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Optimization of Hanger Spacing of Steel Arch Bridges Using Dynamic Loads

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ABSTRACT

Bridges are basic infrastructure that must be met to create regional connectivity in Indonesia. One type of bridge that is often used is a curved bridge, which has the advantages of high strength, attractiveness, aesthetics and economy. In order to accelerate the development of bridge infrastructure, an efficient innovation in curved bridge design is needed. The development of curved bridge structures to achieve efficient designs has received much attention in several decades. However, researchers have only focused on optimising the geometry variation of the arch height. Therefore, the aim of this research is to innovate the optimisation of the hanger spacing on the arch bridge structure. In order to obtain optimal results, a bridge model is carried out by varying the hanger spacing of the centre model with a hanger spacing ratio of (1.3 - 1.1 - 0.9 - 0.7), a flat model with a hanger spacing ratio of (1 - 1 - 1 - 1) and an edge model with a hanger spacing ratio of (0.7 - 0.9 - 1.1 - 1.3), so that from the three models, the effect of hanger location on three conditions is obtained. Each model is modelled in the SAP2000 software and given a bridge service load to obtain the internal forces and deflections that occur. The output of the internal force and deflection is then analysed to determine the effect of the location of the bridge service hanger. The serviceability of the bridge is also analysed by calculating the ratio between the weight of the bridge and the deflection that occurs. The results of the analysis show that the location of the hanger affects the performance of the arch bridge structure. The centre model bridge design produces the most efficient structural performance in resisting the compressive axial forces and moments that occur, and produces the least deflection. Meanwhile, the edge model will provide the most efficient structural performance in resisting tensile axial forces. By referring to the results of the bridge weight to deflection ratio analysis, it can be concluded that the centre model produces the most efficient structural design when compared to other curved bridge models.

1. Introduction

The field of bridge engineering is a profession that studies the science of design, function, construction methods and development related to road and bridge infrastructure [1][2]. The bridge is an infrastructure that functions as a link between places that are separated due to geographical conditions. The function of the bridge is to connect transport routes separated by rivers, lakes, swamps, channels, roads, and other crossings [3]. From an economic point of view, bridges can shorten road travel time and reduce transportation costs. The topography of Indonesia's territory which consists of many seas, rivers, and ravines makes bridge infrastructure development as basic infrastructure to create connectivity between regions [4][5]. Proven that until 2021 the Ministry of PUPR has built 19,135 units of national bridges, 201 units of suspension bridges, and 100 units of special bridges [6].

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But until now, the low efficiency of construction structures with high work intensity will have an impact on increasing environmental damage [2][8]. For this reason, efficient bridge planning is needed in terms of structure, workability and economy (cost effective) so as to reduce the impact of environmental damage [9].

The steel arch bridge is a type of frame structure, featuring a curved design linked by steel cables or hangers to distribute the load of the bridge's floor to the pedestal [10]. The arch bridge is a type of bridge construction that has high strength, the attractiveness of beauty [10][11], aesthetic and economic [12][13] when compared to other bridge types. Efforts have been made to enhance efficiency on arch bridges by seeking the optimum design. One way of achieving this is by modifying the geometry of the bridge. The purpose of setting the geometry of the arch bridge structure is to produce a small bridge deflection [14] by using a lightweight structure so that it will facilitate work and reduce construction costs. In 2016, research conducted by [15] resulted in the optimisation of a arch bridge against weight and deflection by varying the connection material. In another effort, research was conducted in 2018 to optimise the ratio of curvature height to length of concrete bridges by looking at the internal forces generated [16][17]18]. In another study in 2019, the optimisation of trusses on bridge arches was carried out. [19]. Innovations in optimising arch bridges are expanding with variations in arch shape [20], replacing steel hangers with tendon hangers [21][22], varying the shape of the tendon hanger network [23][24], and finding the most optimal tendon hanger angle [22][25][26]. However, most studies only focus on varying the arch height and shape of the arch truss, the shape of the hanger network when using tendons, considering self-weight [27], member buckling [28], or multiple materials [29][30][31][32] in the optimisation formulation and there is no literature that performs optimisation of arch bridge structures by varying the hanger spacing of steel materials.

Carrying the main mission to optimise the structure of steel arch bridges, this research seeks to close the gap of previous research by innovating the optimisation of arch bridge structures by adjusting the distance between bridge hangers. Based on this description, the purpose of this study is to determine the effect of hanger spacing on the arch bridge and get the most optimal steel arch bridge hanger spacing to produce an efficient arch bridge design that still fulfils the requirements and objectives of the bridge.

2. Method

2.1 Materials

An arch bridge is a semicircular or parabolic bridge with abutments on both sides. Structurally, arch bridges rely on curved rods (arcs) and hanging rods (hangers) to withstand and channel loads to the abutment [33]. The arc on the arch bridge will receive a compressive force and the bridge hanger will receive a high tensile force so it is suitable if steel material is used which has the same compressive and tensile strength [34]. The number of segments on the bridge is very influential on the distribution of internal forces that occur, the less the number of segments, the greater the force carried by the bridge segment. Based on the National Standarisation Agency SNI 03 - 1729 - 2002, structural material with BJ - 37 steel quality is used which has a yield stress value (f_y) of 240 MPa and an ultimate stress (f_u) of 370 MPa.

2.2 Modelling of Arch Bridge Structures

The arc bridge to be studied uses the following bridge dimension specifications. The bridge span is 8 metres and the width is 2 metres. Besides that, the bridge has height 1,6 metres with supports joint and roll. The structure material is IWF steel. The profile of IWF steel include logitudinal girder (G) with IWF 125.125.6,5.9, Arch section (P) with IWF 125.125.6,5.9, hanger section (V) with IWF 100.50.5.7, transversal girder (GM) with IWF 100.50.5.7. Steel quality is used which as BJ – 37 with f_y = 240 MPa and f_u = 370 MPa.

The design geometry of the arch bridge can be seen in Figure 1, Figure 2, Figure 3, and Figure 4.

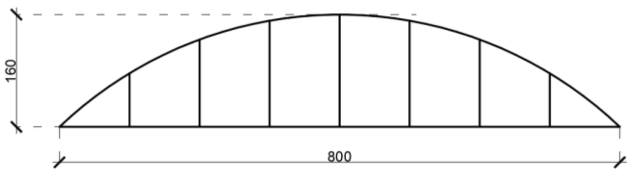

Figure 1. Side view of the arch bridge

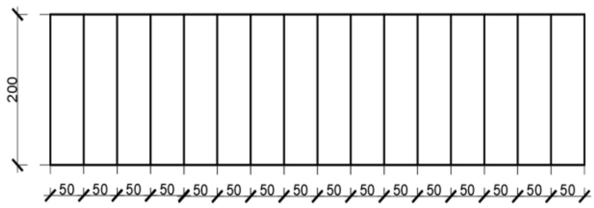

Figure 2. Top view of curved bridge

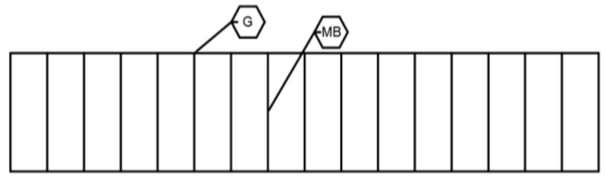

Figure 3. Longitudinal and transverse girder sections

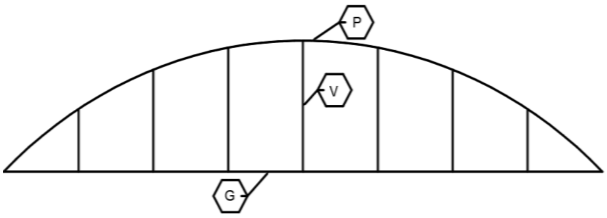

Figure 4. Curved and hanger sections

2.3 Methodology

The concept of this bridge is an arch bridge with a hollow profil steel structure. The structural capability of the arch bridge is influenced by the hanger element as the main support for the bridge floor. Therefore, the placement of the hanger location needs to be optimised.

This research was carried out by varying the position of the hanger when receiving dynamic loads. There are three hanger variations, namely the central model with a hanger spacing ratio of (1.3 - 1.1 - 0.9 - 0.7), the flat model with a hanger spacing ratio of (1 - 1 - 1 - 1) and the edge model with a hanger spacing ratio of (0.7 - 0.9 - 1.1 - 1.3). Each variation is then modelled using SAP2000 software with a bridge service condition load based on SNI 1725 - 2016, namely self-weight load (MS), additional dead load (MA), dynamic pedestrian load (TA), which is then calculated using a load combination in the Strong 1 boundary condition, which calculates the forces acting on the bridge in a normal state, namely 1 MS + 1 MA + 1.8 TP.

The output of the internal forces in terms of bending moments, axial compression, axial tension and deflections obtained are then analysed to determine the performance of the structure due to the influence of the hanger spacing. There are 3 objectives in this study, namely to know the value of internal forces that occur due to dynamic loads in 3 variations of the model, to know the value of deflections that occur due to dynamic loads in 3 variations of the model, and to know the structural capacity in 3 variations of the model so that the most optimal hanger distance is obtained. In order to achieve these objectives, a research flow chart is planned as shown in Figure 5.

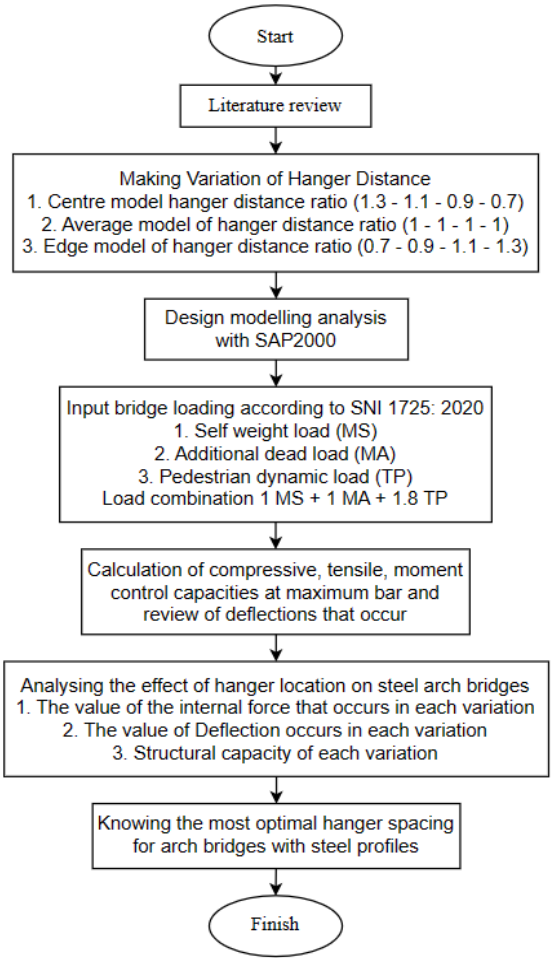

Figure 5. Flowchart of the research

2.4 Research Variables

In this research, the variables used consisted of independent variables and dependent variables which were grouped based on the research objectives. Independent variable consists of hanger distance and test load. Dependent variable involves of deflection value and value of the maximum internal force that occurs.

The variation models tested were divided into 3 groups based on the spacing of the hangers, namely the Centre Model, the Flat Model and the Edge Model. Each model is tested with the same load intensity variation to determine the maximum load that the bridge structure can withstand against the allowable deflection limit and the structural capacity limit specified in the regulations. The configurations of the arc bridges analysed are as follows, with details of the grouping of model variations shown in Table 1.

The centre model is hanger distance ratio (1.3 - 1.1 - 0.9 - 0.7). For the centre model, the bridge hanger spacing is designed to be closer to the centre of the bridge with a spacing difference of 20 cm, can be seen in Figure 6.

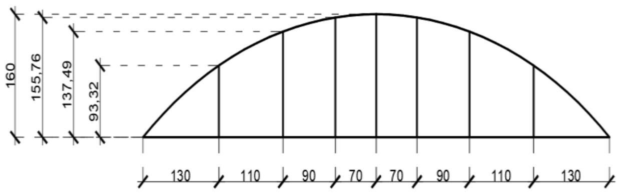

Figure 6. Hanger distance for centre model

The flat model ishanger distance ratio (1 - 1 - 1 - 1). For the flat model, the hanger spacing is designed to be evenly spaced along the span, spaced every 100 cm, can be seen in Figure 7.

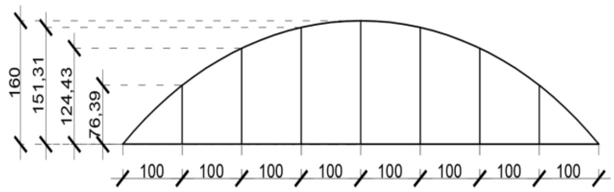

Figure 7. Hanger distance for flat model

The edge model is hanger distance ratio (0.7 - 0.9 - 1.1 - 1.3). For the edge model, the bridge hanger spacing is designed closer to the edge of the bridge with a spacing difference of 20 cm, can be seen in Figure 8.

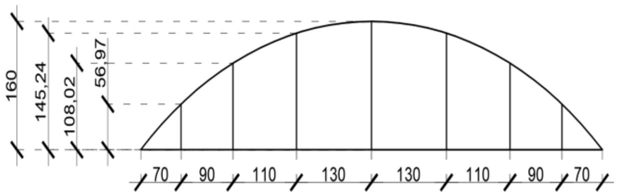

Figure 8. Hanger distance for edge model

2.5 Bridge Loads

The standard used for planning this bridge is SNI 1725 - 2016 concerning Loading for Bridges. In this test, the arch bridge will dead live and live loads.

Dead Load Self Weight (MS). Self-weight is the weight that comes from structural elements plus non-structural elements that the bridge holds and is fixed such as steel structures, bridge floor plates, and bridge railings. The large plan for the self-weight load that works on the pedestrian bridge consist of floor slab load calculated uses Equation 1. The pedestrian bridge with galvanised pipe railing ∅ 2.5" uses Equation 2. Then, the total self-weight load of the structure uses Equation 3.

$$MS1 = L \times P \times t \times \gamma beton \tag{1}$$
$$MS1 = 2\,m \times 8\,m \times 0{,}2\,m \times 2{,}320\,\frac{kg}{m^3}$$
$$MS1 = 7{,}424\,kg$$

$$MS2 = P \times w_{railing} \tag{2}$$
$$MS2 = 8\,m \times 128\,\frac{kg}{m}$$
$$MS2 = 1{,}024\,kg$$

$$MS_{total} = (MS1 + MS2) \div join \tag{3}$$
$$MS_{total} = (7{,}424 + 1{,}024)\,kg \div 34\,join = 249\,kg$$

Where *MS1* is the floor slab load, *L* is the bridge width, *P* is the bridge length, *t* is the floor slab thickness, and γ is the concrete specific gravity (2,320 kg/m^3). Where *MS2* is the railing weight, *w* railing is the railing weight per meter (128 kg/m).

Additional Dead Load (MA). Additional dead weight is the weight on the bridge which is a nonstructural element whose magnitude can change during the life of the bridge such as asphalt layers, overlays, and puddles of rainwater. The following is a large plan of additional dead weight loads working on the pedestrian bridge consist of rainwater flooding load uses Equation 4.

$$MA = L \times P \times t \times \gamma_{air} \div join \tag{4}$$

Where *MA* is the rainwater inundation load, *L* is the bridge width, *P* is the bridge length, *t* is the inundation thickness, and γ is the specific gravity of water (1000 kg/m^3).

$$MA = 2\,m \times 8\,m \times 0.05\,m \times 1{,}000\,\frac{kg}{m^3} \div 34$$

$$MA = 240\,kg$$

Dynamic Pedestrian Load (TP). The dynamic load in question is the pedestrian load (TP) which is planned to be a minimum of 5 kPa or 510 kg/m^2 based on SNI 1725 - 2016. So if made as a centralised load the correlation is calculated as follows Equation 5.

$$TP = L \times P \times \mathrm{TP} \div jumlah\ join \tag{5}$$

where *LL* is the live load, *L* is the bridge width, *P* is the bridge length, and *TP* is the pedestrian load rate (510 kg/m^3).

$$TP = 2\,m \times 8\,m \times 510\,\frac{\mathrm{kg}}{\mathrm{m3}} \div 34 = 240\,kg$$

In this study, loading variations were also reviewed to determine the maximum load that can be withstood by the bridge based on the requirements of the deflection permit and profile capacity. The load variation is the addition of load intensity as shown in the Table 1.

2.6 Deflection of The Bridge

There are limits to the allowable deflection required in bridge design [35], according to the Bridge Management System (BMS) in the Directorate General of Highways Bridge Engineering Planning Regulations 1992, which states that the maximum deflection of a continuous girder is 1/800 x span. And when the bridge is in an urban area with part of the path used for pedestrians, the deflection limit is 1/1000 x span. The maximum deflection at the end of the cantilever must be less than 1/300 x the cantilever length. And for bridges with part of the path used for pedestrians, the deflection limit is 1/400 x cantilever length. The steel arch bridge design for this study is assumed to be a pedestrian bridge located in an urban area. For this reason, the maximum deflection calculation of the bridge is 1/1000 of the bridge span.

$$\Delta = \frac{1}{1000} \times L \tag{6}$$

$$\Delta = \frac{1}{1000} \times 8000 = 8\,mm$$

2.7 Checking the Capacity of Steel Section

The strength testing of steel profiles is based on the Indonesian National Standard SNI 1729 - 2020 on Specifications for Structural Steel Construction, which consists of testing the tensile strength, compressive strength, and flexural strength of IWF profiles (IWF 125.60.6.8 and IWF 100.50.5.7).

Compressive Axial Control. Referring to SNI 1729: 2020 Chapter D, when the profile enters the flexural buckling limit state, the nominal compressive strength must be taken from the lowest value of the 2 formulas. There are if $Fy/Fe \leq 2{,}25$ can be calculate with Equation 7.

$$\emptyset Pn = \emptyset \times \left(0{,}658^{\frac{Fy}{fe}}\right) \times Fy \times A \tag{7}$$

Where Ø is the reduction in compressive strength (0.9), F_y is the yield strength of steel (Mpa), F_e is the elastic bending stress (Mpa), and *Ag* is the cross-sectional area of the profile (mm^2).

Then if F_y/F_e>2.25, *ØPn* can be calculate with Equation 8.

$$\emptyset Pn = \emptyset \times 0{,}887 \times Fe \times Ag \tag{8}$$

Table 1. Grouping of model variation

Model	Dynamic load capacity (kg)
Centre Model	240
	360
	480
	600
	720
	840
	960
	1080
	1200
	1320
Flat Model	240
	360
	480
	600
	720
	840
	960
	1080
	1200
	1320
Edge Model	240
	360
	480
	600
	720
	840
	960
	1080
	1200
	1320

Where Ø is the reduction in compressive strength (0.9), F_e is the elastic buckling stress (Mpa), and Ag is the cross-sectional area of the profile (mm^2) uses Equation 9.

$$Fe \frac{\pi^2 E}{(Lc/r)^2} \quad (9)$$

To determine the compressive axial capacity of the profile cross section, Equation 7 or Equation 8 is used depending on the condition of Fy / Fe. The results of the compressive axial capacity are as follows if $F_y/F_e \leq 2.25$.

$$Fe = \frac{\pi^2 \times E}{(Lc/r)^2} = 767.56$$

$$Fcr = \left(0.658^{\frac{Fy}{Fe}}\right) \times Fy = 210.6$$

$$\emptyset Pn = \emptyset \times \left(0.658^{\frac{Fy}{Fe}}\right) \times Fy \times Ag = 558.182\ kN$$

Tensile Axial Control. Based on SNI 1729: 2020 Chapter E, the nominal tensile strength when the yield condition is the nominal resistance of the profile using Equation 10, while when the tensile collapse condition uses Equation 11.

$$\emptyset Pn = \emptyset \times F_y \times A_g \quad (10)$$

Where Ø is the reduction in yield tensile strength (0.9), F_y is the yield strength of steel (Mpa), and Ag is the cross-sectional area of the profile (mm^2).

$$\emptyset Pn = \emptyset \times F_u \times A_e \quad (11)$$

Where Ø is the reduction in tensile fracture strength (0.75), F_u is the ultimate strength of steel (Mpa), and A_e is the effective net area of the profile cross-section (mm^2).

To determine the tensile axial capacity of the yield condition profile section, Equation 10 is used to calculate the tensile axial resistance capacity.

$$\emptyset Pn = \emptyset \times F_y \times A_g = 638.23\ kN$$

Flexural Control. Based on SNI 1729: 2020 Chapter F, the nominal flexural strength (Mn) is determined based on 3 conditions, namely for compact cross-sections, the nominal flexural strength is equal to the plastic flexural strength of the cross-section (Mn = Mp), when the span length is more than the maximum plastic length which uses the lateral torsional buckling limit, and when the cross-section is non-compact or slender, the flexural strength uses the local buckling limit.

In the planning of this arc bridge, a compact profile cross-section condition is planned with a profile length less than the plastic length limit so that the flexural strength uses Equation 12.

$$\emptyset Mn = \emptyset Mp = \emptyset \times F_y \times Z_x \quad (12)$$

Where Ø is the reduction in flexural strength (0.9), Fy is the yield strength of steel (Mpa), and Zx is the plastic section modulus about the x-axis (mm^3).

To determine the bending moment capacity of the profile section in the yield condition with the compact profile condition, Equation 12 is used to calculate the bending resistance capacity.

$$\emptyset Mn = \emptyset Mp = \emptyset \times F_y \times Z_x = 33{,}206.6\ kN.mm$$

2.8 Bridge Rasio

Bridge ratio is one of the assessment methods in choosing the most efficient bridge design. The bridge ratio is obtained by reviewing the weight of the bridge structure and the amount of deflection that occurs [15]. The heavier the bridge, the less efficient the structure and the greater the deflection of the bridge, the less sturdy the bridge. Therefore, the formula for the weight of the structure multiplied by the actual deflection is used to obtain the value of the bridge ratio. The bridge model with the smallest ratio is the most efficient bridge model.

2.9 Arch Bridge Analysis Method

In this research, the steel arch bridge structure will be analysed using the SAP2000 auxiliary program based on numerical concepts with the finite element method. Steel arch bridge structures with various variations in hanger spacing will be analysed to obtain internal forces and deflections in each structure which will be the basis for determining the efficiency level of each design so that the most optimal design is obtained.

3. Results and Discussion

Bridge structure analysis was carried out on each model against a moving load with a multiple intensity of 120 kg. The internal forces and deflections that occur in each model are then recapitulated and then analyse the effect of hanger distance placement on the ability of the arch bridge structure.

3.1 Compression Axial

Based on the SAP2000 programme analysis of each bridge model, the maximum compressive axial force obtained with the addition of the test load capacity of each intensity on each bridge model is shown in Table 2.

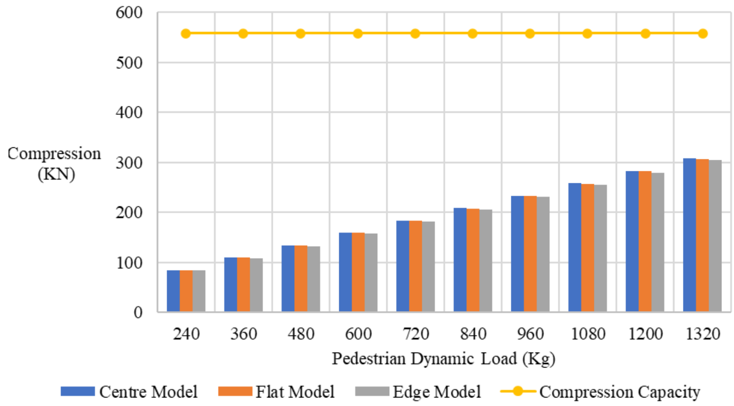

Figure 9. Comparison of øpn vs. pu compression axial calculations for 3 types of bridges

It can be seen that the centre model produces the greatest compressive axial yield. When compared to the compressive axial resistance capacity in Figure 9, the most efficient hanger spacing is in the centre model with the largest compressive axial value ratio of 55.13% to the compressive axial capacity, followed by the flat model with 54.99% and the edge model with 54.33%. So from the results of the analysis it is known that in addition to the higher the arch the more efficient [18], the location of the arch hanger also has an effect with the centre model being the most efficient design in resisting the compressive axial force that occurs.

Table 2. Results of axial stress (pu) analysis of 3 bridge models

Load Kg	Centre Model KN	Flat Model KN	Edge Mode KN
240	85.25	84.95	84.16
360	109.97	109.62	108.63
480	134.69	134.29	133.09
600	159.41	158.95	157.56
720	184.14	183.62	182.02
840	208.86	208.29	206.49
960	233.58	232.96	230.96
1080	258.30	257.62	255.42
1200	283.02	282.29	279.89
1320	307.74	306.96	304.36

3.2 Tensile Axial

Based on the SAP2000 programme analysis of each bridge model, the maximum tensile axial force obtained with the addition of the test load capacity of each intensity on each bridge model is shown in Table 3.

From Figure 10, which compares the axial tensile capacity that the section can withstand with the largest axial tensile force that occurs, it can be seen that the most efficient hanger spacing is on the edge model with the largest ratio of axial tensile value to axial tensile capacity of 41.11%, followed by the flat model with 40.98% and the centre model with 40.95%. From the results of these analyses, it is clear that the location of the hanger of the arch bridge also affects the performance of the structure, with the edge model being the most efficient model to resist axial tensile.

Table 3. Tensile axial analysis results (pu) 3 bridge models.

Load Kg	Centre Model KN	Flat Model KN	Edge Mode KN
240	72,13	72,14	72,27
360	93,07	93,08	93,30
480	114,00	114,03	114,33
600	134,94	134,98	135,36
720	155,87	155,94	156,40
840	176,81	176,90	177,43
960	197,74	197,85	198,46
1080	218,68	218,81	219,49
1200	239,61	239,77	240,52
1320	260,55	260,73	261,55

3.3 Flexural

Based on the SAP2000 program analysis of each bridge model, the maximum moment obtained with the addition of the test load capacity of each intensity on each bridge model is shown in Table 4.

Table 4. Fluxural stress analysis result (mu) 3 bridge models.

Load Kg	Centre Model kN.mm	Flat Model kN.mm	Edge Mode kN.mm
240	2,333.27	1,733.01	2,154.46
360	3,020.37	2,244.04	2,791.41
480	3,707.46	2,755.07	3,428.35
600	4,394.56	3,266.09	4,065.30
720	5,081.66	3,777.12	4,702.24
840	5,768.75	4,288.15	5,339.19
960	6,455.85	4,799.18	5,976.13
1080	7,142.95	5,310.21	6,613.08
1200	7,830.04	5,821.24	7,250.03
1320	8,517.14	6,332.27	7,886.97

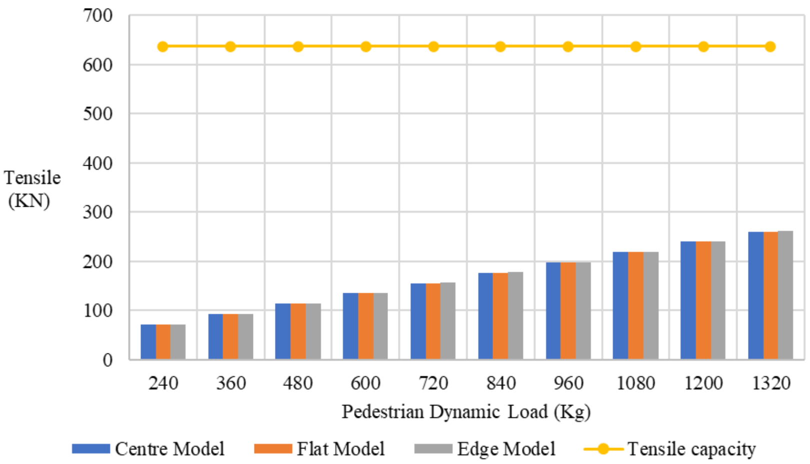

Figure 10. Comparison of øpn vs. pu tensile axial calculations for 3 types of bridges

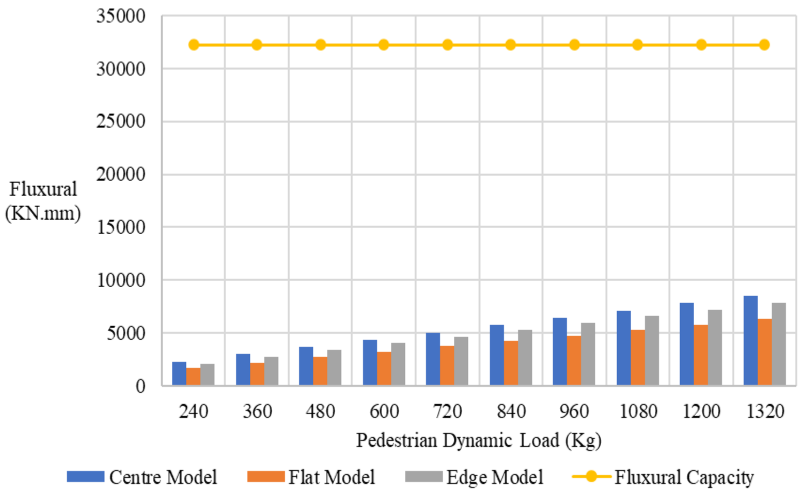

Figure 11. Comparison of calculation of flexural moment ømn against mu 3 bridge models

It can be seen that the centre model produces the largest moment can be seen in Table 4. When compared with the moment resisting capacity in Figure 11, the most efficient hanger spacing is in the centre model with the largest moment value ratio of 26.45% to the profile bending capacity, followed by the edge model with 24.49% and the centre model with 19.66%. Thus, from the results of the analysis it is known that in addition to the higher the arch the more efficient [13], the location of the arch hanger also has an effect with the centre hanger model being the most efficient model in resisting the moment that occurs.

3.4 Deflection

The deflections in the bridge structure were obtained from the SAP2000 analysis of each bridge model. The maximum deflection value is taken at the centre of the bridge span. The maximum deflection is obtained by adding the test load capacity such that each load intensity produces a constant addition of deflection in the three variations of the bridge model. The results of the recapitulation of the deflection magnitude of each intensity of the 120 kg dynamic load increase on each model can be seen in Table 6.

Table 5. Deflection analysis results of 3 bridge models

Load	Centre Model	Flat Model	Edge Mode
Kg	mm	mm	mm
240	2.46	2.58	2.73
360	3.17	3.33	3.53
480	3.88	4.08	4.32
600	4.59	4.84	5.11
720	5.30	5.59	5.90
840	6.01	6.34	6.70
960	6.72	7.09	7.50
1080	7.43	7.84	8.29
1200	8.15	8.59	9.09
1320	8.86	9.34	9.88

From Table 5 can be seen that the centre model produces the smallest deflection, followed by the flat model and the edge model as the bridge model with the largest deflection of the three models. From Figure 12 it can be seen that the maximum dynamic load that can be withstood by the centre and flat models before the actual deflection exceeds the maximum allowable deflection limit is 1080 kg and for the edge model the maximum dynamic load is 960 kg. From the results of the analysis it can be seen that the hanger spacing, as well as being influenced by the bridge connection [15], also influences the deflection value that occurs with the centre model giving the smallest deflection results compared to the flat and edge models.

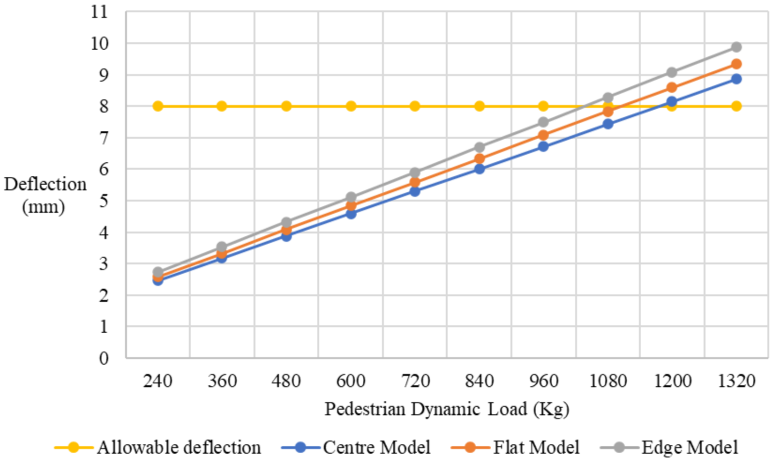

Figure 12. Comparison of allowable deflection calculation to actual deflection of 3 bridge models

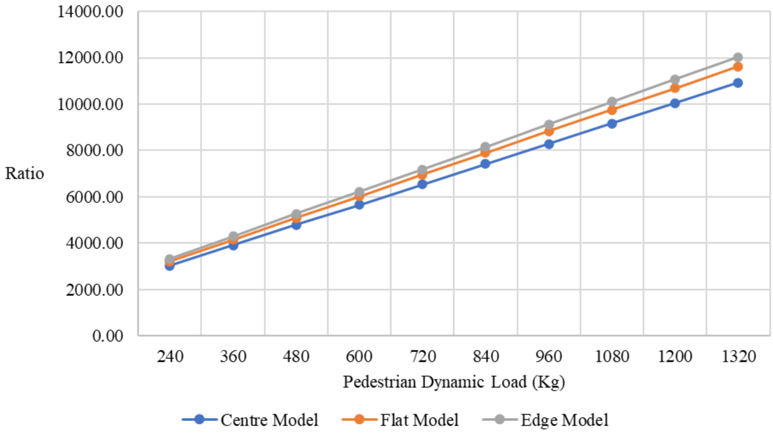

Figure 13. Results of recapitulation of the ratio of each arch bridge model

3.5 Bridge Ratio

From the analysis results it can be concluded that the centre model bridge has the smallest ratio, followed by the flat model bridge and the edge model bridge has the largest ratio can be seen in Figure 13. From these results it can be seen that the effect of hanger spacing on the structural capabilities of the bridge is that the centre model produces the most efficient structural design compared to other arc bridge models. The results of the optimisation of the arc bridge design carried out have closed the gap of previous research, namely that in addition to varying the height of the curved arch and connection, it is also possible to vary the bridge hanger spacing.

4. Conclusions

Based on the results of the research in the form of finding the most optimal arc bridge design based on the location of the hanger, the centre model provides the most efficient structural performance results in resisting compressive axial forces with all three models able to withstand a dynamic load of 1320 kg. The edge model provides the most efficient structural performance results in resisting tensile axial forces with all three models being able to withstand a dynamic load of 1320 kg. The centre model provides the most efficient structural performance results in resisting the moments that occur, with all three models able to withstand a dynamic load of 1320 kg. The centre model provides the least deflection results, with the centre and flat models able to resist dynamic loads up to 1080kg and the edge model only able to resist dynamic loads up to 960kg. Based on the results of the analysis it is known that the centre model has the smallest ratio so it can be concluded that there is an effect of the hanger spacing on the ability of the bridge structure with the centre mode producing the most efficient structural design when compared to other arc bridge models.

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