

## COMPARISON ANALYSIS OF RAILWAY BRIDGE MODUL FOR “I” GIRDER TYPE AND “WARREN” TRUSS TYPE

### ANALISIS PERBANDINGAN MODUL JEMBATAN BAJA KERETA API TIPE GELAGAR “I” DAN TIPE RANGKA “WARREN”

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#### Abstract

The railway bridge in Indonesia, with a width of 1067 mm, was built in 1878, so that maintenance modules are needed to repair or to replace of construction modul at regular intervals. Implementation of maintenance and repairs refers to the Minister of Transportation Regulation No. 60 of 2012. Problems were encountered in the field at the BH182 Daop 2 railway bridge in Bandung due to lowering structural strength. Therefore, it was necessary to repair the bridge module with a new bridge design. The purpose of this study is to analyse and to calculate strength of the structure and to determine effectiveness of the use of construction materials on 2 alternative bridge construction selection with the type of “I” girder and the type of “Warren” Truss. Design implementation method used is to utilize Midas Civil Structure software. The loading used for railway bridges is grouped into three load groups, namely the girder's self-weight, additional dead load, and live load. Additional dead load analysed is line load including bearings, while for live load is trainset load based on loading requirements. From the results of calculations between the steel bridge “I” girder type height of 300 cm and the type of “Warren” Truss height of 600 cm, each span of 30 m showed that those were a function of the railway bridge. It would be more effective to use the type of “Warren” Truss structure that is quite able to withstand train traffic loads in accordance with applicable standards.

Keywords: Load; Railway Bridge; PM 60/2012; SNI 2833:2016; Load Standard; Load Type; Load Combination.

#### Abstrak

*Jembatan kereta api Indonesia lebar sepur 1067 mm dibangun sejak tahun 1878, sehingga perlu dilakukan perawatan, perbaikan ataupun penggantian modul konstruksi secara berkala. Pelaksanaan perawatan dan perbaikannya mengacu Peraturan Menteri Perhubungan No. 60 tahun 2012. Permasalahan yang ditemui pada jembatan kereta api BH182 Daop 2 Bandung adalah karena kondisi kekuatan strukturnya sudah berkurang, maka perlu dilakukan perbaikan modul jembatan dengan desain jembatan yang baru. Tujuan dari penelitian ini adalah untuk menganalisis dan menghitung kekuatan struktur serta mengetahui efektifitas pemanfaatan material konstruksi atas 2 alternatif pilihan konstruksi jembatan dengan tipe gelagar “I” atau tipe rangka “Warren”. Metode pelaksanaan desain mengacu pada SNI 1725:2016, dengan menggunakan software Midas Civil Structure. Pembebanan yang digunakan pada jembatan kereta api dikelompokkan menjadi tiga kelompok beban, yaitu berat sendiri gelagar, beban mati tambahan, dan beban hidup. Beban mati tambahan yang dianalisis yaitu beban jalur termasuk bantalan, sedangkan untuk beban hidup adalah beban rangkaian kereta api berdasarkan persyaratan pembebanan. Dari hasil perhitungan antara jembatan baja tipe gelagar “I” tinggi 300 cm dan tipe rangka “Warren” tinggi 600 cm, masing-masing bentang 30 m sebagai fungsi jembatan kereta api, ternyata akan lebih efektif menggunakan tipe struktur rangka “Warren” yang cukup mampu menahan beban lalu-lintas kereta api sesuai standar yang berlaku.*

*Kata kunci: Beban; Jembatan Kereta Api; PM 60/2012; Standar Pembebanan; Jenis Beban; Kombinasi Pembebanan.*

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## INTRODUCTION

Indonesian railroad track with a width of 1067 mm was built on the Dutch colonial era in 1878. Implementation of maintenance and reparation of railroad tracks including bridges, has followed to the loading regulations stipulated in the Minister of Transportation Regulation No. 60 of 2012 (PM 60/2012)<sup>1)</sup>.

Railroad transportation is a type of transportation that moves on rails. Railroad constructed during the industrial revolution is a means of transportation to transport large quantities of goods for long distances. One freight wagon with an axle pressure of 18 tons can load tens of tons of goods<sup>2)</sup>. Railroad was introduced in Indonesia, during the Dutch colonial period and the first rail line built by the "Staats Spoorwegen" (SS) company. This railroad was constructed between Surabaya-Pasuruan along 115 kilometres and it was inaugurated on May 16, 1878<sup>3)</sup>. In its development to date, railroad transportation has become a major requirement for urban communities in the areas of Jakarta, Bogor, Depok, Tangerang and Bekasi<sup>4)</sup>. The current condition of railroad modes has the least pollution impact on the environment at about 1% compared to other transportation in Indonesia. In addition, trains have various advantages including being free from traffic because they have their own track, and are more fuel efficient due to their large load capacity in one trip<sup>5)</sup>.

In the railroad network, it is not immune to the building of a railroad bridge connecting two disconnected areas and the need for repair and maintenance. In accordance with Law No. 23 of 2007 (6) article 114 paragraph (5) states that the maintenance of large railway facilities can be carried out at the locomotive depot or Balai Yasa. All bridge maintenance is carried out by Balai Yasa Kiara Condong in accordance with applicable regulations. Referring to the National Railroad Master Plan<sup>7)</sup>, the target distribution of passenger transport is of 11-13% and freight transportation is of 15-17% with a railway network of 10,000 km, double tracks and electrification on the main traffic. Trains are targeted to be the backbone of integrated, safe, comfortable and affordable urban transportation. This is a business opportunity that needs to be optimized by PT. KAI.

For the continuity of the railroad business sector, it is necessary to take maintenance measures such as damage to railroad bridges by replacing damaged or patched bridge components with new steel

plates (riveted or electrically welded). Damage to steel that has reached of 25% of the overall weight of the bridge must be replaced by a new bridge<sup>8)</sup> in accordance with the Minister of Transportation Regulation Number: PM 64/ 2014<sup>9)</sup> concerning the implementation of the first and periodic testing of railroad tracks, railway buildings and train operation facilities.

Problems were encountered in the field on the BH182 Daop 2 Bandung railroad bridge spanning a total of 30 meters, because it does not follow uniformity of the loading regulations set out in PM 60/2012 and it reduces structural strength conditions. Therefore, it is necessary to repair the bridge by carrying out a new bridge design. The design implementation method used is to utilize Midas Civil Structure software with design requirements set out in PM 60/2012 in order to determine the type of structure and material profile used. This paper examines and analyses calculations of steel bridges for a 30 m span train on the type of "I" Girder structure height of 300 cm and the type of structure of the Warren Order Truss height of 600 cm.

Loads calculated are those used in accordance with the bridge function for the train. For railroad bridges; loads are grouped into 3 groups namely girder own weight, additional dead load, and live load. For additional dead load analysed, the train load includes bearings, based on PM 60/2012. Living load acting on the structure of a railroad bridge is a burden originating from a series of trains, the amount of which is determined based on the 1921 Load Plan.

Analysis of steel structure type "I" girder bridge for railroad using girder length 30.0 m, centre distance between girder 4.90 m, custom steel girder profile with melting stress 340 MPa, SS400 steel diaphragm 16 mm thick web, wing thickness 25 mm. Dimensions of castoum H3000 x 800 x 32 x 32. As for the analysis of the calculation of steel bridge type "Warren" Truss structure for trains using girder length 30.0 m, centre distance between girder 450 cm, girder profile SM490YB with 340 MPa melting stress, WF steel diaphragm 600x300x16x25.

The objectives of this study are as follows: (1) analyse the structural strength of the "I" profile girder type and the "Warren" skeletal type structure of the forces acting in particular the life load on the railroad tracks; (2) calculate the strength of steel girder I type bridges and Warren Truss types for railroad tracks according to standards of applicable load; and (3) determine the effectiveness of the use of steel girder type

bridge I with Warren steel Truss type bridge as a function of the railroad.

## RESEARCH METHOD

Flow of activities during study is presented on Figure 1. Figure 1 is the research flowchart that shows the research methodology used in this study.

### Calculation Method

Calculation method refers to the standards set forth in SNI 1725:2016<sup>10)</sup>. The loading specifications used in the structure analysis and technical plan refer to the loading specifications used in the structural analysis and the technical plan for the upper building in accordance with the Obligation of RM1921 adopted by PM 60/2012<sup>1)</sup>.

### Dead Load

Specific gravity of material that can be used in dead load calculation is in accordance with the applicable standards in the Minister of Transportation Regulation No. 60/2012 in general can be seen in Table 1.

Table 1.  
Specific Gravity<sup>1)</sup>

Material	Specific Gravity
Steel, Cast Steel	78.50 kN/m <sup>3</sup>
Cast Iron	72.50 kN/m <sup>3</sup>
Wood	8.00 kN/m <sup>3</sup>
Concrete	24.00 kN/m <sup>3</sup>
Waterproof bitumen	11.00 kN/m <sup>3</sup>
Ballast Gravel or Split Stone	19.00 kN/m <sup>3</sup>

### Life Load

Live load used is the largest axle load in accordance with the operated rail facility plan or the scheme of the load plan. For axle loads up to 18 tons the RM1921 payload plan can be used as shown in Figure 2.

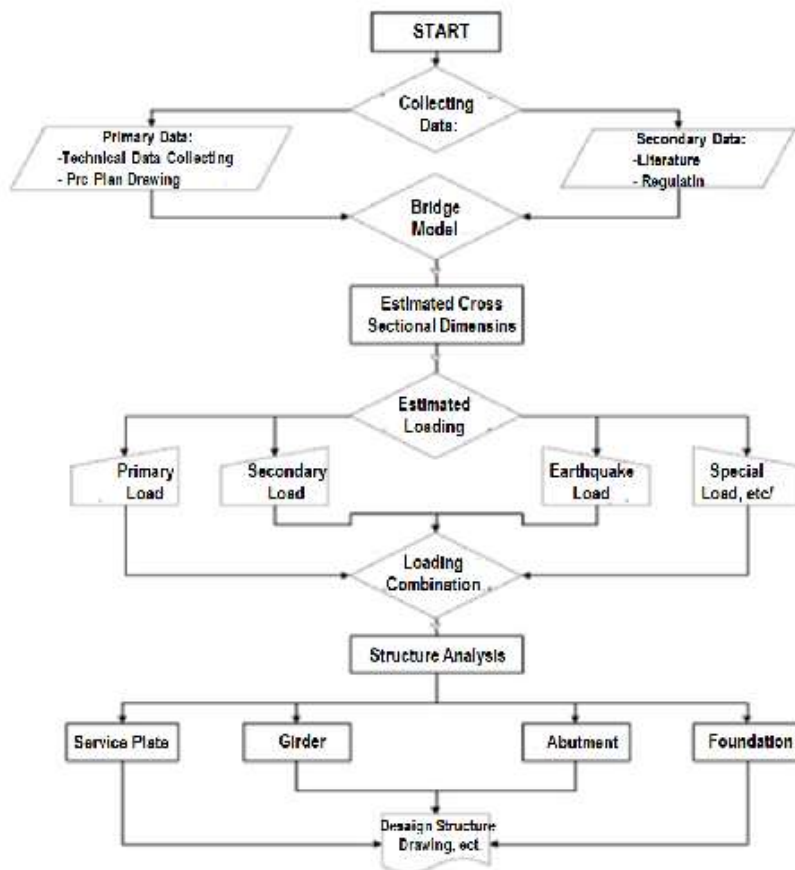


Figure 1.  
Research Flowchart

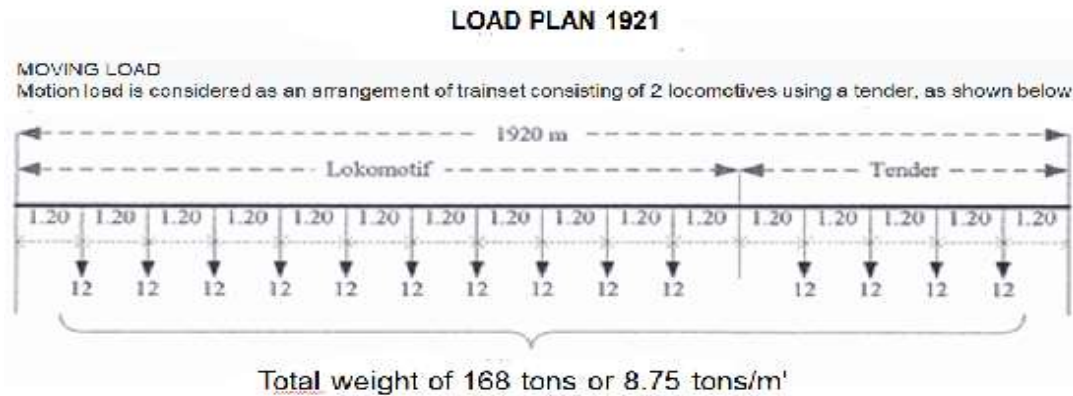


Figure 2.  
Load Plan 1921<sup>1)</sup>

**Additional Dead Load**

Railroad tracks are non-structural parts that must be taken into account as additional dead loads with mass density for 7,850 kg/m<sup>3</sup>.

**Impact Load**

Shock loads are obtained by multiplying *i* factor against the train load. The simple calculation for *i* factor is to use the following formula:

- a. For rails on ballast pads,  $i = 0.1 + 22.5/(50+L)$  (1)
- b. For rails on wood placement,  $i = 0.2 + 25/(50+L)$  (2)
- c. For rails directly on steel,  $i = 0.3 + 25/(50+L)$  (3)

whereas:

*i* = impact factor; and  
L = span length.

**Impact factor  $i = 0.3 + 25 / (50+30) = 0.6125$**

**Horizontal Load**

**a. Centrifugal load**

Centrifugal load is obtained by multiplying the  $\alpha$  factor against train load. The load operates at the centre of the train's gravity in the direction of the rail perpendicular horizontally.

$$\alpha = V^2/(127 R) \quad (4)$$

whereas:

$\alpha$  = centrifugal load coefficient;  
V = max railway speed in curve (km/hr);  
R = curve radius (m).

**b. Lateral load**

Lateral load of the train is shown in Figure 3. The load operates at the top and is perpendicular to the rail direction horizontally. The amount is of 15% or 20% of the axle load for each locomotive or electric/diesel train.

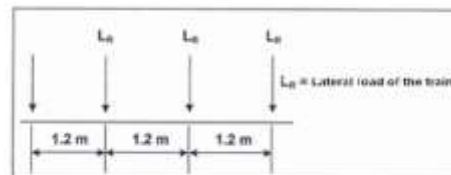


Figure 3.  
Train Lateral Load<sup>1)</sup>

**c. Wind load**

Wind loads work perpendicular to the rail horizontally. The typical values are as follows:

- 1) 3.0 kN/m<sup>2</sup> in the vertical bridge projection area without a train on it. However, 2 kN/m<sup>2</sup> in the projection area of the truss in the direction of the arrival of wind, not including the floor system area.
- 2) 1.5 kN/m<sup>2</sup> in the railroad and bridge area, with trains on it, exceptions are 1.2 kN/m<sup>2</sup> for bridges other than deck/entry girder or composite bridges, while 0.8 kN/m<sup>2</sup> for the truss projection area in the direction of the coming wind.

**d. Earthquake Load**

Bridges must be planned so that they are less likely to collapse but can experience significant damage and disruption to service due to the earthquake with a possibility of exceeding 7% in 75 years<sup>11)</sup>.

Partial or complete replacement of structures is needed in some cases. Higher performance such as operational performance can be determined by the authorities.

**e. Load Combination**

Calculation of bridge construction is calculated from the results of the largest combination of loading. The combination of loading will be further regulated by Regulation of the Director General (Ministry of Transportation). The loading calculation flowchart can be seen in Figure 4.

**f. Deflection Requirements**

Deflection is defined as a magnitude of the deflection that must not exceed the coefficient requirements on the theoretical length. Maximum deflection coefficient of steel bridges, as stipulated in the Minister of Transportation Regulation No. 60 of 2012 in Table 2.

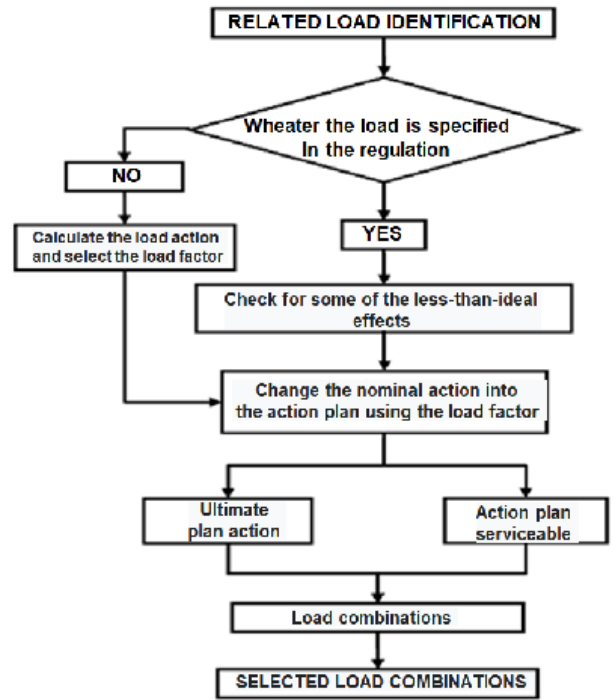


Figure 4. Flowchart of Loading Calculation

Table 2. Max Deflection coefficient <sup>1)</sup>

Type	Girder			Truss
	L (m)	L < 50	L ≥ 50	Whole Truss
Train Type		L/800	L/700	L/1000
Loco		L/800	L/700	
Electric Train and/or Train	V (km/hr)	L/800		
		100 < V ≤ 130	L/800	L/700
		100 < V ≤ 130	L/1100	L/800

**RESULTS AND DISCUSSION**

**Geometry of Bridge Structures**

In determining the geometry of roads and railroad bridges, they must follow the requirements set by the Government as outlined in PM 60/2012 (1) (MOT). Furthermore, the geometry of the "I" Girder steel bridge structure for the railroad in the calculation analysis is the same as the geometry data of the bridge structure in the longitudinal direction of 30.0 m with the width of the transverse direction which is of 4.9 m. The "I" girder segmentation of the longitudinal direction of the bridge is divided into 10 segments with each segment length sequentially of 10 x 3 m. The number of "I" girders in the direction of transverse was 2 pieces with a distance between girders of 4.9 m. Figure 5 is the cross sectional of the "I"

transverse girder bridge structure for the railroad function, while Figure 6 is the cross sectional of the "Warren" Truss Steel Bridge.

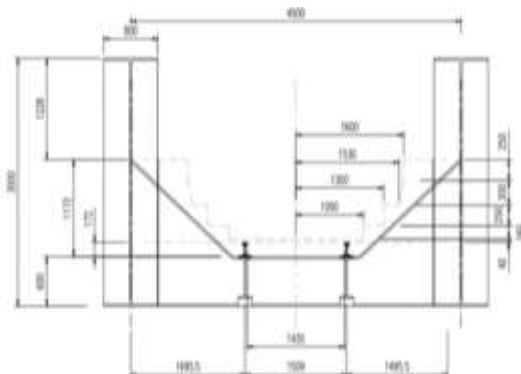


Figure 5. Result Design of Geometry for "I" Girder Bridge Structure

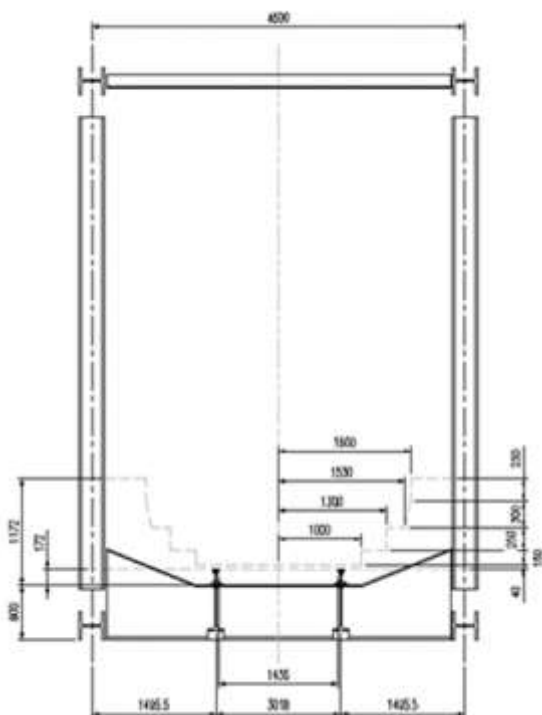


Figure 6.  
Result Design of Geometry Structure for  
"Warren" Truss Steel Bridge

The geometry of the "Warren" steel bridge structure for the railroad in the calculation analysis is the same as the geometry data of the bridge structure in the longitudinal direction of 30.0 m with a transverse direction width of 4.5 m.

The longitudinal Truss segment of the bridge is divided into 10 with the net distance (edge) of the segment being 3.0 m. The number of girders Truss in the direction of transverse as many as 2 pieces with a centre distance between girder of 4.5 m.

### Bridge Material Technical Specifications

The technical specifications of steel bridge type "I" girder structures and types of Warren truss structures can be outlined in Table 3 and Table 4. Numbers presented in Table 3 and Table 4 are results of observation during field investigation.

### Workloads

Loads acting on railroad steel bridges for the type of "I" girder structure and type of Warren Truss structure are presented in Table 5 and Table 6.

Table 3.  
Technical Specification of "I" Girder

"I" Girder	Dimension
Span	30.0 m
Girder Height	300 cm
Girder distance	490 cm
Yield strength of steel Custom (SM490YB)	340 MPa
Track weight	7.850 kg/m3

Table 4.  
Technical Specification of "Warren" Truss

Warren Truss	Dimension
Span	30.0 m
Truss Height	600 cm
Girder Truss Vertical Distance	450 cm
Yield strength of steel profile 300 x 300 x 16 x 20	340 MPa
Track weight	7.850 kg/m3

Table 5.  
Working loads on the "I" Girder

Component of Load	Bridge Function	
	Railway	Load Value/m'
Dead Load	Girder weight	100,962.90 kg
	Track	7,850 kg/m3
	Diaphragm (SS400)	745.01 kN/m'

Table 6.  
Working loads on the "Warren"

Component of Load	Bridge Function	
	Railway	Load Value/m'
Dead Load	Truss weight	81,624.41 kN/m'
	Track	1,850 kg/m3
	Diaphragm (WF 600x200)	42.40 kN/m'

### The Results of Modelling the "I" Girder Type and the "Warren" Truss Type

Modelling the "I" girder bridge is performed by utilizing the Midas Civil Structure software, which begins with the input of material property data used and processes the data through isometric determination of the floor plan bridge at joints, stem numbering, and profiles.

Results of analysis and simulation are presented in Figure 7, 8, 9, and 10. Furthermore, it can be analysed the strength ratio and deflection control due to dead load and live load. The results and analysis are presented in Figure 11, 12 and 13, respectively.

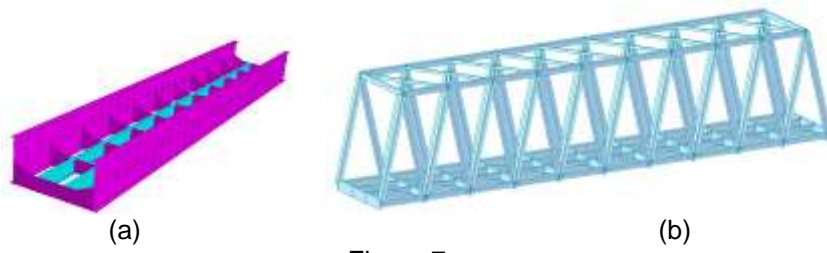


Figure 7.  
 Results for "I" Girder Isometric Modelling (a) and Warren's Isometric Truss (b)

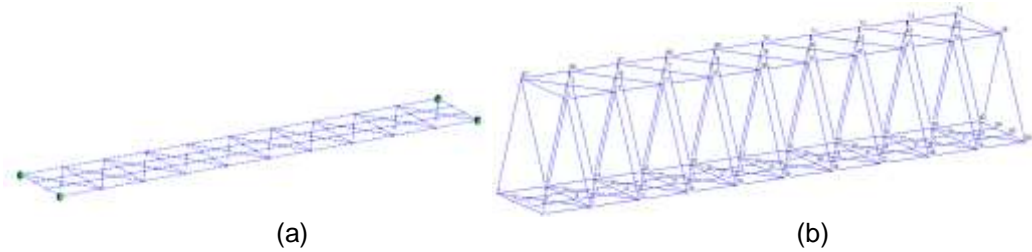


Figure 8.  
 Sketch for the "I" Girder Bar (a) and "Warren" Truss (b)

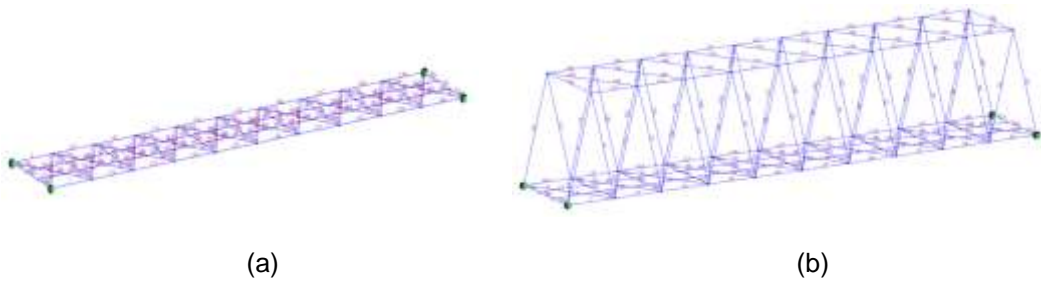
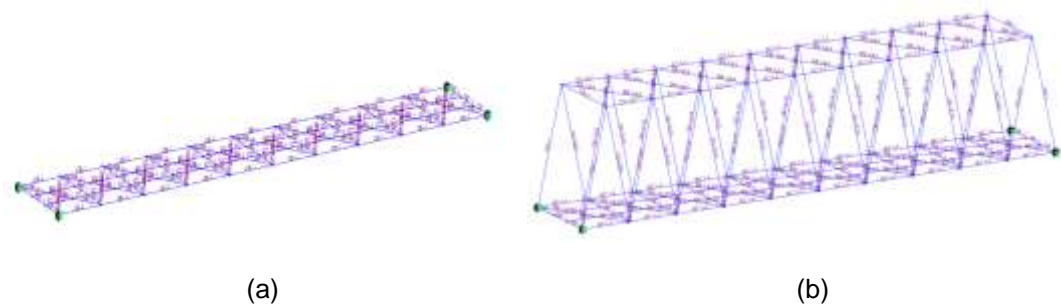


Figure 9.  
 Numbering for the "I" Girder Bar (a) and the "Warren" Truss (b)



Note "I" Girder Bar:  
 GR-1  
 DF-1 : H-3000 x 800 x 32 x 32  
 ST-1 : H-800 x 300 x 16 x 25  
 BR-1 : H-500 x 200 x 10 x 16  
 : L-100 x 100 x 10

Note "Warren" Truss:  
 TC-1&2 : H-300 x 300 x 16 x 25  
 TC-3&5 : H-300 x 300 x 16 x 25  
 BC-1-5 : H-300 x 300 x 16 x 25  
 DG-1 : H-300 x 300 x 16 x 25  
 DG-2&3 : H-300 x 300 x 16 x 19  
 DG-4-10 : H-300 x 300 x 16 x 12  
 DF-1 : H-600 x 200 x 16 x 25  
 ST-1 : H-450 x 200 x 9 x 16  
 BR-1&2 : L-150 x 150 x 10  
 EB-1 : H-300 x 150 x 12 x 19  
 BR-1&2 : H-1500 x 150 x 6 x 6

Figure 10.  
 Selection of "I" Girder Profile Structure and "Warren" Truss

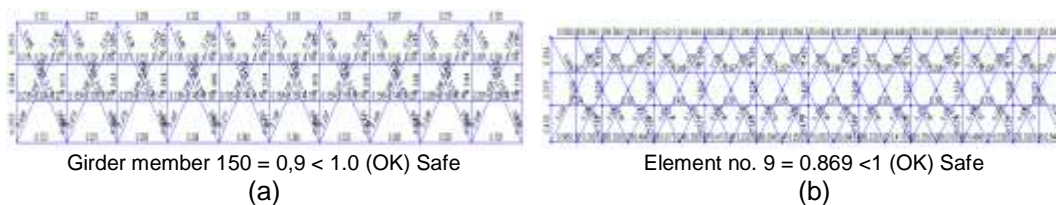


Figure 11. "I" Girder Strength Ratio and "Warren" Truss Strength Ratio

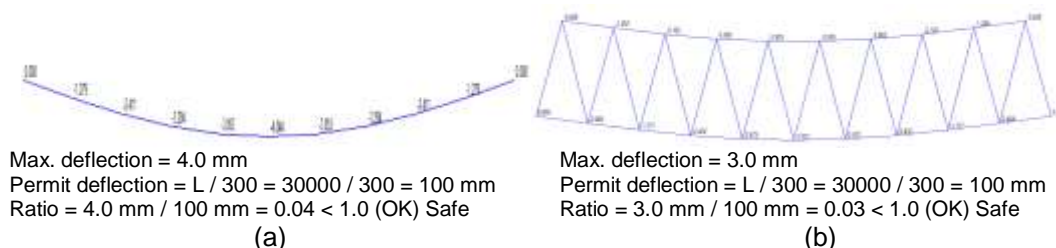


Figure 12. Deflection Control Due to Dead Load and Live Load on Girder type "I" (a), and Warren's Truss type (b)

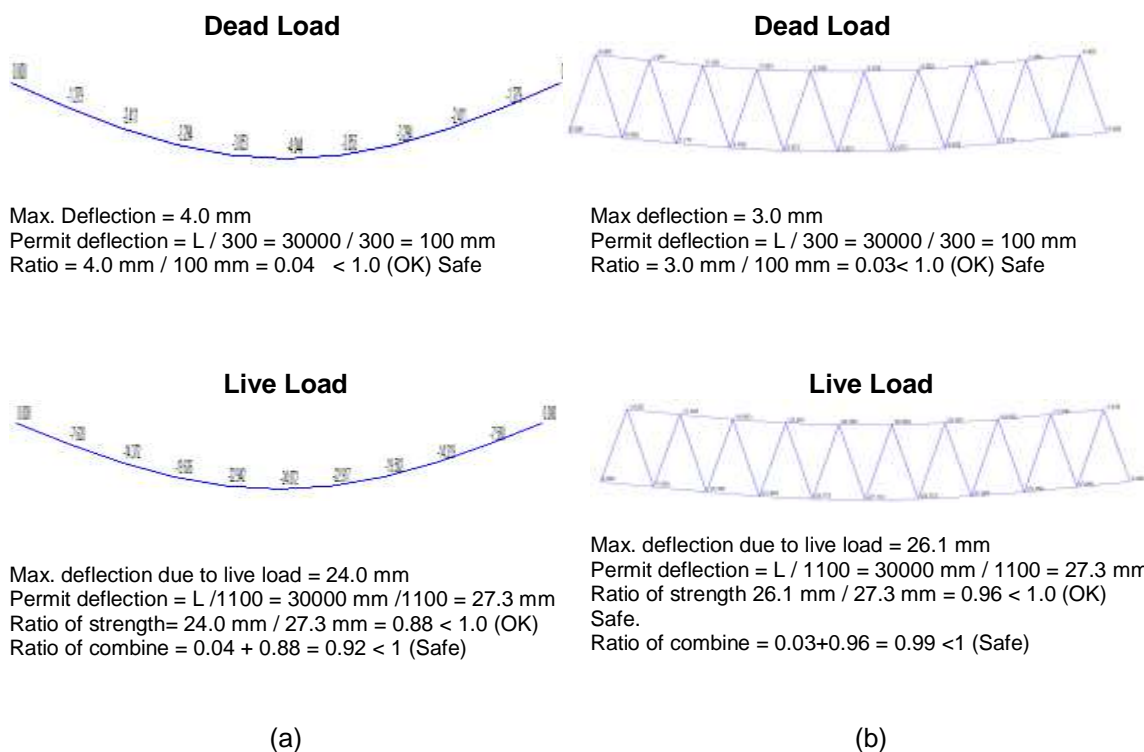


Figure 13. Deflection Control Due to Dead Load and Live Load on Girder type "I" (a), and Warren's skeletal type (b)



### Volume Comparison of Steel Bridge Profile of "I" Girder type structure with "Warren" Truss type structure

Results of modelling analysis shows that determined the amount/volume and weight of the profile used on each steel bridge type "I" girder structure and the type of "Warren" Truss structure significantly different. The results are listed in Table 7, 8 and Table 9.

Considering the results of analysis presented in Table 7, 8 and Table 9, it can be seen that the strength ratio for type of girder structure "I" is of  $0.90 < 1.0$  and deflection ratio of dead load is of  $0.04 < 1$  and deflection ratio of live load is of  $0.88 < 1.0$  (safe); while for the type of Warren Truss structure to the strength ratio is of  $0.87 < 1.0$  and the ratio of dead load deflection is  $0.03 < 1$  and the ratio of live load deflection is  $0.96 < 1.0$  (safe). It means that the type of skeletal structure "Warren" is stronger than those of the "I" type.

From the analysis and calculation of the weight of steel material, the bridge type bridge structure "Warren" spans 30 m has a

material weight of 81,624.41 tons smaller than the weight of the type of girder type structure "I" of 100,962.90 tons. This can happen because based on structural stability analysis on each type of bridge structure, as shown in Figures 11, 12 and 13. The material profile dimensions are obtained as shown in Figure 10 and after calculating the material weight is smaller for the type of "Warren" Truss structure ". From the bridge comparison table as shown in Figure 10, the parameter that stands out the difference is the "weight of steel material" for the type of skeletal structure "Warren" is smaller than the type of the structural structure "I" which means that determining savings is "the weight of steel material".

Theoretically, the mechanics of certain static techniques as exemplified by Karyoto<sup>12</sup>, the higher the structure (type of skeletal structure "Warren"), the deflection factor will be smaller and the moment of inertia greater so that it can withstand greater twisting forces compared to the type of structure low size ("I") girder structure type.

Table 7.  
List of Steel Bridge Materials for "I" Girder Structure Type

No.	Mark	Dimension	QTY.	Length (M)	Quality	Weight (kg)	Weight Amount (kg)
1	GR-1	H-3000x800x32x32	2	30,000	SM490	1,471.88	88,312.50
2	DF-1	H-600x200x16x25	11	3,980	SM490	147.58	6,461.05
3	ST-1	H-500x200x10x16	20	2,680	SS400	89.6	4,802.56
4	BR-1	L-100x100x10	20	4,592	SS400	15.1	1,386.78
Total of Weight Amount (kg)							100,962.90

Table 8.  
List of Steel Bridge Material for Warren Truss Structures Type

No.	Mark	Dimension	QTY.	Length (M)	Quality	Weight (kg)	Weight Amount (kg)
1	TC-1 s/d TC-4	H-300x300x16x25	16	5,143	SM490	149.15	12,273.24
2	TC-5	H-300x300x16x25	2	5,143	SM490	149.15	1,534.16
3	BC-1 s/d BC-5	H-300x300x16x25	4	5,143	SM490	149.15	15,341.55
4	DG-1	H-300x300x16x25	4	5,700	SM490	149.15	3,400.62
5	DG-2	H-300x300x16x19	4	5,700	SM490	122.40	2,790.66
6	DG-3	H-300x300x16x19	4	5,700	SM490	122.40	2,790.66
7	DG-4 s/d DG-10	H-300x300x9x12	4	5,700	SM490	76.02	12,132.68
8	DF-1	H-600x200x16x25	11	9,130	SM490	147.58	14,821.46
9	ST-1	H-450x200x9x16	40	4,794	SM490	79.77	15,297.02
10	BR-1	L-150x150x10	10	5,340	SS400	23.33	1,242.32
11	BR-2	L-150x150x10	20	2,662	SS400	23.33	1,242.09
12	EB-1	H-300x150x12x19	2	9,130	SM490	69.43	1,267.71
13	BR-3	H-150x150x6x6	9	10,775	SM490	20.63	2,000.57

14	BR-4	H-150x150x6x6	18	4,794	SM490	20.63	1,780.19
Total of Weight Amount (Kg)							81,624.41

Table 9.  
Comparison of "I" steel girder bridges and "Warren" Truss

No	Component	Girder I	Warren Truss	Information
1	Weight of steel material (ton)	100,962.90	81,624.41	Warren truss more economical steel material
2	Workspace between the web (cm)	490	450	I girder is looser
3	Working hole	Up and Down	Up and Down	I girder type of work hole and Warren truss type have the same opportunity
4	Bracing	Limited profile	No limited profile	Together SNI material
5	Span development		Longer	Warren truss is more flexible in span setting
6	Permit stress (MPa)	340	340	The same material quality
7	Deflection of dead load (mm)	4.0	3.0	Deflection permit 100 mm
8	Deflection of live load (mm)	24	26.1	Deflection permit 27.3 mm.
9	Power ratio	0.90	0.87	Maximum 1.0

## CONCLUSION

From the results of structural stability analysis of the aspect ratio of rod/element strength and deflection due to dead load and live load, the two types of bridge structures are able to withstand train loads as stipulated in PM 60/2012 with their respective values for the type of girder structure "I" to strength ratio of  $0.90 < 1.0$  and deflection ratio of dead load  $0.04 < 1$  and deflection ratio of live load  $0.88 < 1.0$  (safe); while for the type of Warren Truss structure to the strength ratio of  $0.87 < 1.0$  and the ratio of dead load deflection  $0.03 < 1$  and the ratio of live load deflection  $0.96 < 1.0$  (safe).

Calculation of the volume of material used, the type of "Warren" Truss structure shows that a volume of 88,624.41 tons is smaller than the type of girder structure "I" of 100,962.90 tons. Which means the type of skeletal structure "Warren" is more efficient in the use of materials.

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