Capacity Increase for Existing Steel Bridges Using Prestressed Cables

Ayhan Nuhoğlu[1], Kemal Yücekul[1] , Kasım A. Korkmaz[2]

[1] *Ege University, Department of Civil Engineering, Bornova, Izmir, Turkey*

[2] *Dokuz Eylul University, Department of Civil Engineering,Tinaztepe, Izmir, Turkey*

ABSTRACT

In the present study, a practical approach is proposed for geometric nonlinear analysis of existing steel bridges. The approach is defined by finite element displacement direct rigidity procedure, which is based on an iterative procedure. Tangent rigidity matrix is used for cable truss and/or framed steel structures formed by finite elements. Hence, effects of prestressed cables in system rigidity can be taken into account in the analyses. Moreover, stressing effects on cables are taken into account with equivalent temperature change. The research has three main parts. In the first part, prestressed cables are investigated for capacity increase for steel bridges. In the second part, an iterative procedure is proposed for existing steel bridges that can be used for geometric nonlinear analysis. In the third part, a representative bridge is modeled and analyzed. In the model, first, the representative model is analyzed as it is existing form and then, it is analyzed with prestressed cables in two different forms. So, three different results are investigated for their structural behaviors. In the analyses, geometric nonlinear behavior is investigated and results are evaluated. As a result of the study, capacity change by using stressed cables is defined for existing bridges.

INTRODUCTION

In some specific cases, capacity increase is necessary for existing steel structural systems. Especially for existing bridges, that can be a case to increase the capacity for seismic or excessive loadings. Pre-stressed cables are commonly used to increase the structural capacity of exiting steel structural systems. Especially, for steel bridges and roof systems, pre-stressed cables are preferred due to provided economical solutions.

Up to now, using cable systems to increase the load capacity of steel structures is studied among various researchers. With a methodology developed and patented in 1847 by Squire Whipple, diagonal tension cables are used to increase the structural capacity of Pratt truss systems. In 19th century, different pre-tensioning methodologies with tension cables are used to increase the capacity of steel structures. Moreover, tension cables are preferred to strengthen older existing steel bridges. Bilal has proposed an analytical methodology for existing steel truss bridges [1].

For sure, static and dynamic structural analyses of structural system with tension cables are more complex and time consuming. Saitoh studied steel hybrid structures with tension cables and investigated effects of tension cables on structural behavior [2]. Arda investigated statical analysis of pre-tensioned truss systems with force based method [3].

Babayev has developed a new and simple methodology for pre-tensioned truss system. The method calculates the stresses on tension members due to external loads and adds them to the initial stress to find the final result [4].

Today, in nonlinear approaches to consider deformations and effects of tension cables, Finite Element Analysis is preferred and used. Analyses are developed for such systems and in general, step by step iteration method is used. Nuhoglu proposed a method for pre-stressed truss systems and the method is based on point iteration approach that controls displacements [5]. Yuan has proposed a simplified methodology for 3-D space frames based on linear superposition and structural mechanical theories [6]. Control force level has been determined for pre-tensioned systems. Structural analysis has been carried out in accordance to the determined control force. Kim's research work consists theoretical and experimental studies [7]. Wu worked on a truss systems with tension cables. He determined static and dynamic behavior of structures [8]. Tensegrity systems have been investigated by various researchers [9-11]. These types of structures are formed with cables and trusses and their structural behavior is similar to trusses with tensioned cables.

Pre-tensioning in steel structures changes the structural behavior and increases the capacity. Pre-tensioning provides effectiveness in material and structural behavior. Moreover, increases the structural members' local carrying capacity. In steel structures, pre-tensioning gives better results comparing to the other structure types.

In the present study, strengthening existing steel buildings with pre-tensioning cables. The study covers a new methodology to give better results for steel trusses with less material. In the study, experimental and analytical investigations were carried out for representative steel bridge with pre-tensioned cables. The results are compared in between cases before and after.

REPRESENTATIVE MODEL

In the study a representative model was established. To investigate the structural behavior of the bridges, a steel bridge model was developed. Representative structural model, constructed in mechanical laboratory has 6,5m span and 2m height as seen in Figure 1. In Table 1, structural members of the constructed bridge and their structural properties are given. Elastic modulus is 21.000MPa. Strut as a structural member at the mid point of the span in V shape has been welded after the construction completed for the other bolted members. Moreover, column-beam connection point is also welded connection.

Figure 1 Representative model

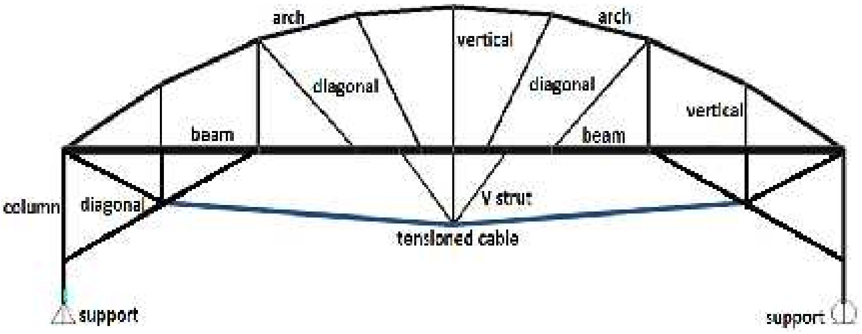


Figure 2 Structural system

Table 1 Member sections

Member	**Type**	**Section Area (cm^2)**
Beam	□ 60x40-t=3,25	6,00
Column	□ 40x40-t=3,25	4,70
Arch	O33,7-t=3,25	3,11
Diagonal	O21,3-t=2,65	1,55
Vertical	O21,3-t=2,65	1,55
V strut	O21,3-t=2,65	1,55
Cable	Φ10	0,80

Steel bridge has been analyzed for three different loading cases. For each loading case, displacements and axial forces in cables have been recorded. First, while cables are not in use, steel bridge deck was loaded. For loading, concrete samples in standard dimensions were used. Then, cables were tensioned with empty deck. Cables were tensioned with a mechanical gauge. While cables are tensioned, bridge deck was loaded with same standard concrete samples. In Figure 3, loaded bridge is shown. Loading cases are as given below.

L1: Loading Case 1; While there is no Pre-tension on the cables, 1,60kN/m distributed load was applied on the bridge deck.

L2: Loading Case 2; While there is Pre-tension on the cables, 1,60kN/m distributed load was applied on the bridge deck and axial force in cables are 6,0kN.

L3; Loading Case 3; While there is Pre-tension on the cables, there is no distributed load on the bridge deck and axial force in cables are 3,5kN.

Figure 2 Loaded Bridge Deck

EXPERIMENTAL AND ANALYTICAL INVESTIGATION

Structural Analyses

For each structural loading case, structural analyses have been carried out through Finite Element Modeling (FEM). In the analyses, Tangent rigidity matrix $\mathbf{K_T}$ has been used. $\mathbf{K_T}$ consists of $\mathbf{K_E}$ elastic rigidity and $\mathbf{K_G}$ geometrical rigidity.

Axial prestresses in cables are applied with assumption of uniform temperature change in cables. Final value of prestress force has been achieved with couple iterations.

Experimental Study

For each structural loading case, experimental tests were conducted. Displacements in mid point of bridge span and axial tension forces in cables are recorded.

Axial tension forces in cables are recorded with digital load cells and data loggers. In displacement record, mechanical displacement data logger. Loading was systematically carried manually. Loading took about an hour depending on the laboratory conditions.

RESULTS

For each loading case, Table 2 summarizes displacement values obtained from experimental and analytical research. According to gained results, displacement values at mid point of the span decreased while cables were pretensioned. Results obtained from analytical and experimental studies are different. Steel bridge model used in the experiments, is a mixed-supporting system including truss and frame elements coupled with bolts originally. This feature notable differences between the experimental and theoretical results are evaluated to be important factors in the formation. However, displacement patterns are similar.

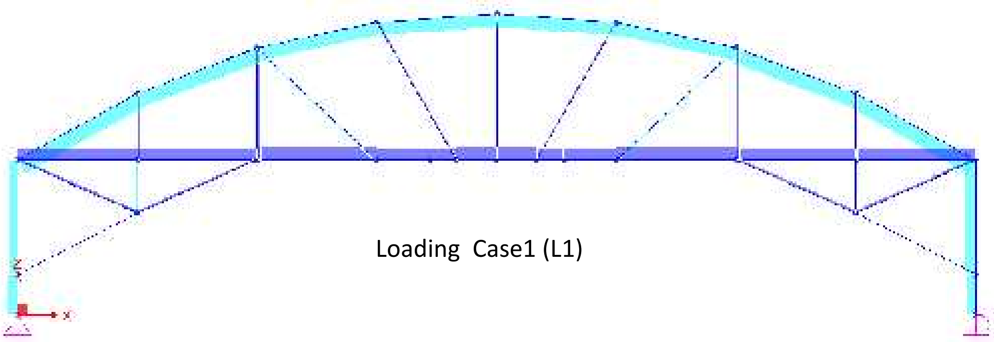
Table 2 Displacement values at mid point of the span

Displacements (mm)			
	L1	**L2**	**L3**

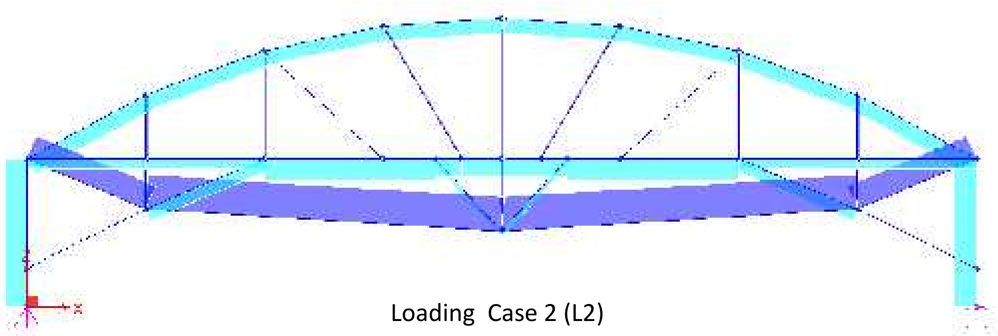
Method	Loading: 1,60kN/m No Pre-stress	Loading: 1,60kN/m Pre-stress: 6,0kN	Loading: 1,60kN/m Pre-stress: 3,5kN
Analytical	-1,80	-0,80	-0,60
Experimental	-3,00	-1,50	-1,40

In Figure 3, axial loads obtained from analytical part have been given. All axial load forces decrease in the bridge deck. Axial loading and max bending in columns, an increase was observed. On the other hand, max. bending moments in deck beams decrease significantly.

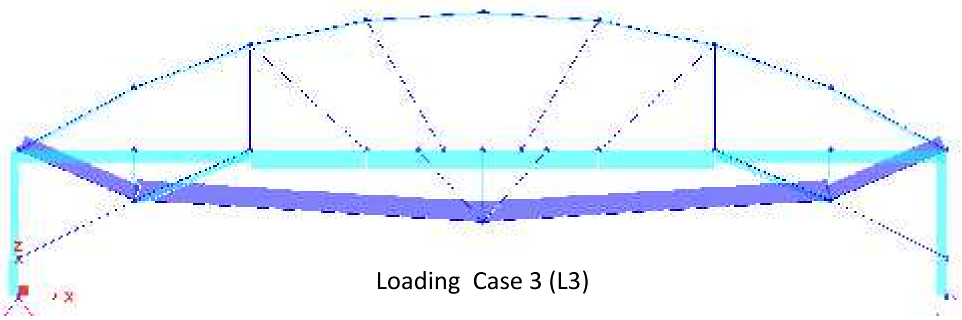
In the present study, the representative bridge is isostatical system and there is no significant change in support reactions. However, for hyperstatical cases, support reactions change significantly. In such a case, internal forces are expected to change dramatically.



Loading Case1 (L1)



Loading Case 2 (L2)



Loading Case 3 (L3)

Figure 3 Axial forces for each loading

In Table 3, internal forces are provided for different structural members. Especially, most critical structural members are listed in the Table.

Table 3 Extremum internal effects for bridge members

	Loading Case		
	L1 Loading: 1,6kN/m No Pretension	**L2** Loading: 1,6kN/m Pretension: 6,0kN	**L3** No Loading Pretension: 3,5kN
Arch- Axial Force	-9,2kN	-6,3kN	2,2kN
Beam-Bending Moment	29,7kNcm	16,9kNcm	5,1kNcm
Beam- Axial Force	8,3kN	-2,1kN	-5,6kN
Diagonal (bottom)- Axial Forc	-0,2kN	-2,5kN	-1,6kN
Diagonal- (up) Axial Force	1,2kN	0,9kN	0,3kN
Vertical- Axial Force	1,6kN	0,9kN	-0,5kN
Column- Bending Moment	8,2kNcm	7,2kNcm	1,7kNcm
Column- Axial Force	-4,9kN	-5,2kN	-0,1kN

CONCLUSION

In the present study, a practical approach is proposed for geometric nonlinear analysis of existing steel bridges. A representative model has been developed for structural analysis and experimental investigation. Experimental results were compared with analytical analyses results. A detailed evaluation has been presented with displacement in mid span of beams and tension values in cables.

As a result of the study, with pretensioned cables, there is a significant change in axial forces of some structural members such as diagonals under the beams. Through a stress comparison in between with and without cables, structure became an advantageous condition with cables. However, there could be some disadvantageous members, and therefore, system should be evaluated through a whole system instead of member evaluation.

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