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Verification of Depth Adjustment Factor in Eurocode 5 for Tropical Hardwood Timbers

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ABSTRACT

The depth adjustment factor for bending strength stated in Eurocode 5 (EC5) is only applicable to timbers having a characteristic density below 700 kg/m^3 . However, most Malaysian timbers are hardwood, some with a characteristic density reaching above 700 kg/m^3 . Therefore, the objective of this study was to examine whether the depth adjustment factor stipulated in EC5 is valid for Malaysian hardwood timbers. Six timber species were selected for this study, namely Kapur (*Dryobalanops* C.F.Gaertn.), Kempas (*Koompassia* Maingay ex Benth.), Keruing (*Dipterocarpus* C.F.Gaertn.), Light red meranti (*Shorea* Roxb. ex C.F.Gaertn.), Geronggang (*Cratoxylum* Blume) and Balau (*Shorea* Roxb. ex C.F.Gaertn.). The determination of bending strength and characteristic density was conducted according to BS EN 408: 2010 and BS EN 384: 2016, respectively. A graph for mean bending strength vs. (150/h) was plotted for each timber species. The power function was selected to analyze the relationship between the two variables. The power of the regression equations varied depending on the characteristic density of the timber species. For species with a characteristic density below 700 kg/m^3 , such as Kapur, Keruing, and Light red meranti, the power was between 0.16 to 0.17. In contrast, for species having a characteristic density above 700 kg/m^3 , namely Kempas and Balau, the power was higher at 0.23 and 0.24, respectively. Geronggang was an exception to this pattern. These values are close to the depth adjustment factor given in EC5, which is 0.2. Based on the results, it can be suggested that the adjustment factor of 0.2 is also applicable to Malaysian hardwood timbers with a characteristic density above 700 kg/m^3 .

KEYWORDS

Depth adjustment factor; Malaysian hardwood timber; bending strength; Eurocode 5

1 Introduction

Eurocode 5 (EC5) [1] is a part of the construction-related European Standard (EN) series. It specifies that buildings and civil engineering projects made use of timber should be designed according to the limit state design principle. The advantage of the limit state design principle is that it considers the ultimate strength and serviceability of the structure under different load combinations. Knowing the strength characteristics of



timber members is essential for ensuring the structure's safety and its load-bearing capacity [2]. However, the Malaysian Standard continues to utilize the permissible stress design philosophy for designing timber structures. The permissible stress is determined by multiplying the grade stress by a series of modification factors. The design stresses for tension, compression, shear, and bending, as outlined in MS 544: Part 2: 2017, are derived from the stresses of small clear specimens that was typically determined by standard laboratory testing method. Despite the fact that small clear specimens that are devoid of defects are commonly used in laboratory tests, they do not provide an accurate reflection of the mechanical strength of timber used in structural applications. As a result, the concept of permissible stress design has been disregarded for the past decade. Instead, new approaches, such as those found in the EC5 [1], have been adopted to provide a better evaluation of timber strength. Therefore, it is crucial for local engineers to adopt EC5 [1] in order to guarantee the continuity of design philosophies described in the British code of practice and also to ensure the safety of the timber structures [3].

The characteristic stresses employed in limit state design stipulated in EC5 [1] were derived from structural size specimens. The mechanical properties determined using structural size specimens are known as the characteristic values which are taken as 5% or less of the normal distribution [4,5]. The characteristic values have no built-in safety factors which is different from the grade stresses given in the Malaysian Standard [6,7]. Several studies have been conducted to determine the strength properties of Malaysian hardwood timbers according to EC5 [8–10]. To obtain the characteristic value of a timber species, it is necessary to adjust the strength data using formulae to the standard reference conditions specified in BS EN 384: 2016 [11]. The standard provides means for adjusting the strength data based on moisture content, timber size, and test length. These adjustments are crucial to ensure that the strength data obtained from testing is comparable across different timber species and conditions.

This study focused only on the depth adjustment factor for bending strength. It is worth noting that the depth adjustment factor for bending strength of 0.2, as stated in BS EN 384: 2016, is only applicable to temperate softwoods and hardwoods with a characteristic density of no more than 700 kg/m^3 [11]. While some tropical hardwoods are listed in EC5 [1], they might not be sourced from Malaysia but from other countries in Southeast Asia, Burma, India, The Andamans, Sri Lanka, Thailand, South Vietnam, Cambodia, and the Philippines [12]. The characteristics and densities of these species may vary from those found in Malaysia. The density of Malaysian heavy hardwoods and medium hardwoods ranges from 880 to 1200 kg/m^3 and 720 to 880 kg/m^3 , respectively. On the other hand, the density of light hardwoods is less than 720 kg/m^3 [6,7]. The lack of an established depth adjustment factor for Malaysian tropical hardwoods prompted this study, which aimed to investigate whether the depth adjustment factor specified in EC5 [1] is also applicable to Malaysian hardwoods with varying densities. Six Malaysian hardwoods, with characteristic densities ranging from 327 to 855 kg/m^3 , were selected for this study.

2 Materials and Method

2.1 Material

Six Malaysian hardwood timbers, namely Kapur (*Dryobalanops* C.F.Gaertn.), Kempas (*Koompassia* Maingay ex Benth.), Keruing (*Dipterocarpus* C.F.Gaertn.), Light red meranti (*Shorea* Roxb. ex C.F. Gaertn.), Geronggang (*Cratoxylum* Blume), and Balau (*Shorea* Roxb. ex C.F.Gaertn.) were selected for this study. The timbers were sourced from three different regions in Malaysia: Pahang, Johor, and Sarawak. The selection of the timber species was based on their common usage and availability from the local sawmill. Prior to testing, the timbers were sawn into structural size specimens in accordance with BS EN 408: 2012 [13]. The different dimensions used in this study are tabulated in Table 1.

Table 1: Matrix for size effect of bending structural size specimen

Size effect Dimension (mm)	Species						Total
	Kapur	Kempas	Keruing	Light red meranti	Geronggang	Balau	
	Number of specimens per dimension						
20 × 50	59	50	59	50	52	–	270
20 × 100	44	40	55	40	41	–	220
30 × 50	55	59	59	62	54	–	289
30 × 60	–	–	–	–	–	8	8
30 × 75	–	–	–	–	–	8	8
30 × 100	44	43	44	44	46	8	229
30 × 125	52	51	54	52	54	8	271
40 × 60	–	–	–	–	–	8	8
40 × 75	–	–	–	–	–	8	8
40 × 100	–	–	–	–	–	8	8
40 × 125	–	–	–	–	–	8	8
50 × 150	40	38	40	–	–	–	118

Following the sawing process, the specimens were air-dried to a moisture content (MC) less than 19%. The duration required for air-drying varies, depending on the species, density and sizes. After achieving the targeted MC, the specimens were visually graded by professional grader from Malaysian Timber Industry Board (MTIB) into HS grade in accordance with EN 1912: 2012 [14]. The total number of specimens used in this study was 1445 as shown in [Table 2](#).

Table 2: Total specimens for size effect of bending test

Species	No. of specimen
Kapur	294
Kempas	281
Keruing	311
Light red meranti	248
Geronggang	247
Balau	64
Total	1445

2.2 Testing Method

The test was conducted in accordance with BS EN 408: 2012 [13]. The test method prescribed by the standard represents a 4-point bending with a loading rate adjusted to reach the maximum load within (300 ± 120) s. The bending specimens were subjected to two loads placed at a distance, $a = L/3$ from the supports, where L is the bending span which was 18 times the specimens' depth. The load was applied to the specimens in two symmetrical points. The specimens were simply supported as illustrated in [Fig. 1](#). In addition, special

bracings as shown in Fig. 2 were needed for specimens with the dimensions of 30 mm × 100 mm × 2000 mm and 30 mm × 125 mm × 2500 mm. These bracings were crucial to keep the specimen in place and to prevent lateral torsion. The dimension of each specimen, i.e., width, thickness and length were recorded prior to the destructive bending test. The bending test was conducted for each specimen until failure [13] and the modulus of rupture (MOR) was then calculated for each specimen. After the test, a section was cut from each specimen to determine its MC and density according to MS 837: 2006 [15].

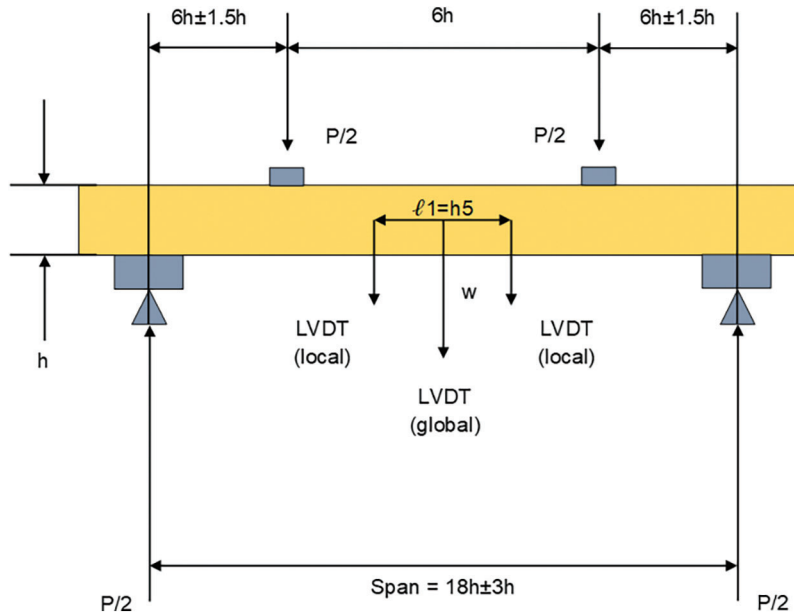


Figure 1: Bending test setup for structural size specimens according to BS EN 408: 2012

where:

P load in newtons;

h beam height in mm;

w deformation direction.



Figure 2: Setup for bending test with bracings for specimens with the length of 2000 and 2500 mm

2.3 Evaluation of Bending Strength

The bending strength was calculated using Eq. (1), which is the classic formula for determining the bending stress in a beam under simple bending.

$$fm = \frac{M}{s} = \frac{F_p \times a}{\frac{b \times h^2}{6}} = \frac{3 \times F \times a}{b \times h^2} \quad (1)$$

where:

a distance between a loading point and the nearest support ($a = 6 \times h$);

b beam width in mm;

h beam height in mm;

F load in newtons.

2.4 Determination of Moisture Content and Density

The MC of the bending specimens was determined using oven dry method according to MS 837: 2006 [15]. Three test pieces with a thickness of 25 mm (parallel to the grain) were cut from each bending specimen. The initial weight of each test piece was recorded before it was placed in the oven. The oven temperature was maintained at $103^\circ\text{C} \pm 2^\circ\text{C}$. After 24 h, the test pieces were removed from the oven and weighed. Then, test pieces were returned to the oven and reweighed every 2 h until no further weight loss was observed. The weight was measured using an electronic weighing balance with a precision of 0.1 decimal point. The moisture content was calculated using Eq. (2) as follows:

$$\text{Moisture content (\%)} = \frac{\text{Weight at test} - \text{Oven dry test}}{\text{Oven dry test}} \times 100 \quad (2)$$

The density for each specimen was determined using the same test pieces used for MC evaluation. Before putting the test pieces in the oven, their dimension was measured. The density was calculated using Eq. (3) as follows:

$$\text{Density, } \rho = \frac{\text{Mass}}{\text{Volume}} \quad (3)$$

2.5 The Depth Adjustment Formula

According to BS EN 384: 2016 [11], for specimens tested with a depth less than 150 mm, and a characteristic density less than or equal to 700 kg/m^3 , the individual bending strength must be adjusted to 150 mm depth by dividing by the factor k_h from Eq. (4):

$$k_h = \min \left\{ \frac{150^{0.2}}{h}, \frac{1.3}{1.3} \right\} \quad (4)$$

In addition, the bending strength must be divided by factor k_l from Eq. (5), if the bending test follows the arrangement as outlined in BS EN 408: 2012 [13], but uses a different span (ℓ) or different distance between the inner load point (a_f) than 18 and 6 h, respectively.

$$k_I = \left(\frac{48h}{\ell_{et}} \right)^{0.2} \quad (5)$$

$$\ell_{et} = \ell + 5\alpha_f$$

where:

ℓ_{et} effective test length in mm;

ℓ span within the test arrangement;

α_f distance between the two inner loading points;

α_f and ℓ are the values taken from the test.

2.6 Determination of Characteristic Density

The characteristic density of the specimens was derived from the 5th percentile density value in accordance with BS EN 14358: 2016 [16] and BS EN 384: 2016 [11]. The derivation process of characteristic density is illustrated in Fig. 3.



Figure 3: The derivation process of characteristic density

Initially, the density at testing, $\rho_{m,0}$ for all the specimens was determined. Since the specimens used in this study vary in terms of species, cross-section and regions, there was a variation in moisture content value. As a result, the densities were adjusted to the reference MC of 12%, $\rho_{m,0,12}$.

Following the MC adjustments, the 5th percentile values for each sub-sample were determined according to BS EN 14358: 2016 [16]. The sub-samples for this study were the sizes of the specimens tested and denoted as $\rho_{0,5}$. Then, the characteristic values for density were derived from the 5th percentile density values as outlined in BS EN 384: 2016 [11] and denoted as ρ_k .

2.7 Evaluation of Density Corrected to 12% Moisture Content

For an accurate evaluation or assessment of the test results, thorough attention must be given to the MC of each specimen. As specified in BS EN 384: 2016 [11], the density of the specimens must be adjusted to the reference MC of 12%, as shown in Eq. (6). When the specimens were tested with MC in the range of 8% to 18%, they were adjusted to 12% moisture content. Meanwhile, for specimens tested above 18% MC, they were adjusted from 18% and not from their actual MC. This modification was carried out to ensure that the value of the strength properties is comparable to their corresponding density at 12% MC.

$$\rho = \rho(u) [1 - 0.005(u - u_{ref})] \quad (6)$$

where:

ρ density

u moisture content at testing ($8\% \leq u \leq 18\%$)

u_{ref} reference moisture content ($u_{ref} = 12\%$)

2.8 Evaluation of 5th Percentile Value of Density

After the adjustments of MC were made, the 5th percentile values were calculated for each sub-sample, where the sub-samples for this study were the sizes of the specimens tested. There were 3 sub-samples and 4 sub-samples for each species. The 5th percentile value was determined using the equation given in BS EN 14358: 2016 [16] as shown in Table 3.

where:

y Means of strength after corrected to moisture content

Sy Standard deviations of the strength

ks(n) ks (n) values for strength properties for p = 5% and α = 75% as in Table 1 section 3.2.2 [ref: BS EN 14358: 2016]

Table 3: The formula for 5th percentile

Percentile	Normally distributed
5-percentile	Mk = y – ks(n)sy

2.9 Evaluation of Characteristic Density Value

The characteristic values for density were derived from the 5th percentile density values by using Eq. (7):

$$\rho_k = \min\left(1.1\rho_{0.5,i,\min}, \frac{\sum_{i=1}^{n_s} n_i \rho_{0.5,i}}{n}\right) * k_n \quad (7)$$

where:

$\rho_{0.5,i}$ 5-percentile density of sub-sample i

$\rho_{0.5,i,\min}$ lowest 5-percentile density of i-sub-samples

n_s the number of sub samples

n_i the number of specimens in sub sample i

k_n factor to adjust for the number of sub-samples as mentioned in Table 1 section 5.5.2.2.1 [ref: BS EN 384: 2016]

3 Result and Discussion

To investigate the depth adjustment factor for bending strength, bending tests were conducted on specimens with varying depths of 50, 100, and 125 mm for five different species, namely Kapur, Kempas, Keruing, Light Red Meranti, and Geronggang. Additionally, specimens with a depth of 150 mm were tested for Kapur, Kempas, and Keruing. For Balau, specimens with depths of 60, 75, 100, and 125 mm were tested. Table 4 shows the mean bending strength for each species of timber with different widths and depths.

Overall, it can be observed that the strength decreased as the depth increased. Besides that, the size of the specimens also affects the bending strength, especially for Kempas and Light Red Meranti. The bending strength decreased as the size of the specimens increased. However, there was a slight deviation of the general trend for Keruing and Geronggang where the strength decreases when the depth increases from 100 to 125 mm. It is worth noting that there are other factors that influence the strength and the property of timber also vary widely between pieces of the same species [17]. The results suggest that, the size of

the specimens can have a significant effect on the bending strength properties either in structural size specimens or small clear specimens due to the dependency of span depth ratio (span length/specimen depth) [18–20].

Table 4: Mean bending strength for all species

Species	Width (mm)	Depth (mm)	Mean bending strength, $f_{m,0}$ (N/mm ²)	COV (%)
Kapur	20	50	85.23	11
	20	100	81.27	18
	30	50	87.38	17
	30	100	80.91	15
	30	125	77.31	15
	50	150	68.51	16
Kempas	20	50	105.41	18
	20	100	96.75	23
	30	50	112.85	10
	30	100	96.65	24
	30	125	91.20	23
	50	150	80.68	29
Keruing	20	50	78.42	18
	20	100	69.50	16
	30	50	91.01	17
	30	100	72.36	24
	30	125	82.74	20
	50	150	66.08	16
Light red meranti	20	50	51.99	19
	20	100	47.36	17
	30	50	50.25	19
	30	100	46.98	20
	30	125	43.00	23
Geronggang	20	50	48.61	33
	20	100	38.63	24
	30	50	45.47	27
	30	100	37.59	16
	30	125	38.30	32
Balau	30	60	119.9	12
	30	75	94.37	18
	30	100	85.19	17
	30	125	92.55	19
	40	60	118.86	13
	40	75	88.10	14
	40	100	107.41	10
	40	125	98.82	11

The size effect on bending strength for timber members has been studied extensively over the last several decades by several researchers. Barrett et al. (1995), Barrett et al. (1990), Bohannon (1996) and Madsen (1990) have laid the foundation of the size effect study for timber [21–24]. However, there are still ongoing debate and discussion among experts about the size effect and its consequences for structural design and safety. Therefore, Vida et al. (2023), Li et al. (2023), Walley and Rogers (2022), Hu et al. (2019) and Nowak et al. (2001) have conducted further researches to address the issue [20,25–28]. Meanwhile, it is widely accepted that the Weibull weakest link theory can effectively represent the size effect in bending, compression and tension [29–32]. According to the weakest link theory, the strength is dependent on the size of the highly stressed volume. Some researchers have discovered that the size effect of clear specimens has been reduced to a depth effect.

BS EN 384: 2016 [11] stated that the bending strength for each specimen needs to be adjusted if the standard reference condition of 150 mm depth is not fulfilled. As a result, a formula for adjusting depth was implemented to ensure that the bending strength, which was determined from specimens of varying depths, remained consistent and comparable. The purpose of this study was to verify the validity of the depth adjustment factor specified in BS EN 384:2016 for six Malaysian hardwood timbers.

The density for Malaysian tropical hardwoods ranged from 720 to 1200 kg/m³ [6]. The density recorded in MS 544: PART 2: 2001 is different from the characteristic density in the EC5 [1]. Fig. 3 depicts the steps involved in determining the characteristic value. The characteristic density value for Kapur, Kempas, Keruing, Light Red Meranti, Geronggang and Balau was calculated and the results are summarised in Table 5.

Table 5: Densities values for all species

Species	$\rho_{m,0}$	$\rho_{m,0,12}$	$\rho_{0.5}$	ρ_k
Kapur	822	801	672	652
Kempas	903	889	753	731
Keruing	813	791	625	578
Light red meranti	460	451	337	327
Geronggang	517	510	402	390
Balau	947	942	855	855

Note: $\rho_{m,0}$ = density at testing; $\rho_{m,0,12}$ = density at 12% moisture content; $\rho_{0.5}$ = 5th percentile density; ρ_k = characteristic density.

As demonstrated in Table 5, the characteristic density (ρ_k) for all species is lower than the density ($\rho_{m,0}$). As outlined in BS EN 384: 2016 [11], the depth adjustment formula is only applicable to specimens with a characteristic density less than or equal to 700 kg/m³. Hence, the investigation on the depth adjustment formula was carried out on Kapur, Keruing, Light Red Meranti and Geronggang, which represent the Malaysian hardwood species with a density of less than 700 kg/m³.

It should be noted that Malaysia is also home to hardwood species with a characteristic density exceeding 700 kg/m³, such as Balau, Kempas, Kelat and Resak. To determine whether the depth adjustment formula is applicable to these species, the investigation was extended to include Kempas and Balau, which are representative of the hardwood species with a density greater than 700 kg/m³ as indicated in Table 5.

According to BS EN 384: 2016 [13], for specimens tested with a depth of less than 150 mm, and a characteristic density less or equal to 700 kg/m³, the bending strength must be adjusted to 150 mm depth by dividing with factor k_h as shown in Eq. (8).

$$k_h = \min \left\{ \frac{150^{0.2}}{h} \right\} \quad (8)$$

where:

h depth in mm.

Therefore, the equation of adjusted bending strength to the depth 150 mm are shown in Eq. (9).

$$f_{m,0,150} = \frac{f_{m,0}}{\left(\frac{150}{h}\right)^{0.2}} \quad (9)$$

To evaluate the applicability of Eq. (9), which represents the depth adjustment formula, for Malaysian hardwoods, graphs were plotted to illustrate the relationship between bending strength and (150/h). Subsequently, a comparison was made between the bending strength equation with adjusted depth (Eq. (10)) and the power trendline equation (Eq. (11)) derived from the plotted graph.

$$f_{m,0} = f_{m,0,150} \left(\frac{150}{h}\right)^{0.2} \quad (10)$$

$$Y = Ax^c \quad (11)$$

X-axis is 150/h;

Y-axis is bending strength ($f_{m,0}$);

C is the power value;

When h = 50, 60, 75, 100 and 125 mm.

The power function was selected for the analysis of the graph so that, the power of the equation derived based on the graph can be used to verify with the power of Eq. (10), which is 0.2. Eq. (10) was primarily utilized for comparison with Eq. (11) to determine the power value, rather than for calculating the adjusted bending strength. Fig. 4 shows the individual relationship graphs of bending strength vs. (150/h) for each species. The R^2 value, presented in each graph, indicates the degree to which the power function fits the data points for each species, providing valuable information regarding the strength and reliability of the relationship between bending strength and (150/h) for all species.

Table 6 displays the power of the regression equation for the depth adjustment formula. Based on Table 6, the power of the regression equations varies by species and ranges from 0.16 to 0.17 for species with characteristic densities lower than 700 kg/m³. It should be noted that Geronggang, while having a characteristic density below 700 kg/m³, displayed a power value of 0.26 which is higher than 0.2. The observed higher power value of Geronggang could be attributed to the high coefficient of variation (COV) in the bending strength data. Consequently, it is possible that the results for Geronggang may not align with the initial hypothesis. Nonetheless, it is worth noting that the depth adjustment formula in EC5 [1] was validated and found to be applicable to Malaysian hardwoods with characteristic density \leq 700 kg/m³.

In addition, for the Malaysian hardwoods with characteristic densities greater than 700 kg/m³, Kempas and Balau exhibited higher power values than that stated in the standard, at 0.23 and 0.24, respectively. This suggests that, while the power trendline for the data may not precisely match the expected power of 0.2, it is still reasonably close to this value. Therefore, the power equation of 0.2 can be deemed applicable for timber species with a characteristic density greater than 700 kg/m³, even though the specific power value may differ

slightly from the expected value. This information can be valuable for researchers and engineers working with timber, as it offers a framework for predicting the adjustment factor of various timber species based on their characteristic density. Based on the results of this study, the adjustment factor of 0.2 can also be applied for timber with a characteristic density greater than 700 kg/m³, but further investigations are necessary to confirm this for a wider range of timber species and characteristic densities.

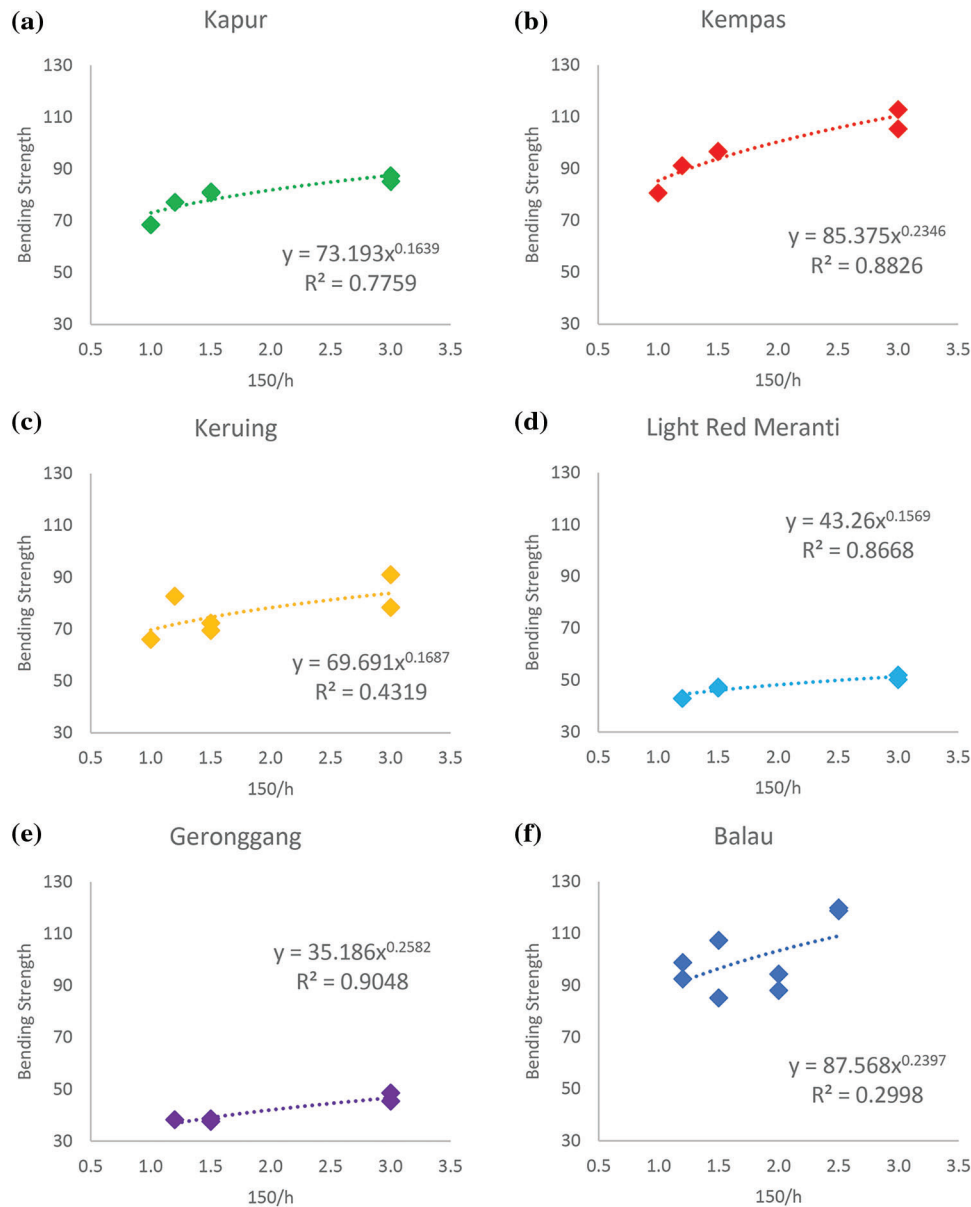


Figure 4: The relationship graph of bending strength vs. (150/h): (a) Kapur; (b) Kempas; (c) Keruing; (d) Light red meranti; (e) Geronggang; (f) Balau

Barrett et al. [21] reported that, for defect free timber members, the size adjustment factor for depth was 0.25. In another study conducted by Hu et al. [27], the authors discovered that the size factor to the depth of timber for bending was 0.23. Walley et al. [26], in their review, summarised that the value for size effect on

bending strength ranged from 0.14 to 0.26. Therefore, based on the analysis of existing literatures on the size effect across various species groups, along with the findings of this study, it can be concluded that a size factor of 0.2 is a suitable value for depth adjustment in relation to bending strength. This value is considered appropriate to be used internationally as well as domestically for the development of standard specifications for wood frame construction in design codes.

Table 6: The power regression equation for depth effect for six Malaysian timber species

Species	Average density	Characteristic density	Power regression equation	Power	R ²
Kapur	822	652	$y = 73.193x^{0.1639}$	0.16	0.7870
Kempas	903	731	$y = 85.375x^{0.2346}$	0.23	0.8826
Keruing	813	578	$y = 69.691x^{0.1687}$	0.17	0.4319
Light red meranti	460	327	$y = 43.260x^{0.1569}$	0.16	0.8668
Geronggang	517	390	$y = 35.186x^{0.2582}$	0.26	0.9048
Balau	947	855	$y = 87.568x^{0.2397}$	0.24	0.3416

Given the extensive research that has been conducted on the depth effect, it is expected that revisions to the depth adjustment factor formula will continue to occur over time. Currently, EC5 [1] specifies a fixed reference depth of 150 mm (h_1) and a depth adjustment factor of 0.2 for bending specimens, but only for specimens with a characteristic density of 700 kg/m³ or less. The findings of this study are consistent with the depth adjustment factor formula in EC5 [1] and suggest that it can be applied directly to Malaysian hardwoods, regardless of whether the characteristic density is less than or more than 700 kg/m³.

4 Conclusion

The depth adjustment formula was investigated using six Malaysian hardwood timbers namely Kapur, Kempas, Keruing, Light red meranti, Geronggang, and Balau. The following are the summary of the key findings of the study:

- i. Overall, the bending of the strength of all specimens was observed to decrease as the depth was increased.
- ii. The characteristic density of Kapur, Keruing, Light red meranti and Geronggang is less than 700 kg/m³, while Kempas and Balau have a characteristic density of more than 700 kg/m³.
- iii. The graphs show that the power of the regression equations for timbers with a characteristic density less than 700 kg/m³, such as Kapur, Keruing, and Light Red Meranti, was 0.16, 0.17 and 0.16, respectively.
- iv. While Geronggang also has a characteristic density of less than 700 kg/m³, it has a high power of 0.26 due to large coefficients of variation (COV) in bending strength data.
- v. The regression power of Kempas and Balau, both of which have characteristic densities exceeding 700 kg/m³, was found to be higher, with values of 0.23 and 0.24, respectively.

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