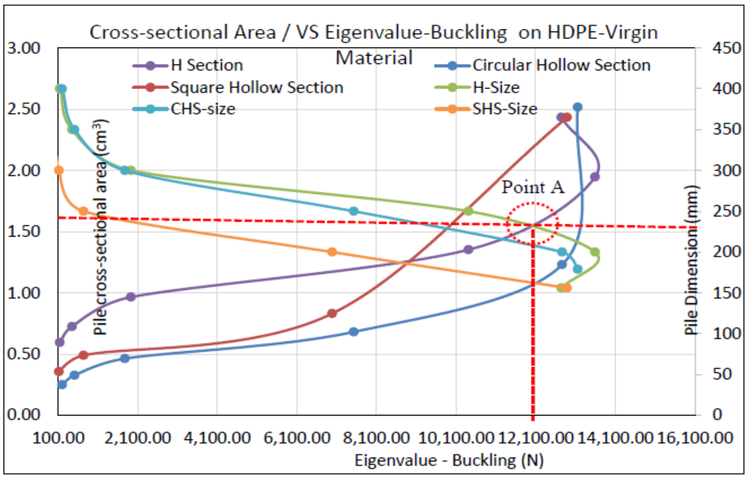

Figure. 14. Three-dimensional graph for HDPE-Virgin

Other than that, many factors can affect the analysis, such as the selection of boundary conditions, meshing, material properties and type of steps or load to apply on the element. This parameter could have a significant impact on the numerical analysis. The validation process is vital to ensure data collected from the numerical method is accurate. Trial and error in a numerical way are essential, leading to the exact desirable condition and result.

From Table 6, the row highlighted with yellow is the highest Eigenvalue expected to be carried before the element fails. H section showed the highest numbers of Eigenvalues, and the square hollow section showed the least Eigenvalue. The biggest dimension was 245mm, and the smallest was 145mm. While for cross-sectional, the biggest area was 1.90 cm^2, and the smallest area was 0.68 cm^2. In terms of material, HDPE had the highest passion ratio enabling it to give better results than other elements.

With the tabulation, it is summarised that;

1. The optimum size was 245 mm with cross-section area of 1.90 cm^2 (appx 190 mm^2) area of the H section. Then, followed by a circular hollow section with 200 mm and cross-section area of 1.40 cm^2.
2. The best shape of the pile was the H section because it had the ability to restrain in all directions. It also produced the least volume in conjunction with the buckling load resistance.

3. The best polymer to be used is HDPE-VR 50 because it achieved 182 MPA. The greater the modulus, the stiffer the material. However, this analysis is limited to buckling. In pile criteria, working load is the ultimate criterion.

Table 6: Summary of point intersected for circular hollow section, Square hollow section, and H section.

Type of material	CHS			SHS		
	Eigenvalue, N	**Dimension, mm**	**Area, cm^2**	**Eigenvalue, N**	**Dimension, mm**	**Area, cm^2**
HDPE -V	13,100	200	1.4	9,100	180	1.35
HDPE-VR-50	12,800	200	1.5	-	-	-
HDPE-Recycled	12,500	255	1.7	12,100	235	1.6
PP-V	11,800	155	1.25	9,250	145	0.9
PP-VR-50	-	-	-	4,000	175	0.7
PP-Recycled	13,000	170	0.9	7,000	185	1.05
PVC-V	12,500	165	0.7	4,950	175	0.68
PVC-Recycled	-	-	-	5,000	180	0.79
	H section					
	Eigenvalue, N	**Dimension, mm**	**Area, cm^2**			
HDPE -V	12,100	205	1.6			
HDPE-VR-50	12,500	245	1.9			
HDPE-Recycled	12,100	245	1.6			
PP-V	11,800	150	1.0			
PP-VR-50	10,800	225	0.82			
PP-Recycled	10,400	225	1.3			
PVC-V	11,800	200	0.82			
PVC-Recycled	11,000	210	0.91			

Costing Analysis

Value engineering focuses on maximizing the value of a product or project while minimizing costs. When considering a new material for a product, cost engineering plays a pivotal role in assessing its feasibility within the context of value engineering. Bakau and Belian Pepper Post (very young belian wood) have been traditionally used in civil engineering projects in light weight structures like drains, sewerage, and water reticulation as piles. As the supply diminishes and demand persists, the prices for Bakau and Belian wood have increased significantly, making them financially unviable for many projects. The Cost Engineering shows that for a typical 150mm X 150mm round solid bakau or belian piles, price range from RM 100 to RM 150.

Another option is to use Reinforced Concrete (RC) piles as wood piles replacement. However, the challenges lie on that the fact the RC piles are typically manufactured as standard sizes of, like 150mm x 150mm x 6m, which actually provide more strength than necessary for lighter structures. Over-engineering increases material costs and might not be the most cost-effective solution. The cost per pile, ranging from RM 150 to RM 200, coupled with the need for specific piling machinery, significantly raises the overall expenses for these projects.

Given these challenges, polymer piles in this study composed of virgin HDPE, PVC, or PP, and designed with a Circular Hollow Section (CHS), offer adequate strength suitable for typical lightweight structures. The estimated material cost falls within the range of RM40 to RM100 excluding manufacturing cost. When compared with the cost per pile of RM180 for RC, RM150 for Bakau, and RM100 for Belian, the pricing of polymer piles emerges as a potentially viable option. Notably, the scarcity of wood piles, particularly Bakau and Belian, in the market further accentuates the feasibility of adopting polymer piles as a cost-effective alternative in civil engineering projects.

CONCLUSIONS

There were 144 finite element models of various selected sizes and shapes have been developed. Data collected from the modelling exercise has enabled a comparison and validation with previous researchers' pile experimental data regarding polymer pile study. The collected Eigenvalues from numerical study were compared to analytical critical loads. In this study, the optimum polymer piles are 245 mm in dimension with cross-sectional area of 1.90 cm^2 from HDPE VR 50 material of H section shape. In comparison to RC, Bakau, and Belian, the pricing of polymer piles emerges as a potentially viable option. Considering the environmental impact linked to polymer production is recommended for future research.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Sarawak Research and Development Council (Sarawak RDC) through the Research Initiation Fund (RDCRG/RIF/2019/11) and Universiti Malaysia Sarawak for their financial support and research facilities. Special thanks to Chiu Ming, Roland Ng for his contribution in data collections and planning to help this project going smoothly.

REFERENCES

Abdul Latip, N., Steven, S.R., Rashid, R., Karim, R., Umar, M.U., Hussin, R., Yusoh, M.P., Stephen, J., Andin, C., Kanyo, N.I. (2022). Change of forest land use based on conservation policy and practice: A Case study in Danum Valley, Malaysia.

Planning Malaysia: Journal of the Malaysian Institute of Planners, *20*(4), 47 – 57.

Akenji, L., Bengtsson, M., Hotta, Y., Kato, M., & Hengesbaugh, M. (2020). Policy responses to plastic pollution in Asia. *Plastic Waste and Recycling,* 21, 531–567.

Awoyera, P. O., & Adesina, A. (2020). Plastic wastes to construction products: Status, limitations and future perspective. *Case Studies in Construction Materials*, 12, e00330.

Baran Toprak, Ozer Sevim, Ermedin Totic, I. K. (2018). The Functions of Pile Types and Piles Used in Construction. *International Journal of Advances in Mechanical and Civil Engineering*, *5*(3), 34–36.

Basmage, O. M., & Hashmi, M. S. J. (2020). Plastic Products in Hospitals and Healthcare Systems. In Renewable and Sustainable Materials (pp. 648–657). Elsevier Ltd.

Correia Diogo, A. (2015). Polymers in building and construction. In Materials for Construction and Civil Engineering: Science, Processing, and Design.

Hibbeler, R. C. (2013). Mechanics of Materials (A. Deb & N. Yi Ling (eds.); 9th ed.). Pearson Education South Asia Pte Ltd.

Kasapoglu, E. (2008). Polymer-based Building Materials : Effects of Quality on Durability. 11DBMC International Conference on Durability of Building Materials and Components, May.

Lee Y.Y., Kuan, N.H.T., Ng, C.K., Ting, S.N. 15 October 2020, https://www.feng.unimas.my/index.php/top-research/characterization-of-recycled-polymer-materials-in-construction-piles-application-for-civil-works

Meyerhof, G. G. (1976). Bearing capacity and settlement of pile foundations. *Journal of the Geotechnical Engineering Division,* 102.3, 197-228.

Rahardjo, P. P. (2005). Chapter 31 The use of bamboo and bakau piles for soil improvements and application of pile raft system for the construction of embankment on peats and soft soils. Elsevier Geo-Engineering Book Series, 3(C), 899–921.

Seaman, G. (2012, May). Plastic by The Numbers. Eartheasy Guides & Articles, 1–14. https://learn.eartheasy.com/articles/plastics-by-the-numbers/

Sharma, A. K. (2020). Understanding the Pile Foundation. *International Advanced Research Journalin Science, Engineering and Technology*, *7*(4), 75–84.

Syed Alwi, S.N.N., Abdul Manaf, L., Amiruddin, A.M., Yusuf Kpalo, S., Nazibudin, N.A. (2023). Riverine litter assessment and recycling potential along Sungai Kelantan at Kampung Pasir Era, Kelantan, Malaysia. *Planning Malaysia: Journal of the Malaysian Institute of Planners*, *21*(5), 48 – 61.

Yuan, Z., Yang, Y., Dou, L., & Sui, Y. (2020). Optimization Design of Double Jacked-in Spun Pile Tip. *Journal of Physics: Conference Series*, *1578*(1).

Yunus, M. O. (2018). Model Test Ultimate Bearing Capacity of Bakau Piles Foundation on Soft Soil Deposit. *EPI International Journal of Engineering*, *1*(2), 94–99.

Received: 22nd Mar 2024. Accepted: 8th July 2024