OPTIMIZATION OF STEEL TRUSS BRIDGE

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DOI: 10.5958/2278-4853.2023.00035.6

ABSTRACT

This thesis aims to optimize the weight for double lane steel truss bridge with RCC composite deck of 100m span. The optimization here is targeted to achieve minimum weight of the steel and relationship between weight of steel and truss height, weight of truss and height to span ratio, wind force and truss height to span ratio. The analysis and design is based on IRC codes and guidelines using MS-excel sheets and SAP2000 computer software. The study outcome shows that total weight of stringer and cross girder found minimum for maximum spacing of stringer possible for minimum thickness of deck. The total wind force acting on the truss bridge girder is increases with increases in height of girder approximately linearly and it decreases with increases in panel spacing up to certain limit then increases with increases in panel spacing.

KEYWORDS: *K-truss Bridge, optimization, panel spacing, height to span ratio, wind force.*

1. INTRODUCTION

Nepal is the mountainous country with a lot of river and rivulets, so we need many bridges to ease the extension of road network. Truss bridge has advantage in Nepalese topography since the construction does not demand construction of pier in narrow deep gorge, work can be carried out in all seasons and flood has less effect on the bridge. Truss is like a deep beam of different truss configurations. Due to strong load- bearing capacity, effective use of materials, affordable to construct, versatile and adaptable design, steel truss bridge design needs to be considered. The greatest benefit of optimization would be the saving of material and speed up the construction process, thus saving time. The saving of material and time ultimately reduces the final cost of the project. In 2019, A. Khadka & B. Mandal [1] has performed the **Parametric Study for Economic Steel K -Truss Bridge**. They concluded that the total weight of stringer and cross girder goes on decreasing as the panel spacing goes on decreasing. V. Khatri & P. Singh et al [2], 2012, performed the **Comparative Study for Different Girder Spacing of Short Span Steel-Concrete Composite Bridge with MS and HPS** and found that the 4-girders system is more economical than 5-girders system. Moreover the theory is comparable to a paper published by A. Naibaho and T. Rochman[3], 2022, **the effectiveness of the using a K- truss type on the Patikraja bridge**, K-Truss type show a good results in internal forces and maximum deflection. In 2014, C. Maraveas et al [4], **optimal design of through-truss steel bridges** were performed the optimum height-to-span ratio for through-truss steel bridges of medium span falls within the range of 1/7 and 1/10 for two traffic lanes and between 1/8 and 1/12 for a single lane, irrespective of deck type. In 2007, J. L. Waling [5] has performed mathematical investigation for the determination of **least weight proportions of bridge trusses**. The results of those calculations show that weight savings can be accomplished by designing these trusses somewhat deeper than is normally done by present-day designers. In 2015, A. Jamadar& H. Jadhav [6] has conducted **optimization of double track railway bridge superstructure using FEM,** showed that the weight minimization can be done by designing the bridge somewhat deeper than they are normally built. The optimum height to span ratio of 50m bridge was found to be at 1/6.73 and for 60m at 1/6.91. And also in 2016, V. Gandhe & P. Chowdhary [7] conducted **parametric study of truss bridges for economic consideration**, concluded that as the span of truss and height of truss increases, the modified trusses are economical with respect to conventional truss bridge. In 2017, S. Gupta et al [8] provided the **comparative analysis of different truss type railway steel bridge considering railway loadings**. They have considered four vehicle load cases along with dead load & rail load for the Steel Bridge of 50m span for analysis and observed that out of all four cases **howe type truss** bridge shows least values construction material i.e. 697.683 Newton. The relationship between steel weight, wind force and truss height to span ratio on long span truss bridge has incorporated. Therefore, this study is helpful to find the relationship among steel weight, wind force, truss height to span ratio to optimization of steel truss bridge. It will provide economy in truss bridge design and construction with relatively longer span.

2. Need of the Study

About 250 to 300 road bridges are built annually across Nepal *(DoR, GoN, 2021)*. According to official data, 3000 bridges has been built until now and in coming 10 years 2500 bridges planned to be built by DoR*(Economic survey report, MoF, GoN, 2078/2079)*. In terai, the eroding behaviour of rivers and higher cost of pile foundations, require longer span lengths, while in the hills, such bridges are the only options in large rivers like Koshi, Karnali, Gandaki, etc. To move ahead with such a big construction there must be cost effective solutions for most of the long span bridges can be truss bridges. Previous studies have been carried out on medium span truss bridges by working stress methods. The design of two-lane truss bridges up to length 60 m has already been standardized by the DoR, GoN. The depth and shape of truss are chosen by rule of thumbs mentioned in books and optimization is not carried out for each design. For long span truss bridges, the effect of different parameters such as height to span ratio, relationship between wind force and truss height to span ratio need to be incorporate for economy. The findings can be used by engineers in Nepal in order to achieve lighter and more economic truss design in the future.

3. Research Objectives

The overall objective of the study is to find the relationship among weight of truss, truss height to span ratio, wind force to optimization of steel truss bridge. To achieve the goal following specific objectives are targeted.

a) To evaluate the relationship between weight of truss and truss height to span ratio.

b) To evaluate the relationship between wind force and truss height to span ratio.

4. Theoretical Concept

The depth of the deck slab depends upon spacing of stringer given. As spacing of the stringer increases the slab increases and depth of the deck slab also increases and vice versa. The optimum depth of the RCC deck slab is obtained by given different trial spacing of stringer. Note that the minimum thickness of the deck slab should be 200mm. The spacing between the cross girder decreases the span of stringer also decreases so that the weight of the stringer decreases but increases the number of cross girder causes increase in weight of steel. The minimum weight of truss bridge is obtained by combination of certain number of stringer and cross girder. Number of nodes where weight of cross girder and stringer becomes minimum give the minimum weight of truss and ultimately minimum total weight of truss bridge or for the truss configuration for which minimum weight of truss is obtained can give the total weight of the truss bridge minimum. The parameters panel span, cross section of member and height influence the optimization of truss bridge. The load on chord member decreases and remains same in web member as height of truss increases. The weight of the truss decreases due to decrease in loads i.e. X-section on chord member while web member becomes slender due to increase in length. So the additional weight adds to the web member to make stiffer that avoid the buckling. The weight of truss decreases due to reduced weight of chord member as the height increases. Beyond certain value of height of truss due to heavy web member the total weight of truss increases. The span to depth ratio of a truss girder bridge which makes the minimum weight of chord members nearly equal to the minimum weight of web members of truss that gives the economy. The member sections will be varied so as to achieve the demand-capacity ratio members in a certain range for which the truss will be considered safe.

Wind force on a truss depends on several factors including location, height above ground, exposed area, shape of members, etc. For a given location, basic wind velocity is constant. For a 100m span truss, generally built-up sections are used as members. Thus, the coefficient of drag can be assumed constant. With variation in height of the truss for given span of 100m, small variation may occur in design wind pressure that depends on height. The major cause of variation in wind force may be due to the exposure area. When height increases, the exposed envelope area of the truss increases, the length of the internal members will increase, so their exposed area will increase and but the forces in the chord members decreases, thus smaller sections can be used in chord members, so exposed area of chord members will decrease. Since some factors increase while others decrease when height to span ratio of truss is varied, its relationship needs to be studied, while optimizing the height to span ratio of the truss. Similarly, the geometry of top chord of the truss will be parabolic and diagonal member shall be K-truss girder which gives the minimum weight of steel. The least weight of truss, stringer and cross girder for given panel spacing and height and total weight of truss bridge by calculating the least weight of RCC deck for given stringer spacing and try to obtain minima with overall truss with best diagonal angle and cross girder span.

5. Research Framework

For conducting this study the methods will be undertaken on K-truss Bridge which gives the least weight of truss bridge. A truss bridge has floor system, truss panel and height & width of truss. As the spacing of cross girder reduces, size of stringer and cross girder reduces, but numbers of panel increases. As the numbers of panel increases, numbers of vertical, diagonal members increase that leads to increase weight of truss. On the opposite if spacing of cross girder increases, it reduces weight of diagonal and vertical members but increases size of cross girder, stringer and depth of deck slab. That again increases dead load of bridge and finally weight of truss. With the variation of panel spacing and height of truss, the steel weight of the truss will be noted and it will be plotted against the parameter that is being varied on a graph. On the other side, generally standard steel sections were used in bridge construction. Its optimum use is great importance in economic design of a truss bridge. To overcome the way forward to these questions literature review is back bone of this study. Therefore in first hand almost all research papers related to these topics would be studied. Based on the current research, a conceptual frame work would be defined for the targeted objective. As per the conceptual frame work, analysis proceeded to achieve the goal i.e. to find the relationship among weight of truss, truss height/span ratio, wind force to optimization of steel truss bridge.

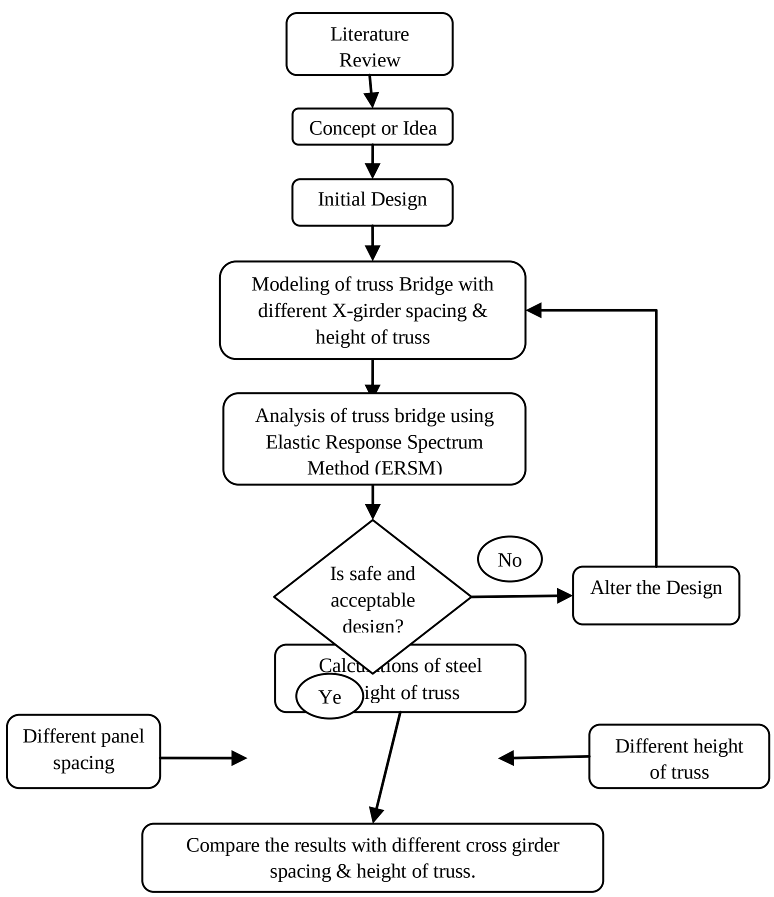

Figure 1: Methodological Framework

6. Analysis and Design

SAP2000 software is suitable for finite element analysis of the truss and design code is selected as IS 800-2007, since it is closest to the recommended IRC: 24-2010 code for steel bridge design. Deck is analyzed as a one way slab, using effective width method and designed in bending manually recommended in IRC: 112-2011. Stringers are designed by manual calculations for superimposed dead loads and live loads as steel I-beams. Cross beam is designed from manual analysis as a steel beam. Dead loads and live loads are assigned as per loads transferred from stringers. Design of truss members is carried out by using section designer in SAP2000. The section sizes of the members are tuned so as to achieve maximum demand capacity ratio indicating optimum design of the member.

6.1 Deck, Stringer and Cross-Girder

The unit weight of RCC deck considered is 25kN/m3 while wearing coat is 22kN/m3. The thickness of the wearing coat is taken as 0.075m while the thickness of the slab is fixed as 0.22m for 3-stringer and 0.20m for 4 and 5-stringer case. For the analysis and design 3nos stringer (3.3m spacing), 4no stringer (2.475m spacing) and 5nos stringer (1.98m spacing) system was selected while the number of cross-girders depends on the panel length (7.14m, 6.25m, 5.55m, 5m and 4.54m).

6.2 Truss

K-truss configurations with inclined chords are selected as these are the most common types of trusses used. According to IRC24:2010, depth or height of the truss taken should be equal to or more than 10m for 100m span so, the height of truss above 14m was selected. The overall width of the bridge is taken as 10.5m of which 1m footpath and 7.5m is the total carriageway width. Three cases of number of stringers are taken, viz. 3-stringer, 4-stringer and 5-stringer and five cases of cross girder spacing are taken, viz. 4.54, 5, 5.55, 6.25, and 7.14m. Five depth of truss girder viz. 16m, 18m, 20m, 22m, and 24m at the mid are considered for the study.

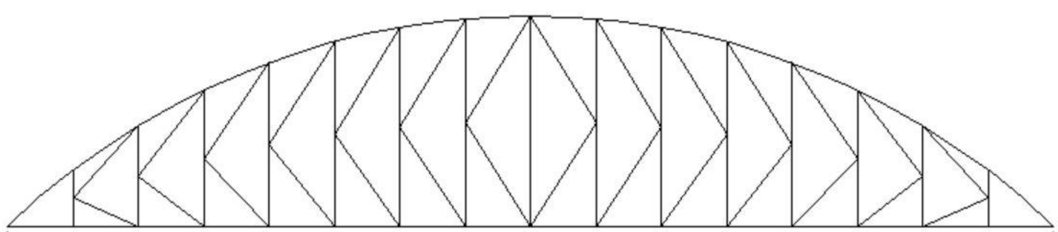

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Figure 2: K-truss gird

6.3 Modeling:

The Finite Element modeling of K-truss Bridge with a height of 20m and having span 100m modeled using SAP2000. The materials used are M25 grade concrete and Fe350steel.3D geometry of truss is created as a center-line model, i.e. all members meeting each other at their respective centroids. Thus, some eccentricity in the connections of members mostly cross members like crossbeams, braces and stringers is ignored. Members of the steel truss shall be composed of either Indian Standard sections or steel plates and shall be single or built-up and are modeled in Section Designer of SAP2000 without considering lacing/battens. The bridge roadway deck has been modeled with diaphragm constraints. Steel bridge elements top and bottom chords, cross girders, diagonals and stringers are modeled with frame elements. End releases are not applied in the software, in order to evaluate actual moments at the joints. Bearing is modeled as one pin and other transverse-free at one side of the truss, and as one longitudinal-free and other free in both directions at other side of truss.

6.4 Load and load combinations

Superimposed loads are calculated manually in excel. Thickness of deck slab is assumed as 220 mm for 3-stringer and 200mm for 4 and 5-stringer case, plus a wearing course of 75 mm thickness. IRC Class A and 70R vehicle loads are assigned in the model. Moving load analysis option provided in the software is used based on the concept of influence lines. Wind load is applied as point load at joints of the truss as per convention at a height of 20m above normal water level. Uniformly distributed load along the member length would be a more realistic model. Braking forces and effect of wind on live loads are applied on the cross girder at the junction with stringers. Lift due to wind is applied as pressure on the deck slab. Uniform temperature load is applied on all frame members. For a simply supported span of 100m, seismic analysis shall be done using Elastic Response Spectrum Method (ERSM) as per IRC SP114-2018. Load combination is done as per IRC 6-2017 Annex B based on limit state design.

7. Results

The results of calculations are shows the weight of 100m span two lane traffic through type K-truss bridge, M25 grade concrete deck composite with several different panel spacing and height. IS 800 code-based design is also carried out in SAP2000. The results of calculations are summarized and also calculated data are plotted on the graphs below.

7.1 Variation in weight of deck with change in number of stringer

The weight of slab for 3-stringers spacing is highest among the weight of slab for 4-stringer and 5-stringer. As the number of stringer increase the span of slab and thickness decreases. This again is due to the increase in span of the slab resulting in higher depth. The slab depth has reduced by 0.02m when 4-stringer and 5-stringers is used as below.

TABLE 1: WEIGHT OF SLAB FOR DIFFERENT NO OF STRINGER

No of Stringer	Thickness of deck slab (mm)	Weight of deck slab (KN)
3	220	4125
4	200	3750
5	200	3750

7.2 Variation in weight of stringer with number of panel point

The overall weight of the stringer is in decreasing order with the increase in panel number. This is attributed due to the decrease in design responses. If we take a closer look and make comparison of weight between three different arrangements of stringers; 3, 4 and 5 by varying number of panels, we can deduce that the least weight is obtained for combination of 3-stringer and 18 panels. It can also be observed that with the increase in number of stringer the weight is also seen to be increasing. Despite having almost same section requirement, the cause in increase in total weight is primarily due to increase in number of stringers.

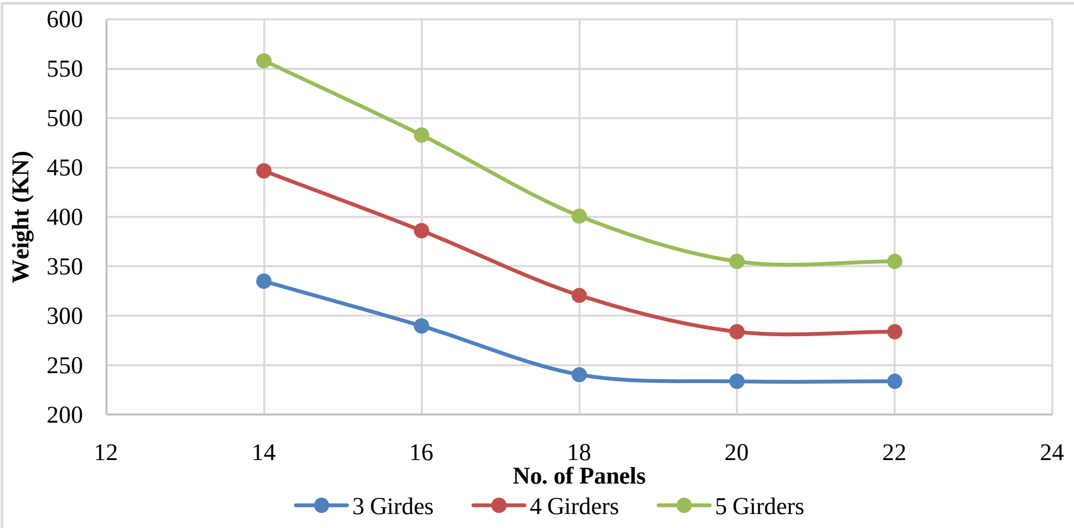

Figure 3: Weight of stringer VS no of panel point

7.3Variation in weight of stringer and cross girder with number of panel point

The nature of the graph has almost taken a parabolic shape. For all the number of stringer the lowest total weight is achieved when the panel number is 18. And the overall lowest weight is for the combination of 3 stringers and 18 panels. The explanation behind achieving this nature of graph is for the increase in panel number there is increase in weight of cross girder and for stringer. This is because of the variation in length of stringer. Since one parameter under observation is in increasing in weight and other is decreasing, combination of both the gives lowest value at one point, which in our case is 18, for 3 numbers of stringers.

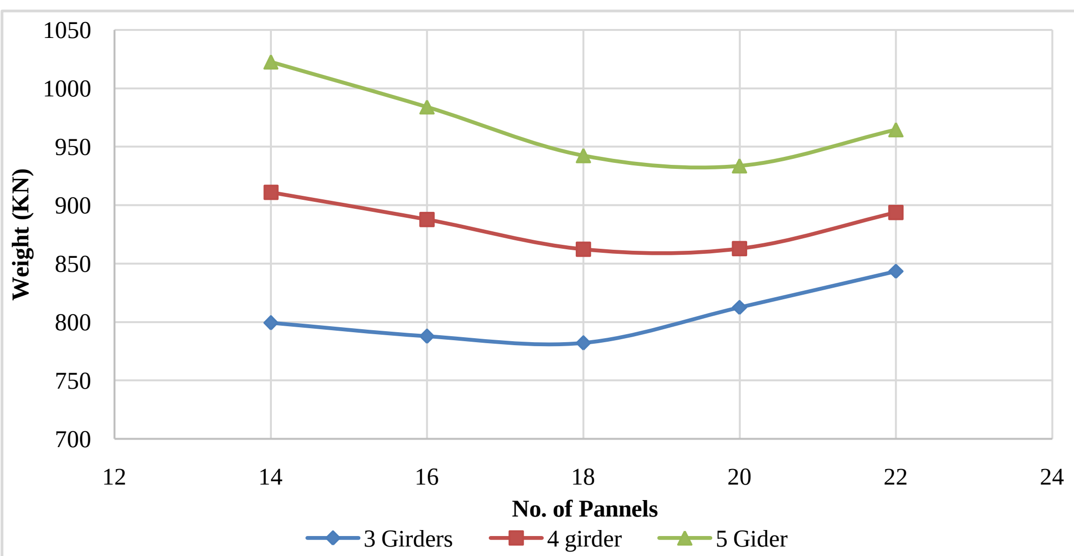

Figure 4: Total Weight of stringer & X-girder VS no of panel point

7.4 Variation in weight of cross girder, stringer with number of panel point for 3-stringer

There is slight variation in total weight when the numbers of panels are varied. The weight of stringer has been decreasing as the panel number increases but the weight of cross girder increases. This is because as the number cross girder is increased the load on the stringer is reduced and hence weight of stringer is reduced. The total weight of stringer and cross girder is found to be minimum with 3-stringer for 100m span bridge when the no of panel point is18, i.e. spacing of cross girder at 5.55m.

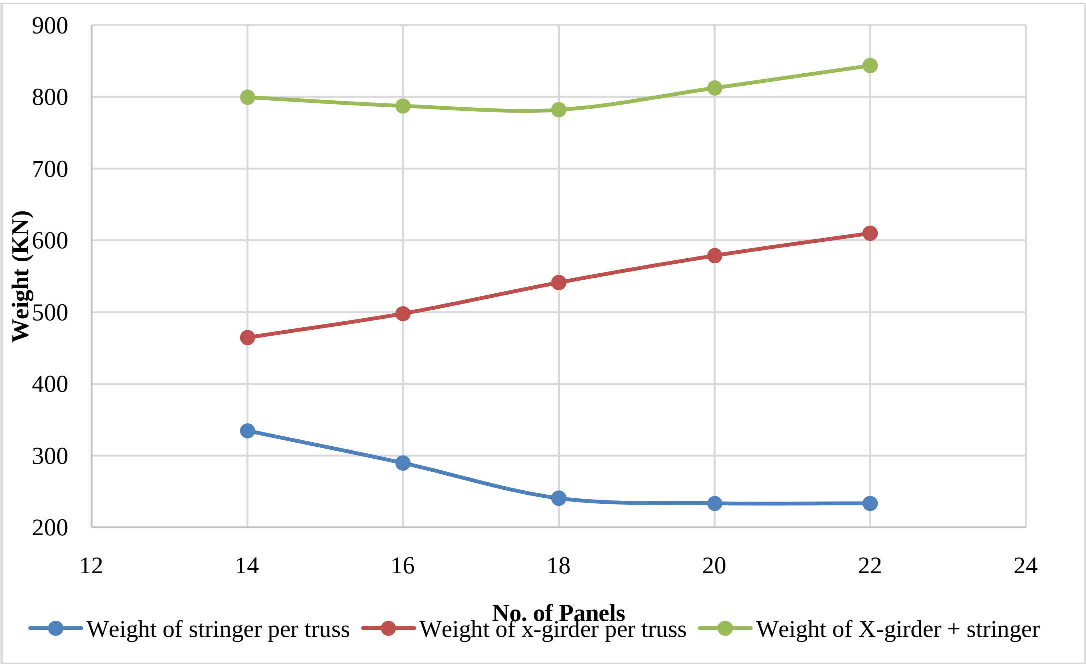

Figure 5: Weight of cross girder, stringer vs. number of panel point for 3-stringer

7.5 Variation in Weight of Component of Truss with Height of Truss for 6.25m Panel Spacing

The height of bridge increases the slender member achieved which liable to buckling due to which the member section increases which adds weight of member. On the other hand, by increasing the height of bridge force on the top and bottom member becomes lower due to which small section is used which make the bridge light. In table 5.5 as the height of the truss is increased the weight of bracings is slightly increased, weight of cross girder and stringer remains constant, but the weight of bottom chord member goes on decreasing and top member becomes zigzag and the weight web member goes increasing.

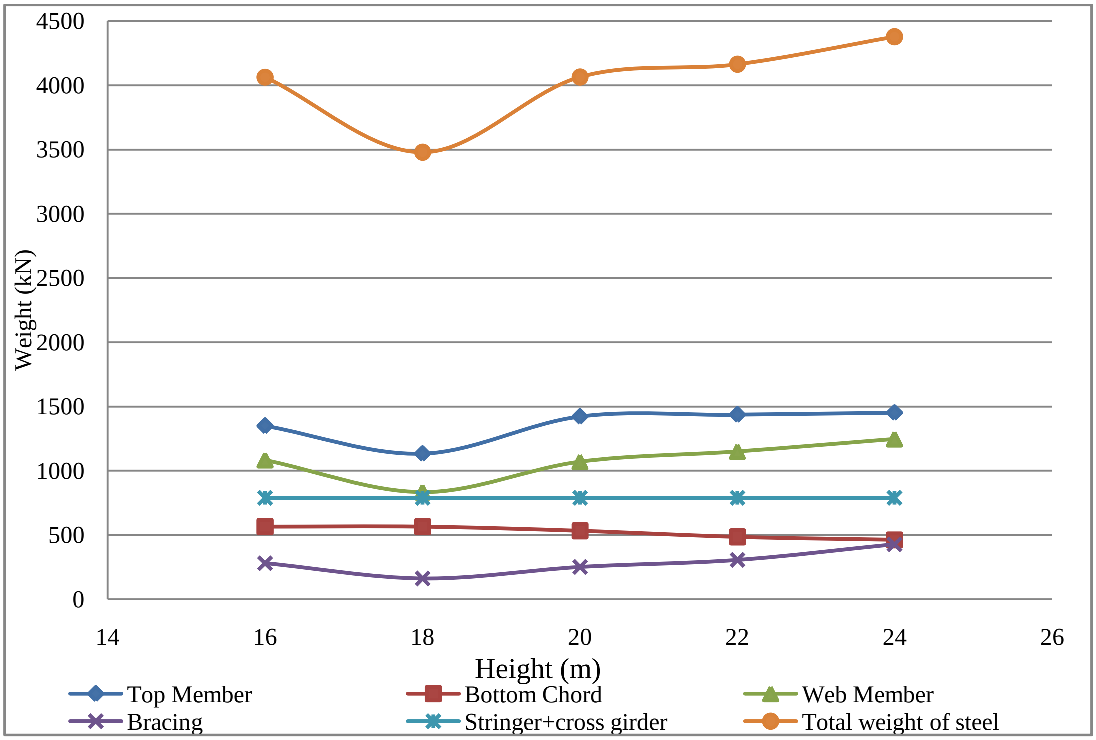

Figure 6: Weight of component of truss with height of truss for 6.25m panel spacing.

7.6 Variation in Total Steel Weight with Height for Each Panel Length

At panel length of 6.25m and truss height of 18m gives the minimum weight. The minimum weight is obtained at 18m height (height to span ratio 1/5.55) for panel length of 6.25m and 5.55m and at 16m height (height to span ratio 1/6.25) for panel length of 7.14m, 5m and 4.54m respectively. The weight of steel goes on decreasing with increase in height but after certain height weight goes on increasing for each panel length.

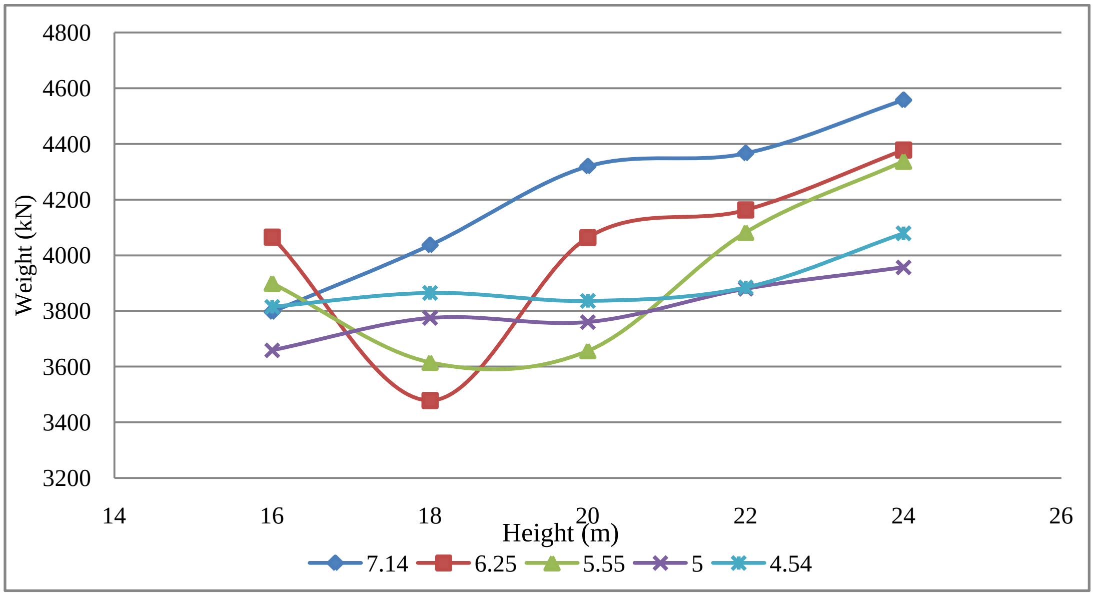

Figure 7: Total steel weight vs. height for each panel length.

7.7 Variation in Total Steel Weight with Different Panel Spacing and Height

Figure 8 and 9 shows the minimum weight of steel for different panel spacing and height respectively. Up to height to span ratio 1/5.55 the weight of truss girder has decreased and then increased. The ratio is not less than 1/10 and slightly equal to 1/6-1/8 as indicated by Indian code and other writers respectively. At 6.26m panel length and girder height of 18m the minimum weight is obtained.

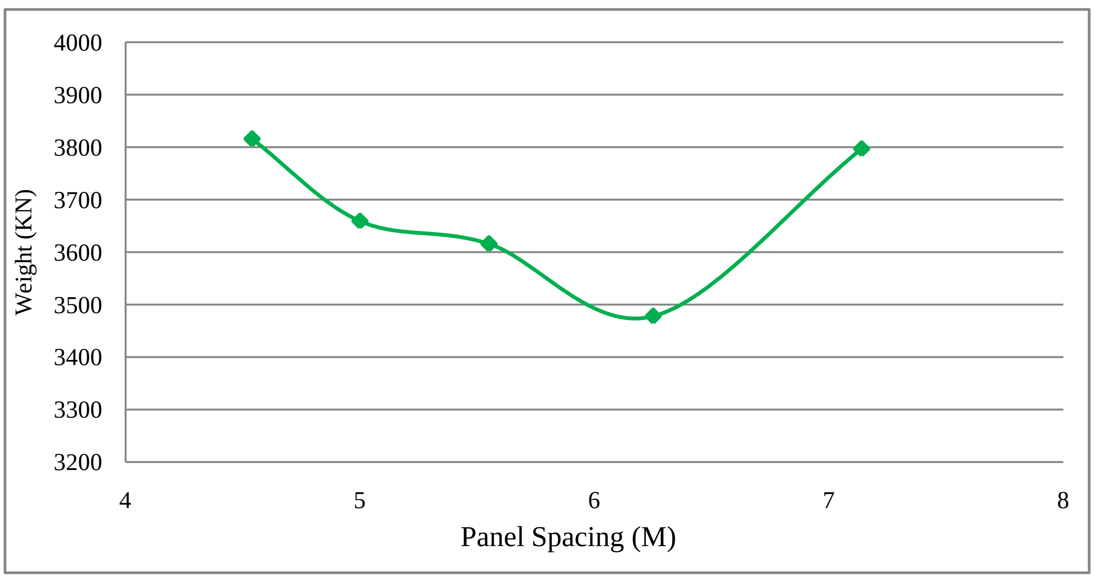

Figure 8: Minimum weight vs. panel length

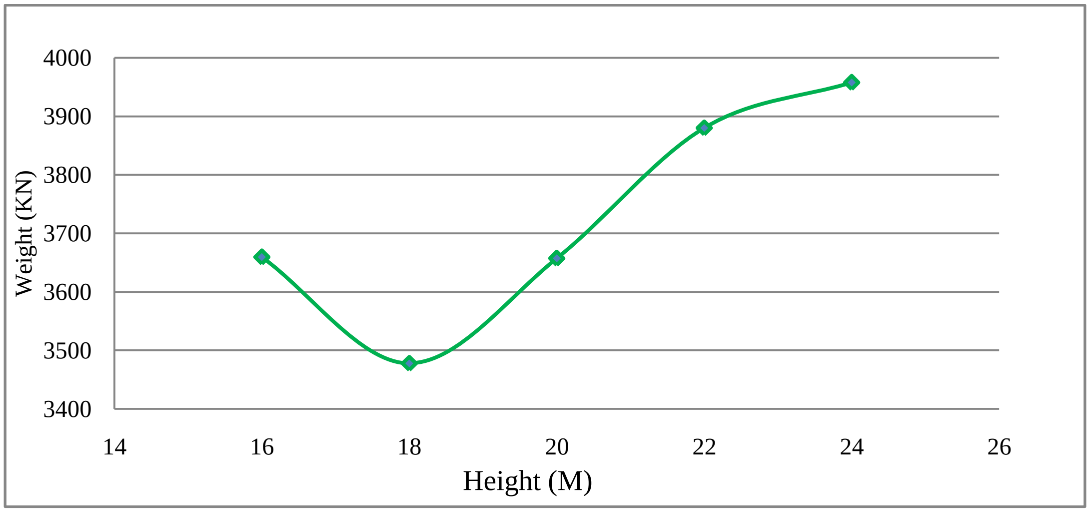

Figure 9: Minimum weight vs. height of truss girder

7.8 Comparison between total Weight Stringer and Cross Girder, Minimum Weight of Truss and Total Weight of Steel

Table 2 shows the comparison between minimum weight of truss, total weight of stringer and cross girder and total weight of steel for the given panel spacing. The minimum weight of cross girder and stringer is found to be at panel spacing 5.55m. Whereas the minimum weight of the truss only is obtained at 6.25m spacing. The total minimum weight of steel is found at 6.25m panel spacing. Hence by providing the combination of uneconomical weight of stringer and cross girder and economical truss weight, the minimum weight of the steel has been achieved.

TABLE 2: TOTAL WEIGHT, STRINGER AND CROSS GIRDER AND MINIMUM WEIGHT OF TRUSS

Panel spacing (m)	Minimum weight of truss (kN)	Weight of stringer +cross girder (kN)	Total weight of steel (kN)
7.14	2997.870	799.361	3797.235
6.25	**2690.370**	787.728	**3478.094**
5.55	2833.820	**782.012**	3615.827
5	2846.938	812.549	3659.487
4.54	2972.233	843.507	3815.740

7.9 Variation in Wind Forces with Panel Spacing

Figure 10, 11, 12 and 13 shows that the variation of wind forces with panel spacing of truss girder. It shows that wind force decreases with increases in panel spacing up to certain limit then it increases with increases in panel spacing. The minimum wind force obtained at panel spacing of 5.555m in both transverse and longitudinal directions with respective height of truss girder. It is because at this panel spacing the perimeter and the area of truss member has minimum.

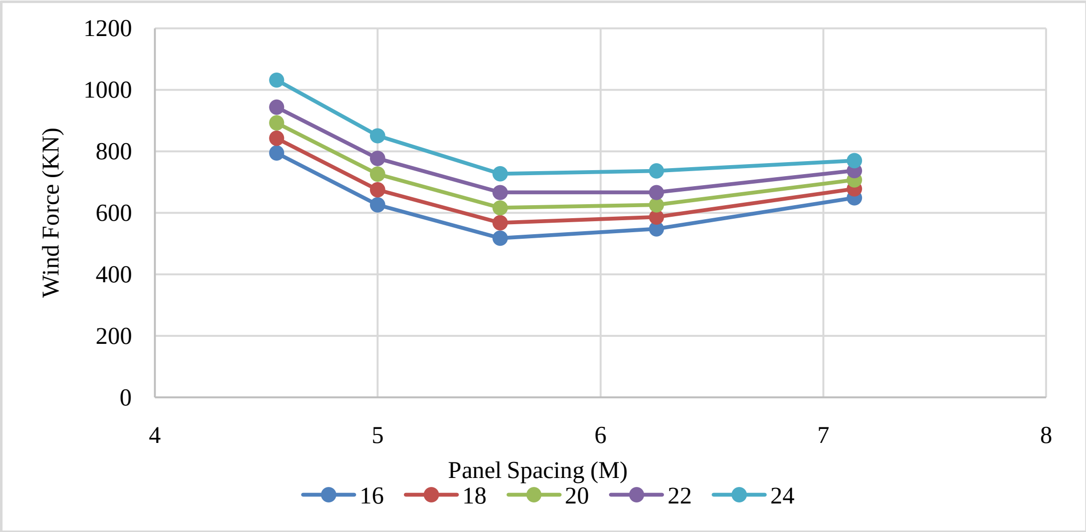

Figure 10: Windward Force vs. Panel spacing in Transverse direction

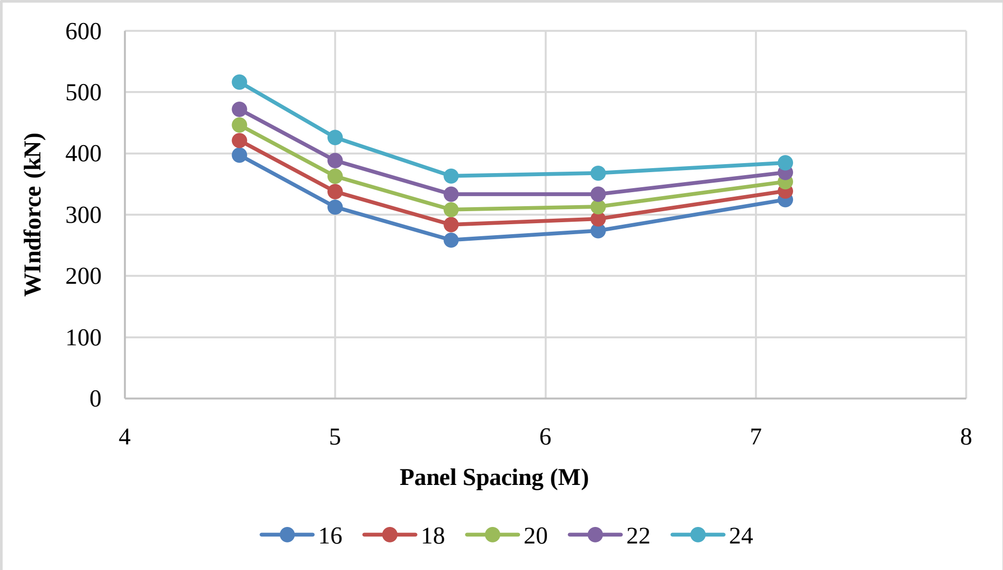

Figure 11: Windward Force vs. Panel spacing in longitudinal direction

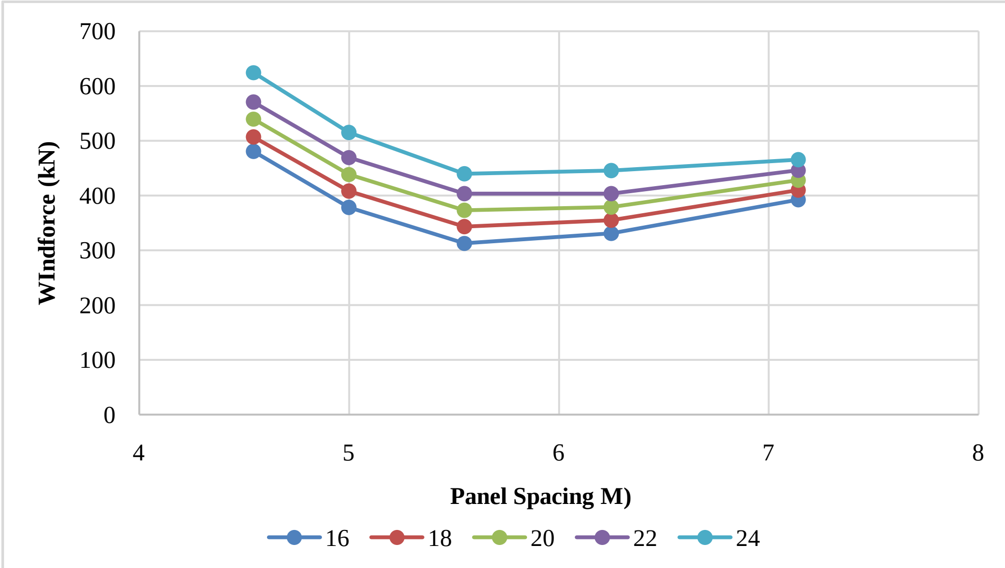

Figure 12: Leeward Force vs. Panel spacing in transverse direction

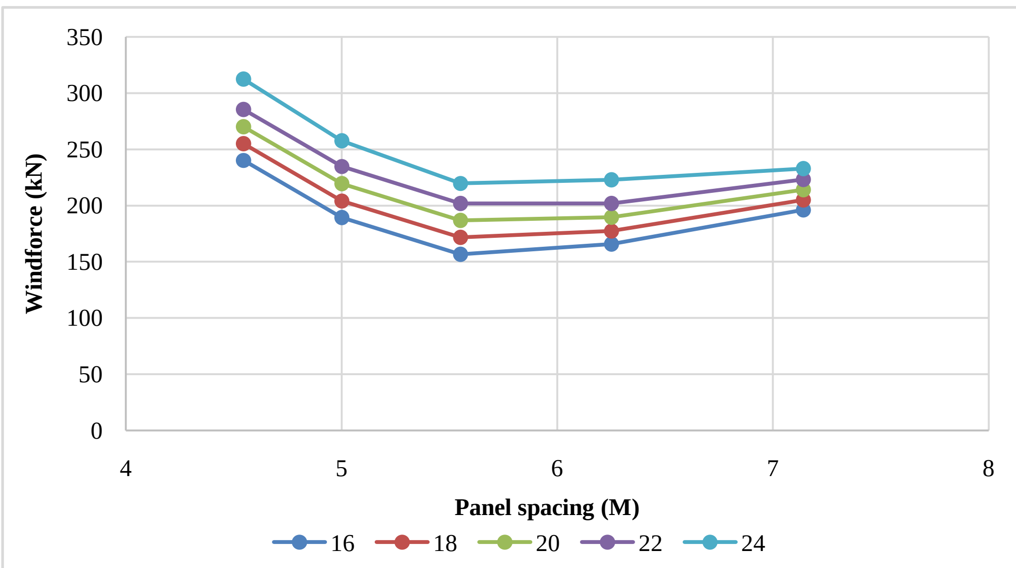

Figure 13: Leeward Force vs. Panel spacing in longitudinal direction

7.10 Variation in wind forces with truss height

Figure 14, 15, 16 and 17 shows that the variation of wind forces with height of truss girder. It shows that wind force increases with increases in height approximately linearly. It is because as height increases, the perimeter and the area of truss member increase in both transverse and longitudinal directions with respective panel spacing of truss girder.

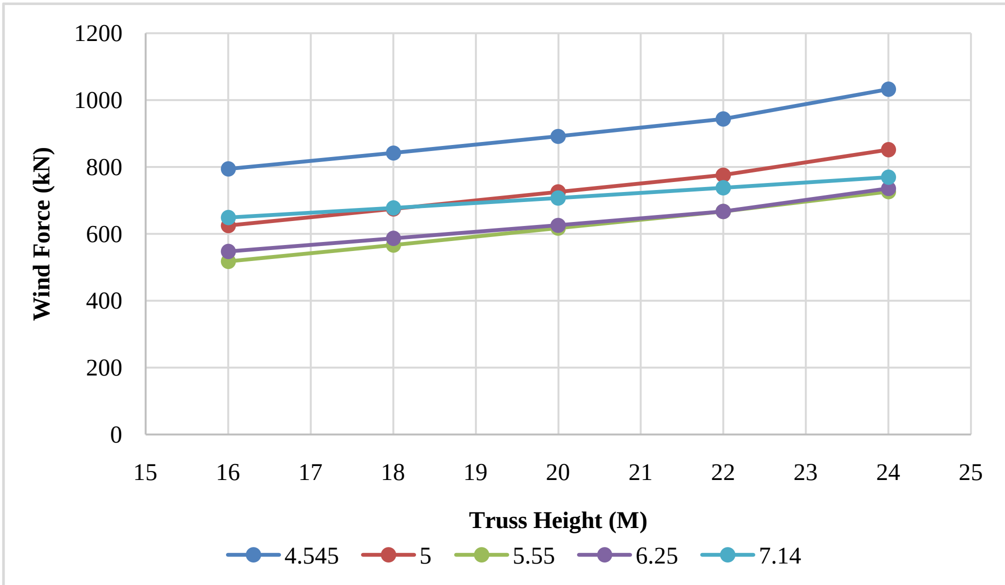

Figure 14: Windward Force vs. truss height in transverse direction

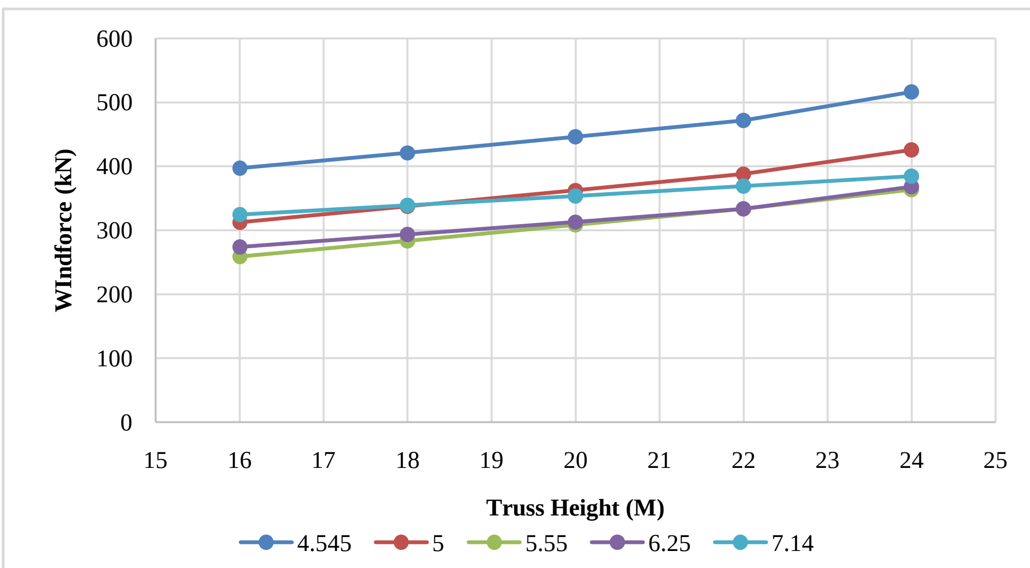

Figure 15: Windward Force vs. truss height in longitudinal direction

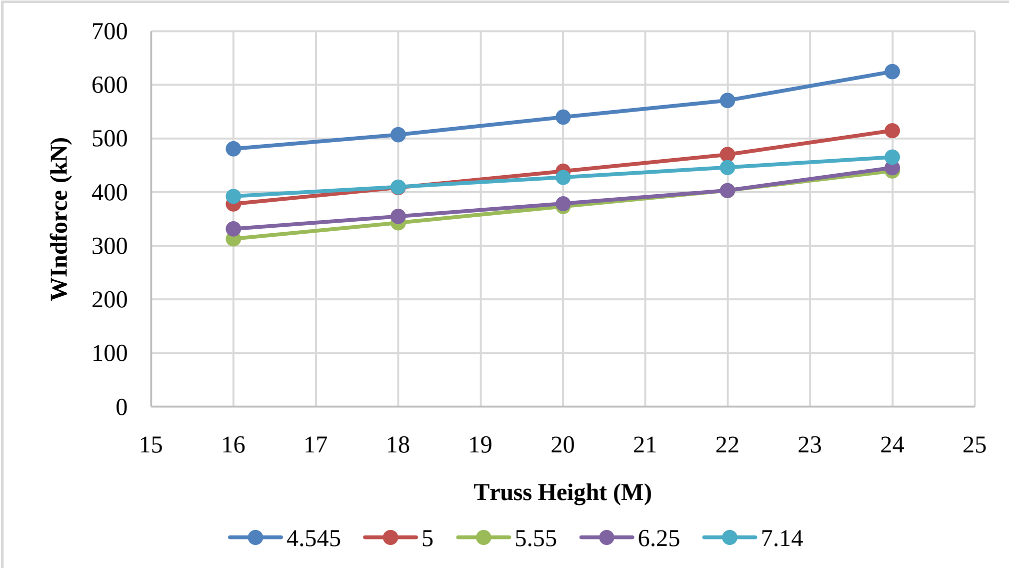

Figure 16: Leeward Force vs. truss height in transverse direction

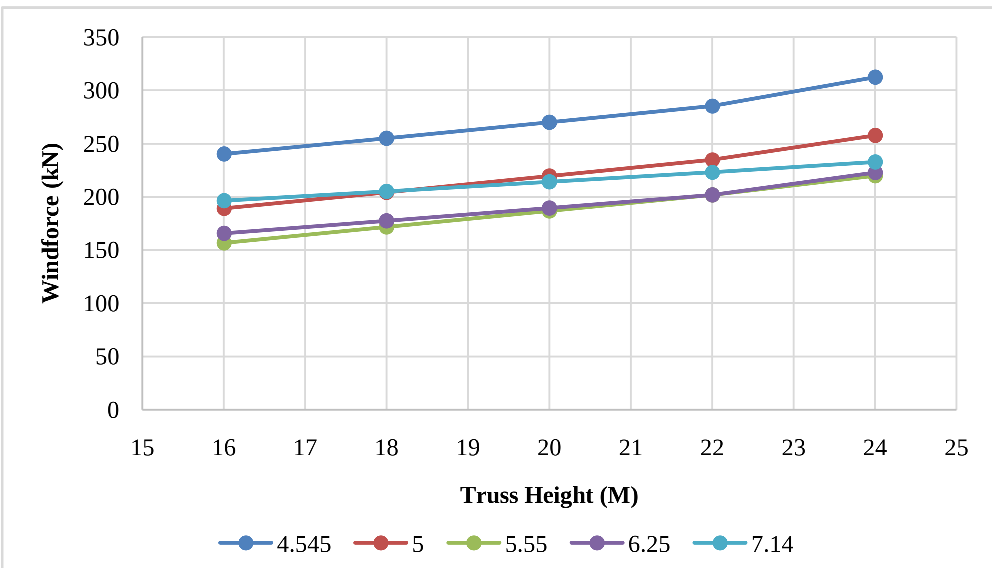

Figure 17: Leeward Force vs. truss height in longitudinal direction

8. CONCLUSIONS

In the present work, three dimensional model of common steel100m span steel K-truss Bridge have been analyzed for IRC loading using SAP2000 commercial software. The major conclusions that were drawn from this thesis work are;

- Total weight of stringer and cross girder minimum for maximum spacing of stringer possible for minimum thickness of deck i.e. 19 number of cross girder. The weight of truss and total weight of steel is found minimum at 6.25m panel spacing and 1/5.555 height to span ratio for k-truss steel bridge.

- The total wind force acting on the truss bridge girder is increases with increases in height of girder approximately linearly and it decreases with increases in panel spacing up to certain limit then increases with increases in panel spacing. The minimum wind force is found at panel spacing of 5.55m in both transverse and longitudinal directions with respective height of truss girder.

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