CAMES, **28**(4): 351–367, 2021, doi: 10.24423/cames.399

Design of Steel Footbridges for Unpredictive Loadings by STAAD Pro: LRFD vs. ASD for Cost Saving

Armghan NAEEM[1)*], Muhammad MUNEEB[2)], Asad YOUSAF[1)], Muhammad Mohtasham NAEEM[3)]

[1)] *Department of Mechanical Engineering*
University of Engineering and Technology
Taxila, Pakistan
*Corresponding Author e-mail: armghannaeem23@gmail.com

[2)] *Department of Mechanical Engineering*
University of Engineering and Technology
Lahore, Pakistan

[3)] *Department of Mechanical Engineering*
University of Engineering and Technology
Kala Shah Kaku, Pakistan

Steel footbridges are common means of connecting two zones separated by any kind of physical obstruction to the pedestrian crossing. In the last century, they were mostly designed using manual calculations. With the advent of powerful software, the designing process has become more accurate and less time-consuming. In this paper, complete designing process of steel footbridges is conducted using STAAD Pro: a dedicated steel structure design and analysis software, under unpredictive loading, i.e., dead, live, pedestrian, wind and seismic loading. Two design approaches are popular in steel footbridges designing. These are allowable stress design (ASD) and load and resistance factor design (LRFD), and both are compared with the focus on material/cost saving as cost is the major issue in underdeveloped and overpopulated countries. The critical load combination giving a minimum factor of safety for both approaches is also obtained. It is evaluated that the LRFD design approach results in stronger and lighter structures for unpredictive loadings. The factor of safety for ASD is 20% lower than that of LRFD, and thus LRFD provides material/cost savings of about 20% compared to ASD.

Keywords: steel bridges, LRFD, ASD, STAAD Pro, loading combinations, cost reduction.

Notation

L – live load,
D – dead load,
S – snow load,

l_r – live load of roof,
W – wind load,
R – rain load,
E_h – horizontal component of seismic activity (earthquake),
E_v – vertical component of seismic activity (earthquake).

1. Introduction

Footbridges are scaffolding structures used for the transportation of pedestrians, cyclists, and riders of low velocity and assistive devices such as wheelchairs. Footbridges are not designed for any sort of vehicular activity, and they have numerous applications all around the world. In developed countries, they are used to connect two zones separated by either roads, canals or a body of water between them. In underdeveloped countries, where traffic and over congestion are major problems, they may be used to give access to public buildings such as shops and universities. They are also used to connect to high-rise buildings from top floors, and in this case, they are specifically called "skyway" [1].

Footbridges are usually manufactured using the following types of materials: concrete, steel and timber, however steel footbridges are preferred in situations where the bridges have long spans and there is the quick availability of structural steel members. A great amount of technical literature is available on these members. The American Institute of Steel Construction (AISC) manuals are available in which standard shapes of these structural steel members are available along with important design specifications, i.e., weight/length, the moment of inertia and section modulus, etc. [2]. Further, local area suppliers/manufacturers of steel members also provide their standard shapes and their technical specifications. This helps the designer to choose standard shapes easily and design the steel bridge with the members available in the local market, and thus results in inexpensive manufacturing. In this paper, we have chosen steel as a material for a footbridge. Another important point in selecting steel is that its strength to mass ratio is better than that of timber or concrete. Moreover, painted steel looks aesthetically attractive.

2. Previous related work

Under the leadership of Professor Theodore V. Galambos, the development of LRFD from 1969 to 1985 took place. Predictably, LRFD has brought up new research prospects and problems [3]. Since then, the cost and strength comparison between the LRFD and ASD approaches has been the focus of several studies. Sometimes these two approaches are compared in general and sometimes for specific steel structures with loadings applied to them. In 1990, a comparison was performed between the ASD and LRFD methods for general steel structures. The load and resistance variables rationales were summarized. The design method's general principles were explained and they were contrasted to other design concepts such as the ASD and ultimate strength design. The study revealed that structures constructed using the LRFD approach had distinct cost advantages [4].

In the same year, a study was performed to find the resistance factors of the LRFD by calibrating the necessary design provisions for components of structures made of stainless steel by cold forming [5]. In 1991, a paper was written on LRFD vs. ASD for floor beams, which ultimately showed that specifications of LRFD are gaining popularity in the design community. LRFD is a more logical design method based on an ultimate strength and reliability approach. It was concluded that when just strength concerns are taken into account, LRFD is found to be much more cost-effective than ASD for floor beams spanning 30 to 46 feet [6]. In 1997, the minimum weight for the steel design frame structures in space was determined using the AISC LRFD and ASD approaches. In addition to vertical loads by dead and live loads, the wind loading was also applied to the structure as per the uniform building code (UBC). It was demonstrated that LRFD produces structures with less weight [7]. In 2005, nonlinear steel frames were analyzed in [8]. The design procedure selected acceptable sections from steel sections, which are standardized worldwide, such as AISC wide-flange (W) members. The results of ASD were matched with those produced using the LRFD code. In addition, the results showed that the LRFD procedure produces inexpensive frames [8]. The comparison was performed on outputs of the ASD and LRFD techniques for wood laminated by glue (glulam) bridges by Warren *et al.* in 1998 [9]. In 2006, the emphasis was given to the fact that engineers must be aware of the changes that occur as timber bridges shift from the ASD to LRFD approaches [10]. In 2007, a study was performed specifically in the field of bridges to compare common buckling stability checks for steel cable-stayed bridge girders and towers. The equations in the American Association of State Highway and Transportation Officials (AASHTO) LRFD and ASD standards were used to evaluate the design of essential components of cable-stayed bridges. The LRFD requirements were shown to be 20% more cost-effective than the ASD standards on average [11].

In the past, the design of structures and implementation of the LRFD and ASD approaches were conducted manually. However, in the past decade, with the advent of structure analyzing software, the trend has shifted to design structures with various designing programs such as STAAD Pro, etc. In 2012, international residential code requirements and load application (live load and dead load) were used on a structure in one dimension to evaluate a basic span T-beam bridge. The STAAD Pro program was used to conduct a finite element analysis of a three-dimensional construction [12]. In 2016, STAD Pro was used to create and analyze a flyover. After finishing the design, the authors analyzed the structure and examined the bending moment and shear force data in post-processing mode [13]. In 2020, a bridge made of steel and having arch type arrangement with Warren frame in India was used as an alternative bridge design. Badung-Bali is a steel-framed bridge with a 360-meter overall span and a 9.6-meter width. The LRFD technique was used to design the bridge this time, and the STAAD Pro V8i assistance application was used to simulate the structural analysis [14].

From the previous research data, it is evident that comparison between LRFD and ASD has been made for general steel structures, i.e., steel frames and buildings but not specifically for steel foot-bridges, which are gaining popularity worldwide and require special attention. Also, in the past, the above-said comparison was not made with standardized loadings such as wind, earthquake and pedestrian loading, and the same was usually conducted manually. However, as powerful steel designing software programs such as STAAD Pro are now easily available and provide great accuracy, there is a special need to compare LRFD and ASD by utilizing these software programs. Software with already proved results will greatly reduce the lengthy calculation process and make designing complex and aesthetically attractive structures easy and accurate for structural engineers.

3. Design approaches

For the design of different steel structures, two types of design approaches are usually applied: LRFD and ASD. These design approaches have different ways of formulating the factor of safety. Thus, when we implement both of these on the same steel structure, they give different results. Different type of loading is usually applied to steel bridges according to the application and location of the bridges. Commonly used loadings are dead load: the self-weight of the bridge steel members, live load: a load which varies with time such as of pedestrians, snow load: load of snow that accumulates on the bridge (only applicable if snow falls in the location of the bridge), wind load: loading on the bridge due to wind blowing, and earthquake load: loading due to seismic activities in the earth where the bridge is installed. The live pedestrian loading, wind loading, seismic and snow loading are also called unpredictive loadings as these events can happen any time.

These design approaches have different loading combinations available. All of these combinations are applied to steel bridges while designing, and the one that gives the minimum factor of safety is the limiting load case [15].

3.1. Allowable stress design (ASD)

This design approach has been in use for the last 100 years for designing different types of steel structures [16]. The other names used for this approach are working stress design (WSD) and service load design (SLD). The philosophy/concept of this design method is that when a bridge is under its service and loading condition, the maximum stress occurring in a steel structural member must necessarily be less than the allowable stress. To calculate this allowable stress against a specific material, its nominal strength is divided by a factor of safety. The equation for ASD can be written as:

$$\sum \sigma_{\text{working}} \leq \sigma_{\text{allowable}} = \frac{\sigma_{\text{nominal}}}{F_{\text{safety}}}. \tag{1}$$

Against failure, the ASD design approach cannot provide a true factor of safety, although its application is very simple. The factor of safety for the ASD approach includes all the uncertainties in the resistance of material and loading [17].

3.2. Load and resistance factor design (LRFD)

LRFD was first accepted as a design approach in 1986 and now many designers have shifted from ASD to LRFD [16]. This approach can be understood by the following equation:

$$\phi R_n = \sum_{1}^{i} \gamma_i Q_{ni}, \tag{2}$$

where γ_i are the load factors associated with each load effect of Q_i, ϕ is the resistance factor, Q_{ni} is the load effect, and R_n is the nominal strength.

For the LRFD case, $\phi < 1$ and $\gamma_i > 1$ handle the uncertainties that occur during the calculation of nominal strength and the effects of load that occur as a result of loads' natural variations, the specifications of materials, the approach accuracy and the analysis precision [18].

3.3. Comparison between LRFD and ASD

The LRFD design approach has two factors: load type and resistance. The ASD design approach uses only one factor: factor of safety. So LRFD is more consistent because it uses two factors and it takes into account the fact that, for example, the uncertainties of live load are greater than dead load and thus $\gamma L = 1.6$ and $\gamma D = 1.2$ [18].

According to their respective factors, AISC in the specifications for structural steel buildings have published different load combinations for both of the approaches, as given in Table 1 [15].

So when designing the structural steel buildings, i.e., footbridges, these load combinations are applied according to their applicability based on the application and location of the structure/bridge.

TABLE 1. Load combinations.

Load combinations	ASD	LRFD
1	D	$1.4D$
2	$D + L$	$1.2D + 1.6L + 0.5(l_r \text{ or } R \text{ or } S)$
3	$D + (l_r \text{ or } R \text{ or } S)$	$1.2D + 1.6(l_r \text{ or } R \text{ or } S) + (L \text{ or } 0.5W)$
4	$D + 0.75L + 0.75(l_r \text{ or } R \text{ or } S)$	$1.2D + W + L + 0.5(l_r \text{ or } R \text{ or } S)$
5	$D + 0.6W$	$0.9D + W$
6	$D+0.75L+0.75(0.6W)+0.75(l_r \text{ or } R \text{ or } S)$	$1.2D + E_v + E_h + L + 0.2S$
7	$0.6D + 0.6W$	$0.9D - E_v + E_h$
8	$D + 0.7E_v + 0.7E_h$	
9	$D + 0.525E_v + 0.525E_h + 0.75L + 0.75S$	
10	$0.6D - 0.7E_v + 0.7E_h$	

4. STAAD Pro

STAAD Pro is a design and analysis software of Bentley Systems. It is a software for structural analysis that was originally developed in 1997 by Research Engineers International. The most helpful aspect of this software is that it has 90 international design codes for steel, aluminum, concrete and timber, including LRFD and ASD.

This software provides easy modeling, interfacing and applying loads. Thus, it is used all around the world for steel structures and footbridge designing. Lots of past research on steel structures and buildings have been done with the help of STAAD Pro. Kuman and Prakash performed planning analysis and design of industrial building using STAAD Pro [19]. Harle performed analysis of different structural elements with the help of STAAD Pro [20].

5. Methodology

The footbridge discussed in this paper is a bridge connecting two family parks in Islamabad, Pakistan, which have a water stream flowing between them, as shown in Fig. 1.

The steel footbridge under consideration is designed to have the following dimensions as per installation site requirement:

clear span = 28.5 m,
deck width = 2 m,
height of railing = 1 m,
main girder I beams = I 500 mm $\times$ 150 mm $\times$ 15 mm $\times$ 18 mm,
cross I beams = I 150 mm $\times$ 75 mm $\times$ 6 mm $\times$ 8 mm.

FIG. 1. 3D computer-generated visualization of the footbridge at the proposed location.

The schematic of the footbridge is shown in Fig. 2 with its standard views (a), (b) and (c). Also, the 3D visualization of the bridge is shown in Fig. 3.

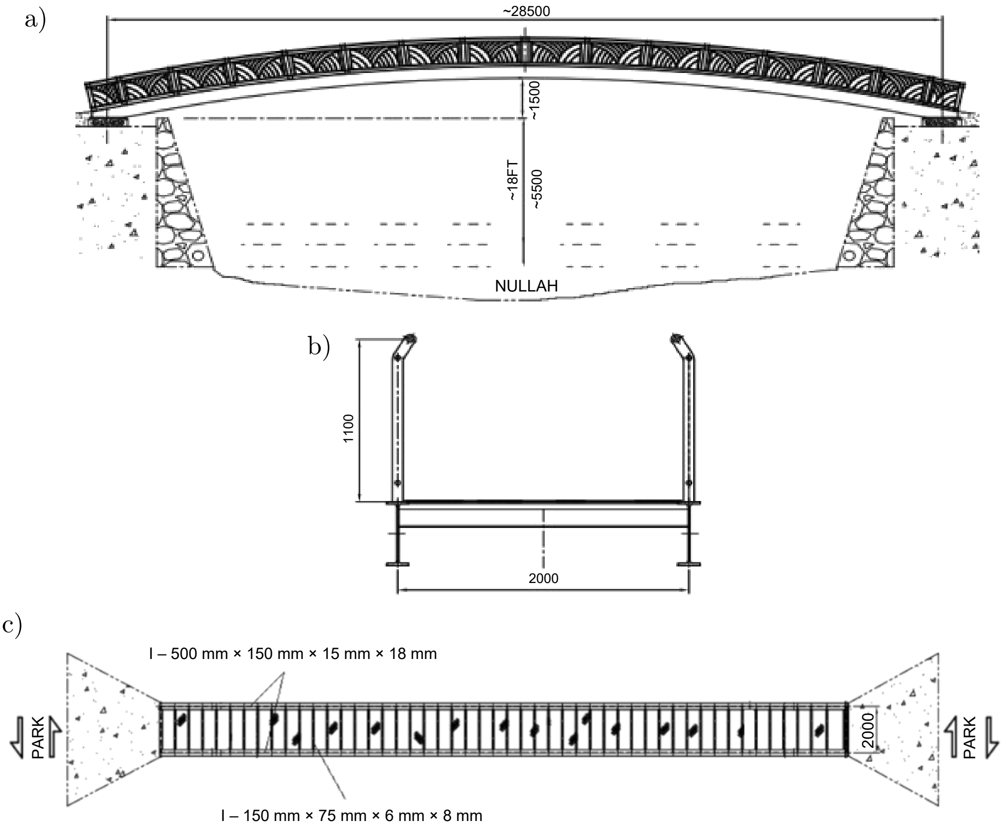


FIG. 2. Schematic of the footbridge: a) front view, b) side view, c) top view.

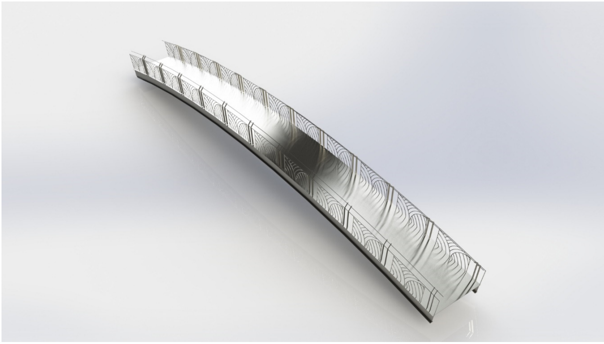


FIG. 3. 3D computer-generated visualization of the bridge.

First, the footbridge was modeled in the STAAD Pro software as per the actual dimensions from which the footbridge will be manufactured. After that, steel structural members were assigned. Then, proper loading was applied as per the respective standards. The bridge was analyzed by all the load combinations of LRFD and ASD. The respective actual ratios were then identified both for LRFD and ASD by STAAD Pro for all the beams.

The actual ratio is:

$$\text{actual ratio} = \frac{\sigma_{\text{working}}}{\sigma_{\text{allowable}}}, \tag{3}$$

where σ_{working} and $\sigma_{\text{allowable}}$ are calculated based on the design approach by the software.

The maximum actual ratio corresponds to the reference of the design safety and is called the critical ratio. If the critical ratio is equal to one for any approaches, then it means that based on that approach, the design has reached its maximum stress-bearing point and more stress would result in the failure of the structure. We compared the critical ratio for both approaches to conclude which approach results in weight saving while being safe for applied loading, i.e., the load combination that resulted in maximum critical ratio.

5.1. Modeling

The railing and the chequered plate are non-load bearing members of the steel footbridge. and thus when performing analysis, these are eliminated to simplify the analysis. In the current design, the main load-bearing member is the deck of the footbridge and it is modeled in STAAD Pro, as shown in Figs. 4a–4c. In the STAAD Pro software, a node is created where two structural members are connected and the loading is transferred by these nodes. The total length of each structural member is divided between nodes, as shown in Fig. 4d. The results

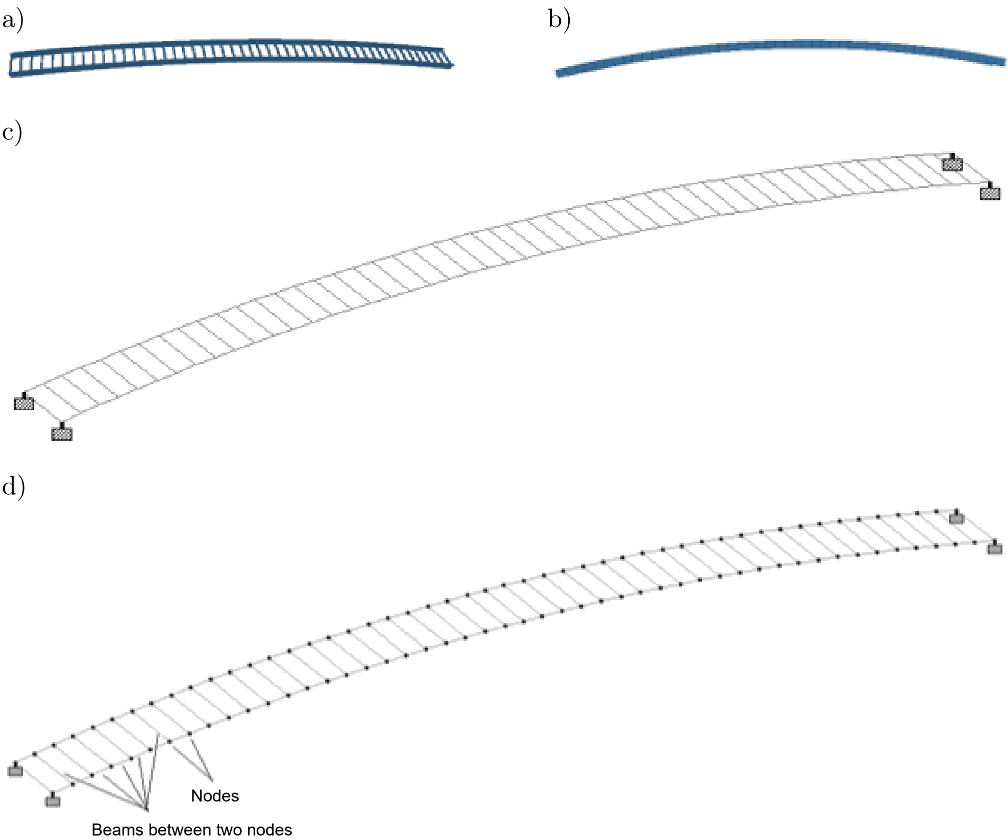


FIG. 4. Load bearing deck of the footbridge modeled in STAAD Pro: a) isometric 3D view, b) front 3D view, c) isometric line view with fixed fixture at both ends, d) nodes and beams.

and actual ratios are obtained for all divided beams. There are 146 beams in the modeled bridge.

5.2. Fixture assignment

The footbridge is fixed from two ends, as shown in Fig. 4c. During installation, these four points are placed on the ground with foundation bolts and base plates, but as our analysis is limited to deck members, we fixed these points. This is a standard practice in bridge designing in STAAD Pro [19].

5.3. Steel sections assignment

In the next step, the structural steel members are assigned to the respective locations, as shown in Figs. 5a and 5b. These members are selected based on availability from the local market.

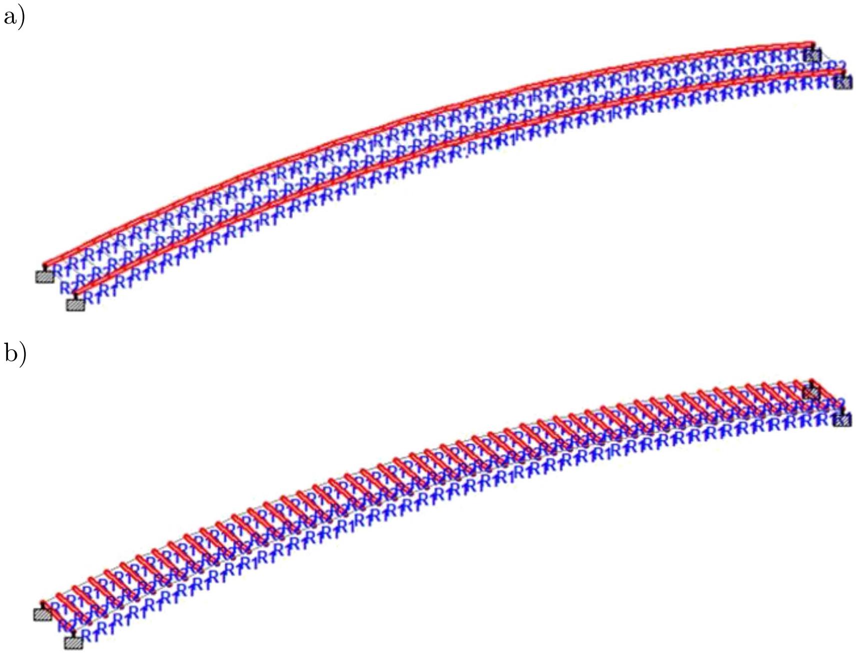


Fig. 5. Section assignment: a) I 500 mm × 150 mm × 15 mm × 18 mm and b) I 150 mm × 75 mm × 6 mm × 8 mm.

5.4. Wind load application

The wind loading is applied as per ASCE-7 (2010) chapter 26. The building classification category is selected as II, the basic wind speed is selected as 110 mph, the exposure category is selected as B and the structure type is selected as lattice framework because the railing of the bridge constitutes a major area in front of wind, which closely resembles lattice framework. All these specifications are shown in Fig. 6a, and the wind load application is shown in Fig. 6b. The wind load is applied to windward and leeward/sidewall accordingly by software [15].

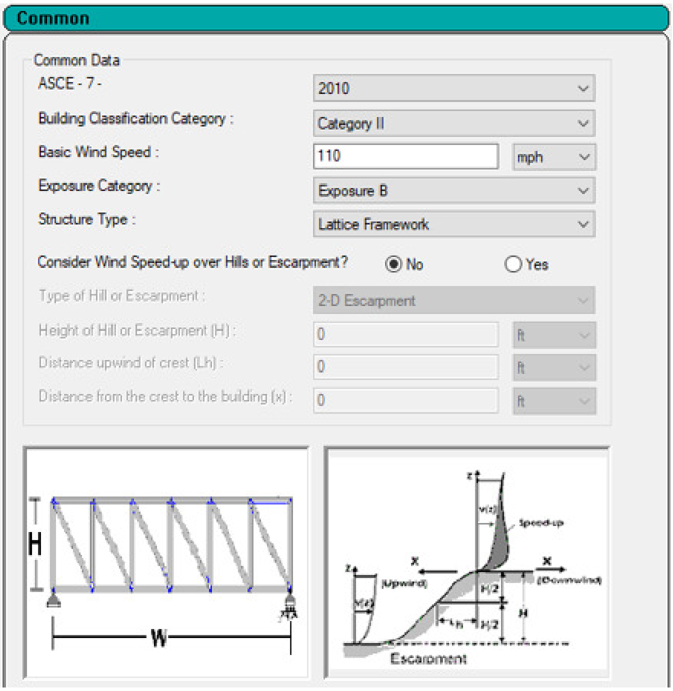
5.5. Live load application

The pedestrian live load is applied in downward direction to the deck and its magnitude is set at 415 kg/m^2 as per AAHTO specifications [21]. This is called floor load in the software as shown in Fig. 7.

5.6. Earthquake load application

Earthquake loading is applied as per UBC 1997, which is also available in STAAD Pro [22]. The parameters selected as per location of bridge: Islamabad, Pakistan are shown in Fig. 8.

a)



b)

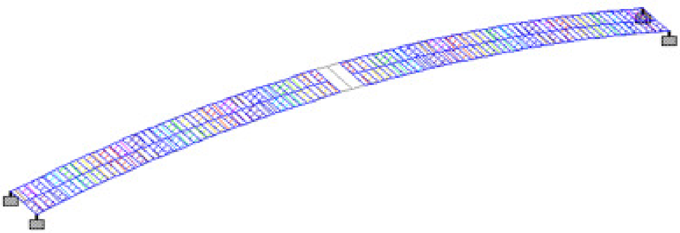


Fig. 6. Wind load application: a) parameters selection and b) wind loading applied.

Fig. 7. Pedestrian live load (floor load) applied to the deck as per AASHTO.

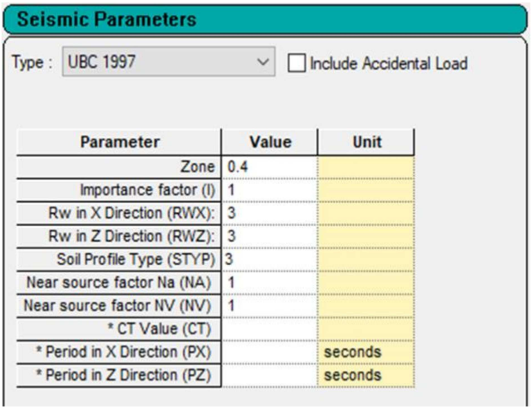


Fig. 8. Earthquake (seismic) parameters as per UBC 1997.

6. Application of load combinations

In the STAAD Pro software, the load combinations given in Table 1 are generated and applied for both the LRFD and ASD approaches, accordingly. The snow loading is not applied as in Islamabad, Pakistan, snow does not fall. For snow falling countries, this should be added in software load combinations, as shown in Table 1.

7. Results

The actual ratios and limiting load case for both the ASD and LRFD design approaches are given in Table 2 for all the beams of the footbridge. STAAD Pro gives actual ratios instead of the factor of safety for each bridge member. Actual ratios are just the inverse of the factor of safety. So the bridge member with the highest actual ratio will have the minimum factor of safety. STAAD Pro also gives limiting load case no. from all the load combinations given in Table 1. It applies all the load combinations of Table 1 and provides the load combination number, which gives the highest actual ratio, i.e., the minimum factor of safety, which is our main concern. STAAD Pro gives a wide range of other results too, i.e., shear and bending moment diagrams for each member. However, in the current study, the results in Table 2 are taken out of this wide range of results. The beam's 138 results are the most important as this beam has the highest actual ratio in the footbridge, i.e., the minimum factor of safety, and thus marked in Table 2 given below with "*". Table 2 is made short as other bridge structural members' factor of safety greater than that of member 138 is not important because if the bridge fails it will fail due to member 138.

TABLE 2. Results of analysis.

Beam no.	Member specification	ASD		LRFD	
		Actual ratio	Limiting load combination	Actual ratio	Limiting load combination
1	I 500 × 150 × 15 × 18	0.507	9	0.412	6
2	I 500 × 150 × 15 × 18	0.437	9	0.344	6
3	I 500 × 150 × 15 × 18	0.384	9	0.293	6
. . .					
137	I 150 × 75 × 6 × 8	0.655	8	0.525	6
*138**	*I 150 × 75 × 6 × 8*	*0.658*	*8*	*0.528*	*6*
139	I 150 × 75 × 6 × 8	0.649	8	0.520	6
. . .					
144	I 150 × 75 × 6 × 8	0.231	8	0.191	6
145	I 150 × 75 × 6 × 8	0.031	2	0.033	2
146	I 150 × 75 × 6 × 8	0.083	2	0.089	2

8. Discussion

From the results, it is clear that as a whole, the bridge is safe for given loading as no member possesses an actual ratio more than or equal to 1 for both the LRFD and ASD approaches, i.e., the factor of safety of all the bridge structural members is greater than 1. The maximum actual ratio, also called the critical ratio, exists for member no. 138, which is I-Beam I 150 mm × 75 mm × 6 mm × 8 mm for both the ASD and LRFD approaches, as shown in Fig. 9.

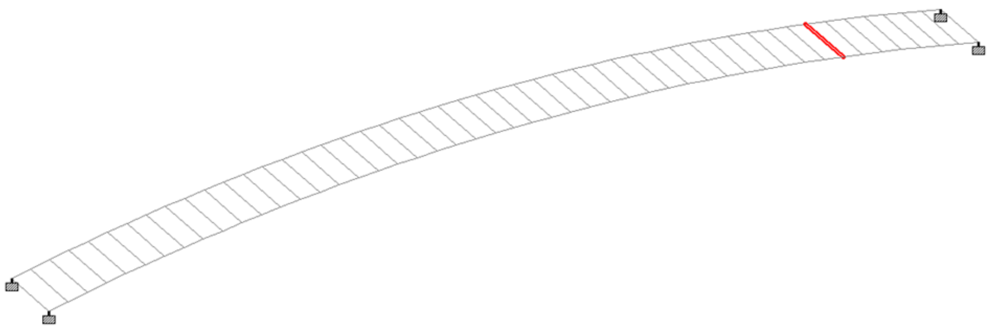


FIG. 9. Member no. 138 with maximum actual ratio.

The value of the critical ratio is 0.658 for ASD and 0.528 for LRFD, as shown in Table 2. As the factor of safety is the inverse of the critical ratio given by STAAD Pro, therefore:

The minimum factor of safety of footbridge for:

$$\text{ASD} = \frac{1}{\text{critical ratio for ASD}} = \frac{1}{0.658} = 1.52, \tag{4}$$

$$\text{LRFD} = \frac{1}{\text{critical ratio for LRFD}} = \frac{1}{0.528} = 1.89. \tag{5}$$

So it is observed that for the steel footbridge design under unpredictive loadings such as live pedestrian loading, seismic loading and wind loading, LRFD gives greater factor of safety than ASD. The graph in Fig. 10 shows the comparison of LRFD' actual ratios vs. ASD' actual ratios.

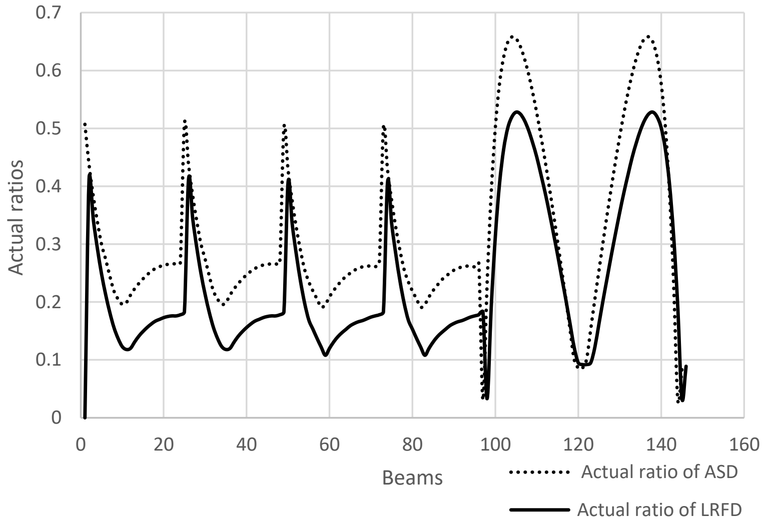


Fig. 10. Actual ratios vs. beams.

The minimum factor of safety percentage of ASD falling below LRFD:

$$\begin{aligned} &= \left(1 - \frac{\text{minimum factor of safety of footbridge for ASD}}{\text{minimum factor of safety of footbridge for LRFD}}\right) \\ &= \left(1 - \frac{1.52}{1.89}\right) \times 100 = 20\%. \end{aligned} \tag{6}$$

It is also clear from the above that the minimum factor of safety for LRFD is 20% greater than ASD or the actual ratio for LRFD is 20% lower than ASD. The same is also true for actual ratios of all the structural members for ASD and LRFD, as can be seen in Fig. 10 and Table 2 (actual ratio values).

LRFD results in lighter structures because LRFD will reach the minimum limit of 1 for the minimum factor of safety earlier than ASD, i.e., when the minimum factor of safety of LRFD will be 1, the minimum factor of safety for ASD will be 0.80 for the same conditions. So in order to obtain the same minimum factor of safety, the ASD criteria require to add more strength to the footbridge. Also, it can be concluded that the footbridge will pass the LRFD criteria first but it will fail in ASD. The LRFD criteria are more accurate because they accommodate for uncertainties in both loading and resistance, and this results in the footbridge being 20% stronger than in ASD, as the bridge can bear more forces than in the case of ASD before failing.

From the results in Table 2, it is also clear that following are the limiting load combinations for the ASD and LRFD approaches (given by member 138 with the maximum actual ratio/critical ratio, marked with "*" in Table 2):

- limiting load combination for ASD: case no. 8 (as given in Table 1) = $D + 0.7E_v + 0.7E_h$,
- limiting load combination for LRFD: case no. 6 (as given in Table 1) = $1.2D + E_v + E_h + L + 0.2S$.

The above limiting load cases suggest that the steel footbridges fail when the earthquake or seismic load combines with the dead or live load. This result can help designers make their steel footbridge design safer by making it stable for seismic loading. This suggests that designers in the case of steel footbridges should give attention to load combination having seismic loading in it. If the bridge is safe for such a load combination, it will be safe for others as well. This will greatly reduce the design time and effort.

It is clear from the above discussion that if a bridge is safe for both the LRFD and ASD approaches (the factor of safety for both is greater than 1) and a specific factor of safety is to be obtained/maintained for the footbridge then go for the LRFD approach as it will provide for the factor of safety earlier than ASD and will be lighter, ultimately resulting in lower cost. For ASD to obtain/maintain the same factor of safety, one would have to make the structure heavier, which will lead to more steel usage and ultimately increased cost.

The total weight of the footbridge under consideration is around 7098 kg (obtained from the software) so its 20% (from the factor of safety difference between LRFD and ASD), around 1420 kg, is needed if the ASD approach is used to obtain/maintain the same factor of safety as that of LRFD. This is a very significant cost saving that is about 20% of total cost in just raw steel members. The cost of manufacturing, coating, transportation and installation will be in addition to this.

These results are very close to the results of Choi *et al.* [11] when they performed the same comparison between LRFD vs. ASD on cable-stayed bridges and concluded that LRFD is 20% more cost-effective than ASD. The only difference is that they compared it using manual calculations. Thus, obtaining the same result of 20% with the help of software proves the validity and importance of the analysis by STAAD Pro. Ultimately, this results in saving of design time and achieving highly accurate results.

The cost is a very important factor, especially for densely populated and underdeveloped countries. Hence, the LRFD approach is highly recommended for such countries. This difference of a factor of safety and ultimately cost reduction can be generally applied for all the steel footbridges having any value of span with unpredictive loading as these values of actual ratios will change, but their ratio will always be around 20%. Their limiting load combination will also be the same as the one obtained above. The only required condition is that the loading applied is the same as for the bridge under discussion, i.e., dead, live, pedestrian, wind and seismic loading.

Data availability statement

The authors state that all data, models, and codes that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. A. Vashisth, M. Kumar, A. Kumar, Ashish, *Design of Foot Bridge*, 2012, doi: 10.13140/RG.2.2.17428.81285.
2. L. Muir, C.J. Duncan, The AISC 2010 Specification and the 14th Edition Steel Construction Manual, [in:] *Structures Congress 2011*, April 14–16, 2011, Las Vegas, Nevada, United States, pp. 661–675, doi: 10.1061/41171(401)58.
3. B.R. Ellingwood, LRFD: implementing structural reliability in professional practice, *Engineering Structures*, **22**(2): 106–115, 2000, doi: 10.1016/S0141-0296(98)00099-6.
4. C.W. Roeder, Comparison of LRFD and allowable stress design methods for steel structures, 5th Seminario de Ingenieria Estructural, San Jose, Costa Rica, November, 1990.
5. S.-H. Lin, W. Yu, T.V. Galambos, ASCE LRFD method for stainless steel structures, [in:] CCFSS Proceedings of International Speciality Conference on Cold-Formed Steel Structures (1971–2018), 1, University of Missouri–Rolla, 1990, https://scholarsmine.mst.edu/isccss/10iccfss/10iccfss-session5/1.
6. T. Culp, R. Mathur, LRFD vs. ASD, *Modern Steel Construction*, **31**(11): 24–27, 1991.
7. R. Soegiarso, H. Adeli, Optimum load and resistance factor design of steel space-frame structures, *Journal of Structural Engineering – ASCE*, **123**: 184–192, 1997, doi: 10.1061/(ASCE)0733-9445(1997)123:2(184).
8. M.S. Hayalioglu, S.O. Degertekin, Minimum cost design of steel frames with semi-rigid connections and column bases via genetic optimization, *Computers & Structures*, **83**(21–22): 1849–1863, 2005 doi: 10.1016/j.compstruc.2005.02.009.

9. H. Warren, H.B. Manbeck, J.J. Janowick, R.W. Witmer, Differences in LRFD and ASD outcomes for hardwood glue-laminated bridges, *Transactions of ASAE*, **41**(3): 803–811, 1998.

10. J.S. Groenier, Load rating of wood bridges using LRFD and ASD, [in:] *Structures Congress 2006*, May 18-21, 2006, St. Louis, Missouri, United States, doi: 10.1061/40889(201)139.

11. D.H. Choi, H. Yoo, J.L. Shin, Comparative study on stability evaluation methods with ASD and LRFD for steel cable-stayed bridges [in:] *Proceedings of the 8th Pacific Structural Steel Conference – Steel Structures in Natural Hazards*, PSSC 2007, Wairakei, New Zealand, pp. 165–170, 2007.

12. R. Shreedhar, S. Mamadapur, Analysis of T-beam bridge using finite element method, *International Journal of Engineering and Innovative Technology* (*IJEIT*), **2**: 340–346, 2012.

13. K.P. Kumar, B. Shankar, P.M. Rao, Evaluation and design of flyover using Staad pro, *International Journal of Professional Engineering Studies*, **7**(2): 31–36, 2016.

14. S. Indra, M. Efran, Mohammad, I.K. Dedi Wijaya, Alternative design of the building structure of steel frame bridge type steel arch with warren frame in Tukad Bangkung Bridge in Badung – Bali, *Journal of Sustainable Technology and Applied Science*, **1**(1): 22–27, 2020, doi: 10.36040/jstas.v1i1.2610.

15. American Society of Civil Engineers, *Minimum design loads and associated criteria for buildings and other structures*, American Society of Civil Engineers, 2017, doi: 10.1061/9780784414248.

16. C.G. Salmon, J.E. Johnson, *Steel Structures: Design and Behavior*, 4th ed., Harper Collins, New York, NY, 1997.

17. W. Lin, T. Yoda, Bridge Planning and Design, *Bridge Engineering: Classifications, Design Loading, and Analysis Methods*, pp. 31–58, 2017, Butterworth-Heinemann.

18. T.V. Galambos, M.K. Ravindra, Load and resistance factor design, *Engineering Journal*, AISC, **18**(3): 78-84, 1981.

19. K.P. Kumar, D.S. Prakash, Planning analysis and design of industrial building using STAAD PRO, *International Journal of Pure and Applied Mathematics*, **119**(17d): 131–137, 2018.

20. S.M. Harle, Analysis by STAAD-PRO and design of structural elements by MATLAB, *Journal of Asian Scientific Research*, **7**(5): 145–164, 2017, doi: 10.18488/journal.2.2017.75.145.164.

21. T. Zokaie, AASHTO-LRFD live load distribution specifications, *Journal of Bridge Engineering*, **5**(2): 131–138, 2000.

22. Uniform Building Code (UBC-97), Structural Engineering Design Provisions, International Conference of Building Officials, Whittier, 1997, p. 492.

Received September 30, 2021; revised version February 8, 2022.