EFFECT OF RAIL-STRUCTURE INTERACTION ON CABLE FORCES FOR RAILWAY EXTRADOSED BRIDGES

Rahul A. Dhanwani[1], Ashwin G. Hansora[2], Jignesh B. Gandhi[3]

[1]P.G. Student, Department of Applied Mechanics, L.D. College of Engineering, Ahmedabad
[2]Assistant Professor, Department of Applied Mechanics, L.D. College of Engineering, Ahmedabad
[3]Managing Director, CASAD Consultants Pvt. Ltd., Ahmedabad

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Abstract – *Extradosed bridges have become a popular pick among the bridge designers for the span range of 50 to 250 m across waterways where there is a navigational clearance requirement. In railway bridges, additional stresses are induced in the rails due to rail-structure interaction phenomenon. In extradosed bridges these additional stresses can be controlled by reducing the vertical deflection of the bridge deck which leads to increased axial force in the cable. The purpose of this study is to explore this increase in the maximum cable forces in a railway extradosed bridge when rail-structure interaction phenomena is taken into consideration. This study has been performed for extradosed bridges having different pylon heights and soil conditions. The live loads have been defined as per Eurocode-1991. Midas-Civil software has been used to analyze the bridge structure and compute the necessary cable pretension to control bridge deck deflection. The increase in the maximum resultant force in the cables due to consideration of rail-structure interaction phenomenon is then calculated and compared for different pylon heights and soil conditions.*

Key Words: **extradosed, rail-structure interaction, railway bridge, cable force, RSI**

1. INTRODUCTION

An extradosed bridge employs a structure that combines the main elements of both a prestressed box girder bridge and a cable stayed bridge. As this type of bridge offers requires shorter pylons as compared to cable-stayed bridges and slender deck as compared to girder bridge. In this type of bridge, the loads are transferred from the deck to the pier by stay cables and by longitudinal girder element in spanning-action between the main bridge supports. For railway bridges, additional stresses are induced in the rails the stiffness of the bridge deck is considerably less than that of solid ground. The less stiffness of the bridge results in its deformation under various loads/ thermal effects and the rails, being continuous, are not free to move and resist these movements, which induces loads in them. The interaction effects include actions due to following –

- Difference of temperature between deck and rail,
- Braking / tractive forces from rolling stock
- Vertical bending caused due to vertical live loads.

These effects are studied as rail-structure interaction (RSI). The final deformations/ stresses in track and bridge depend on this interaction phenomenon.

1.1 Aim and Objective of study

This study has been carried out to determine the changes in the maximum cable force when the vertical deflection profile of a railway extradosed bridge is adjusted for RSI. This study takes into consideration variation in pylon heights (height of vertical structural element above the deck level) and soil stiffness.

The analysis of the structure has been carried out in midas-Civil 2020 software.

1.2 Literature Review

The concept of an extradosed bridge was introduced by Mathivat (1988) for a design of Arrêt-Darré Viaduct in which external prestressing tendons were placed above the deck instead of within the cross-section. Virlogeux (1999) has explained that this concept was introduced to allow the use of higher value of allowable stress for prestressing cables (0.65 f_u) as compared to that of cable stays (0.45 f_u) (f_u is ultimate tensile strength). Komiya (1999) has presented the advantages of an extradosed bridge over cable stayed or prestressed concrete girder bridge. Chio Cho (2002) has provided certain design recommendations based on his study about structural behavior of extradosed prestressing during construction and in service. Mermigas (2008) has provided recommendations for geometric parameters like tower height, pier cross-section and girder depth and its influence on structural behavior of the bridge. Bujnak, Odrobirak and Vican (2013) have provided validation regarding design assumptions for impact factor for extradosed road bridge. Youcef, Sabiha, Mostafa, Ali and Bachir (2013) have studied the influence of track irregularities on dynamic responses of railway bridges. Romero, Solis, Dominguez and Galvin (2013) have studied the influence of soil-structure interaction on the dynamic characteristics of a railway bridge such as natural frequency, dynamic amplification factor, damping ratio, critical velocity of train and acceleration under loads in relation to the stiffness of the supporting soil. Mao and Lu (2013) have studied the influence of moving load type (single carriage and multiple carriages) and total mass of carriages (negligible and significant with respect to bridge self-weight) on the resonance severity for a railway bridge. Sogabe, Watanabe, Goto, Tokunaga, Kanamori and Tamai (2014) have investigated dynamic characteristics for railway extradosed bridge to ensure safety against resonance phenomenon taking into consideration the train running safety and passenger comfort criteria. Articles are available for the design of some specific extradosed bridges but little research has been done on the geometry of railway extradosed bridge taking rail-structure interaction into consideration.

2. METHODOLOGY

2.1 Bridge Geometry

The extradosed bridge considered for study is a 440 m long three-span bridge having main span equal to 200 m and side span equal to 120 m. The pier (vertical support column below the deck level) height is 20 m from the base. The pylon (vertical support column above the deck level) height has been varied as a function of span-to-depth ratio. Three different pylon heights – 17 m, 21 m and 25 m have been considered for this study (within limits recommended by Komiya (1999)). The deck of the bridge is made of prestressed concrete box girder having overall depth 3.75 m at center of span and 5.6 m at the pier in accordance with span/35 to span/55 limits as suggested by Komiya (1999). The width of the deck is 11.9 m as required for a 2-track railway bridge. 56 cables (28 in each cable plane) support the deck. Spacing between cables, on deck, is 10 m center to center and on pylon is 2 m center to center. The cable arrangement for 7 m tall pylon is shown in Fig.-4. For 17 m, 21 m and 25 m pylons, the lowermost cable is attached to the pylon at height 4 m, 8 m and 12 m from top of deck respectively and rest is same as shown in Fig. 4.

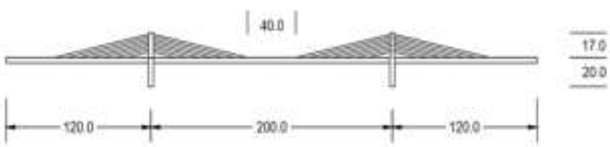

Fig -1: Extradosed bridge with 17 m pylon

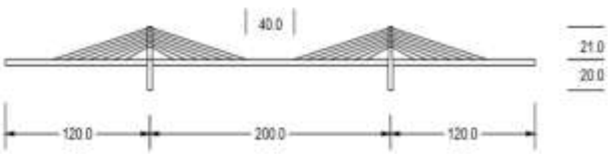

Fig -2: Extradosed bridge with 21 m pylon

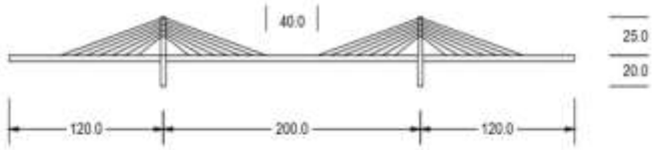

Fig -3: Extradosed bridge with 25 m pylon

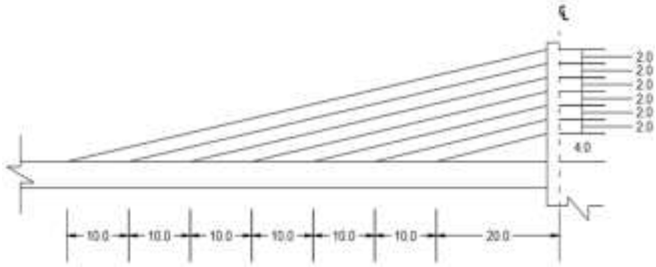

Fig -4: Cable arrangement for 17 m pylon
(Note: All dimensions are in m)

2.2 Support (Soil type)

Four different support conditions have been taken into consideration (arranged in decreasing order of stiffness)-

- Fixed base (fixed support at pier base-no foundation system)
- Soil model 1 (25-pile (Φ=750 mm) group having pile length = 25 m)
- Soil model 2 (25-pile (Φ=750 mm) group having pile length = 40 m)
- Soil model 3 (25-pile (Φ=750 mm) group having pile length = 55 m)

(Note: Φ = pile diameter)

The soil springs for pile elements have been generated by midas-Civil software to simulate the effect of soil-structure interaction. The arrangement of different layers in above soil models is given in Table -1. The properties of the different types of soils are given in Table-2

Table -1: Soil layers (top to bottom)

Model name	Layer 1 (m)	Layer 2 (m)	Layer 3 (m)
Model 1	Dense-32	-	-
Model 2	Medium-37	Dense-10	-
Model 3	Loose-37	Medium-15	Dense-10 m

Table -2: Soil Properties

Properties	Dense	Medium	Loose
Unit wt. (kN/m^3)	18.8	17.4	16
Φ (degrees)	32°	30°	28°
Elastic Modulus (kN/m^2)	80000	50000	20000

2.3 Loads

The self- weight of the structure is calculated automatically by the software. The live loads for this structure are defined as per EN 1991-2:2003 (E). Three different train load models are taken into consideration-

- HSLM A2
- HSLM A4
- HSLM A6

There are two railway tracks on the bridge and for maximum cable force both are loaded at the same time.

The partial safety factors for the ultimate limit state (ULS) and serviceability limit state (SLS) have been taken from Eurocode EN 1990:2002 (E).

2.4 Analysis Procedure

The bridge models as listed in Table -3 are prepared corresponding to parameters listed in section 2.1 to 2.3 for static analysis and rail-structure interaction (RSI) analysis. First the static analysis of each model is carried out. The cable pretension is adjusted so that the deck meets the minimum serviceability requirements provided by Eurocode EN 1990:2002 (E). In this condition, resultant cable forces corresponding to the longitudinal deflection profile of the deck are least as RSI is not taken into consideration. Now, a similar model is prepared for rail-structure interaction analysis. The vertical and braking/traction loads corresponding to the train load models are applied as per Eurocode EN 1991-Part 2:2003. The temperature of track is taken as 62 °Cand that of bridge deck is taken as 53 °C(based on empirical equations) for atmospheric temperature = 45 °C The stresses in the rail are calculated as per procedure given in code UIC 774-3R. The maximum value of compressive and tensile stress is compared with the limits provided in Eurocode EN 1991 EN 1991-Part 2: 2003 and UIC 774-3R. Limits for track stress are-

- Maximum compressive stress = 72 MPa
- Maximum tensile stress = 92 MPa.

If the rail stresses exceed the above limits, the values of cable pretension in the static model are readjusted to reduce the vertical deflection of the deck and for the new values, rail-structure model is reanalyzed. This process is repeated until the rail stresses are within the limits. For all models, the maximum cable force for pretension corresponding to the final deflection profile (obtained taking RSI into consideration) is then compared with the maximum cable force (without RSI). The results are provided in Table -4. The maximum force requirement (with RSI) corresponding to different pylon heights and different soil conditions are then compared.

Table -3: Bridge Models

Model No.	Pylon Height	Soil Type	Train Model
1	17 m	Fixed	HSLM A2
2	17 m	Fixed	HSLM A4
3	17 m	Fixed	HSLM A6
4	17 m	Dense	HSLM A2
5	17 m	Dense	HSLM A4
6	17 m	Dense	HSLM A6
7	17 m	Medium	HSLM A2
8	17 m	Medium	HSLM A4
9	17 m	Medium	HSLM A6
10	17 m	Loose	HSLM A2
11	17 m	Loose	HSLM A4
12	17 m	Loose	HSLM A6
13	21 m	Fixed	HSLM A2
14	21 m	Fixed	HSLM A4
15	21 m	Fixed	HSLM A6
16	21 m	Dense	HSLM A2
17	21 m	Dense	HSLM A4
18	21 m	Dense	HSLM A6
19	21 m	Medium	HSLM A2
20	21 m	Medium	HSLM A4
21	21 m	Medium	HSLM A6
22	21 m	Loose	HSLM A2
23	21 m	Loose	HSLM A4
24	21 m	Loose	HSLM A6
25	25 m	Fixed	HSLM A2
26	25 m	Fixed	HSLM A4
27	25 m	Fixed	HSLM A6
28	25 m	Dense	HSLM A2
29	25 m	Dense	HSLM A4
30	25 m	Dense	HSLM A6
31	25 m	Medium	HSLM A2
32	25 m	Medium	HSLM A4
33	25 m	Medium	HSLM A6
34	25 m	Loose	HSLM A2
35	25 m	Loose	HSLM A4
36	25 m	Loose	HSLM A6

3. RESULTS

The maximum cable force with and without consideration of RSI phenomenon are presented in Table -4

Table -4: Maximum Cable Force

Model No.	Max. force without RSI (kN)	Max. force with RSI (kN)	Change in force due to RSI (%)
1	31018.2	36109.6	16.41
2	31149.9	35727.9	14.70
3	31199.9	35571.2	14.01

Model No.	Max. force without RSI (kN)	Max. force with RSI (kN)	Change in force due to RSI (%)
4	31451.7	37712.6	19.91
5	31270.5	37626.1	20.32
6	32911.4	37119.0	12.78
7	31275.3	39334.2	25.77
8	31710.9	39008.5	23.01
9	29451.5	39046.7	32.58
10	35405.8	40994.6	15.78
11	31373.4	40674.4	29.65
12	31674.5	40861.5	29.00
13	26097.6	28486.2	9.15
14	25997.3	28764.0	10.64
15	25919.3	28375.8	9.48
16	27353.5	30878.8	12.89
17	27695.6	31465.6	13.61
18	28440.8	31024.4	9.08
19	26125.7	33327.8	27.57
20	25166.5	33376.7	32.62
21	28106.9	33290.8	18.44
22	30148.7	36925.7	22.48
23	28717.3	36776.4	28.06
24	28448.4	36509.6	28.34
25	20537.8	23384.0	13.86
26	21452.8	23602.2	10.02
27	20597.7	23383.8	13.53
28	24340.0	26207.6	7.67
29	22763.2	26579.5	16.77
30	22110.5	26090.3	18.00
31	21876.0	28839.1	31.83
32	25506.4	29570.4	15.93
33	22843.4	29375.4	28.59
34	25403.6	33221.3	30.77
35	24910.1	33256.3	33.51
36	24774.7	33188.2	33.96

3.1 Comparison of forces with respect to support condition

In this section, the maximum design forces for both (without and with RSI) are compared for different support conditions.

Chart -1 presents the forces for models – 1, 4, 7, 10
Chart -2 presents the forces for models – 2, 5, 8, 11
Chart -3 presents the forces for models – 3, 6, 9, 12
Chart -4 presents the forces for models – 13, 16, 19, 22
Chart -5 presents the forces for models – 14, 17, 20, 23
Chart -6 presents the forces for models – 15, 18, 21, 24
Chart -7 presents the forces for models – 25, 28, 31, 34
Chart -8 presents the forces for models – 26, 29, 32, 35
Chart -9 presents the forces for models – 27, 30, 33, 36

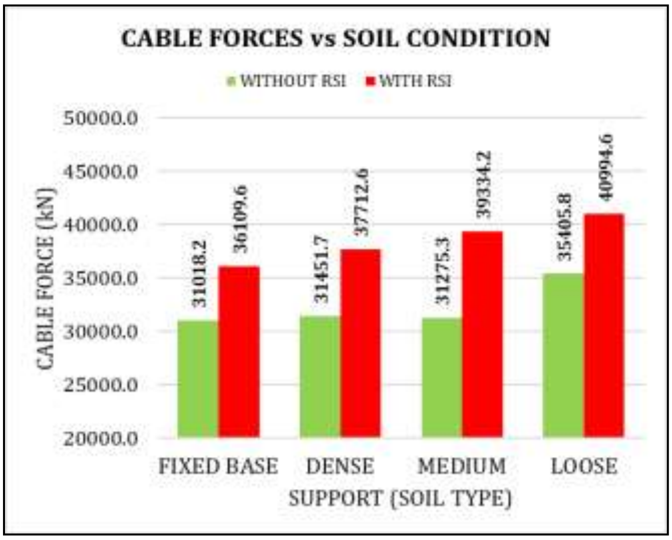

Chart -1: Cable force – 17 m pylon and HSLM A2

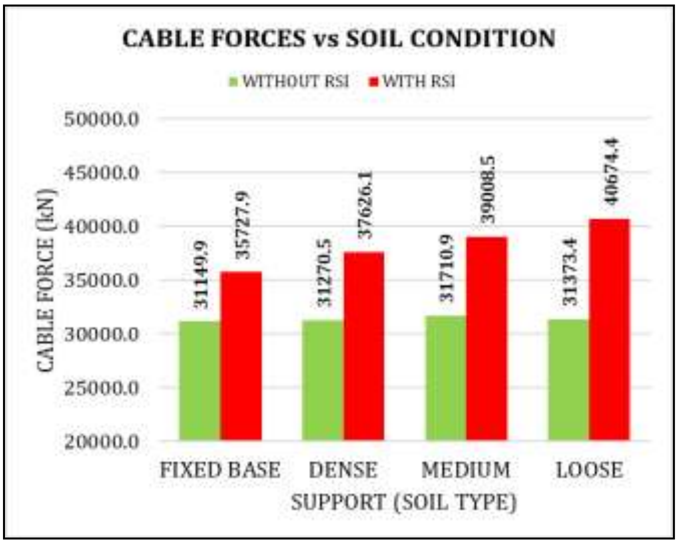

Chart -2: Cable force – 17 m pylon and HSLM A4

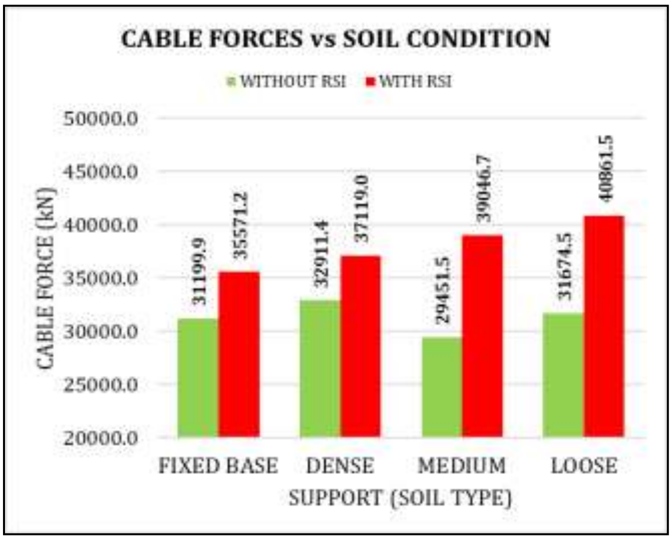

Chart -3: Cable force – 17 m pylon and HSLM A6

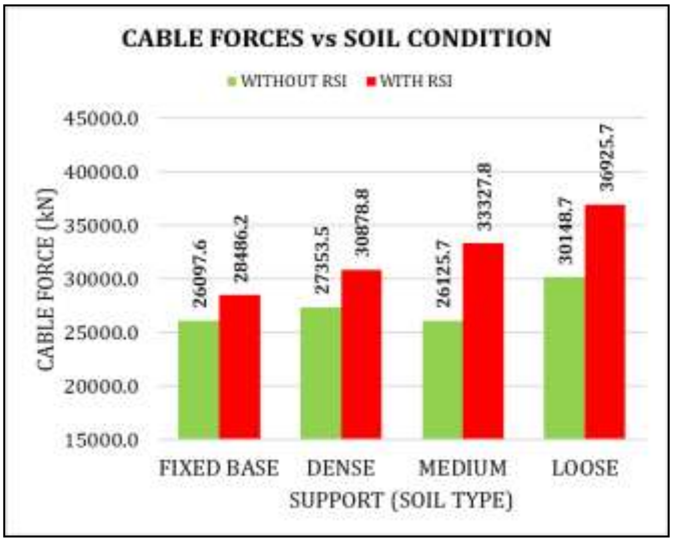

Chart -4: Cable force – 21 m pylon and HSLM A2

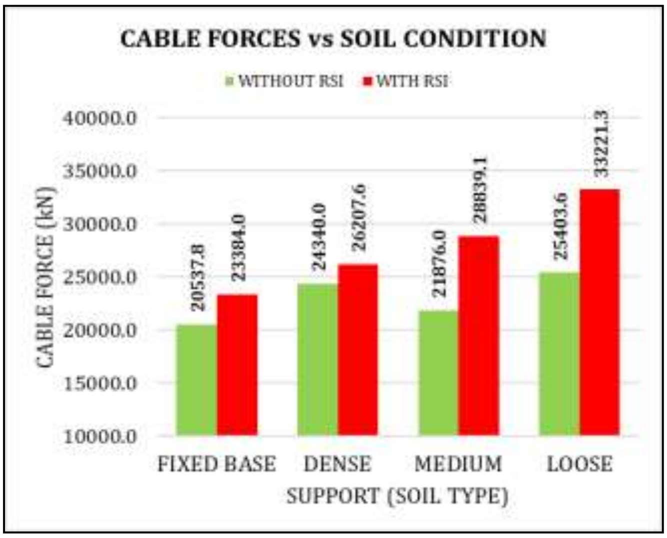

Chart -7: Cable force – 25 m pylon and HSLM A2

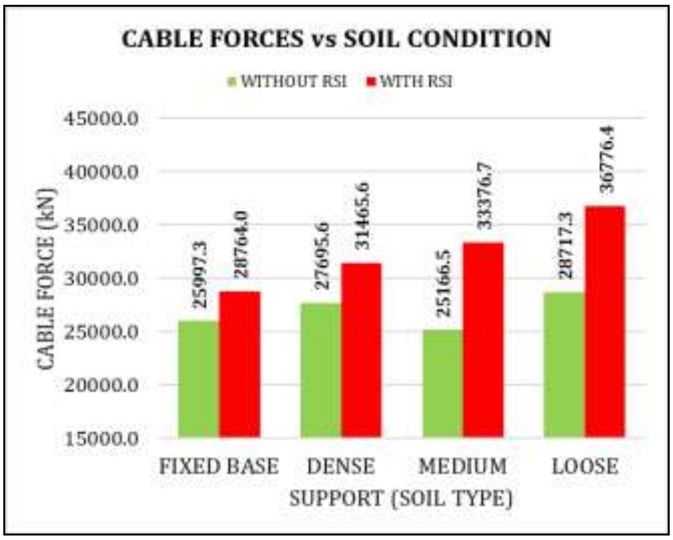

Chart -5: Cable force – 21 m pylon and HSLM A4

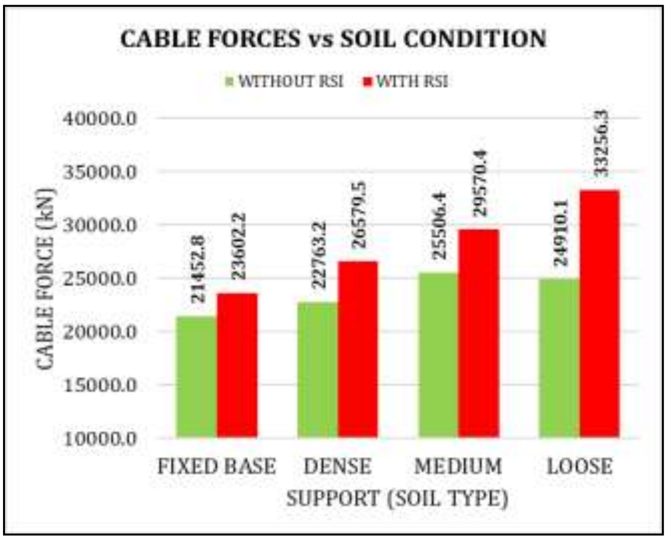

Chart -8: Cable force – 25 m pylon and HSLM A4

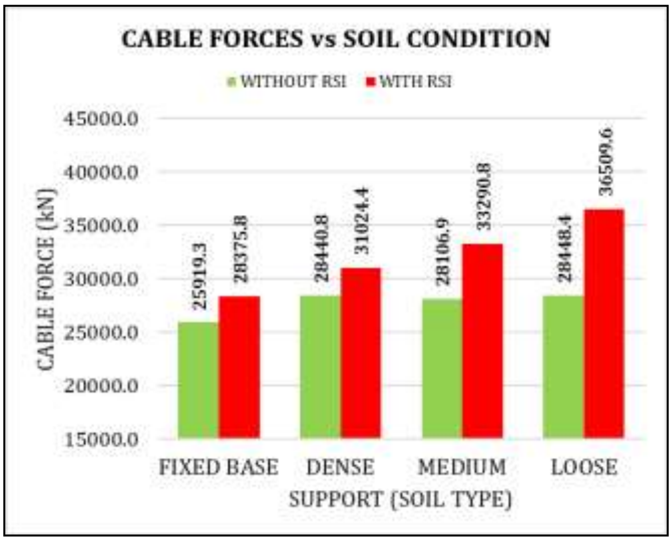

Chart -6: Cable force – 21 m pylon and HSLM A6

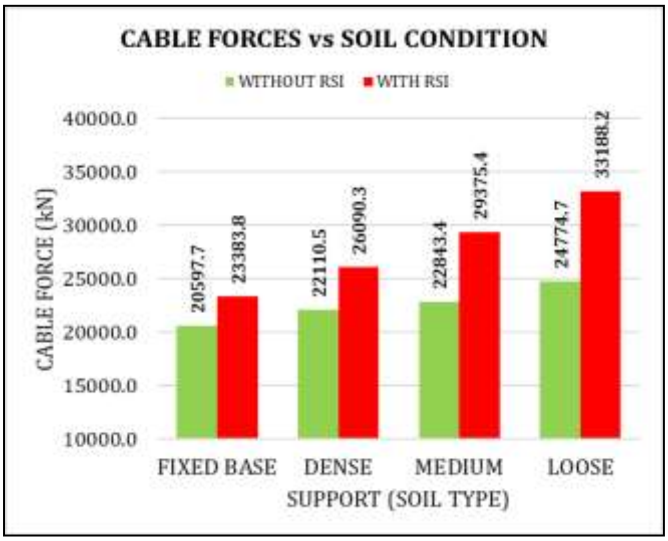

Chart -9: Cable force – 25 m pylon and HSLM A6

3.2 Comparison of forces with respect to pylon height

In this section, the maximum design forces for both (without and with RSI) are compared for different pylon heights.

Chart -10 presents the forces for models – 1, 13, 25
Chart -11 presents the forces for models – 2, 14, 26
Chart -12 presents the forces for models – 3, 15, 27
Chart -13 presents the forces for models – 4, 16. 28
Chart -14 presents the forces for models – 5, 17, 29
Chart -15 presents the forces for models – 6, 18, 30
Chart -16 presents the forces for models – 7, 19, 31
Chart -17 presents the forces for models – 8, 20, 32
Chart -18 presents the forces for models – 9, 21, 33
Chart -19 presents the forces for models – 10, 22, 34
Chart -20 presents the forces for models – 11, 23, 35
Chart -21 presents the forces for models – 12, 24, 36

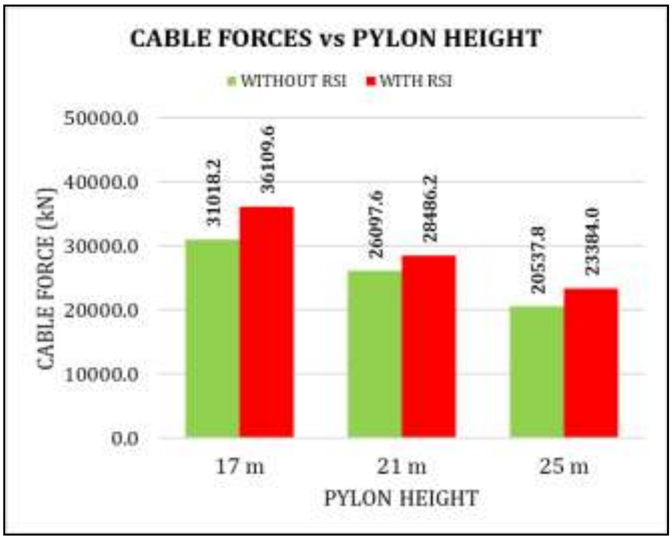

Chart -10: Cable force – Fixed base and HSLM A2

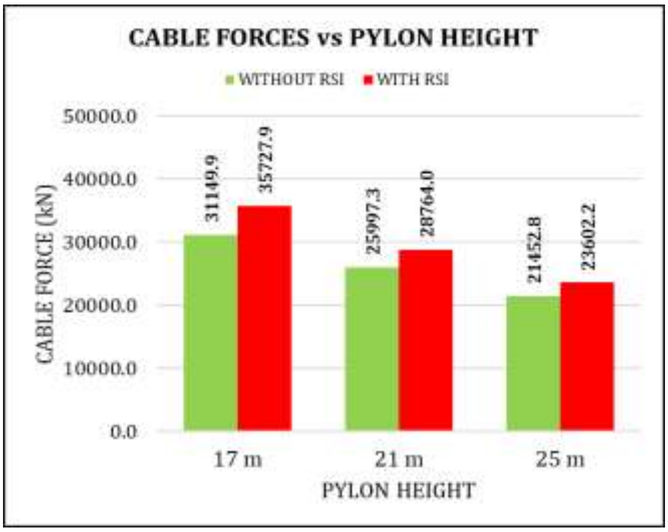

Chart -11: Cable force – Fixed base and HSLM A4

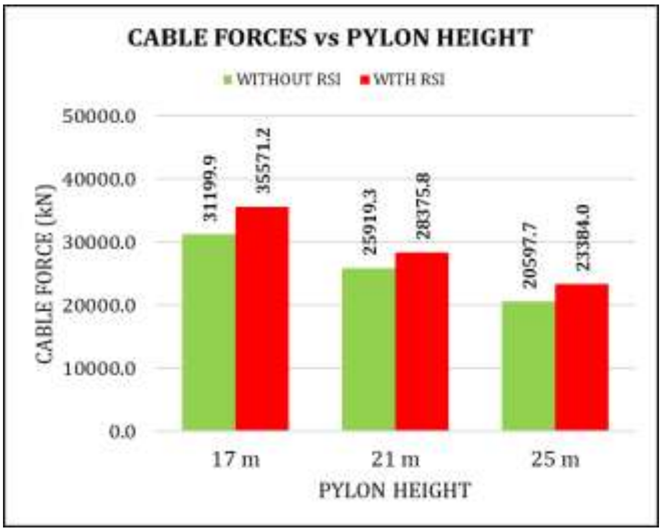

Chart -12: Cable force – Fixed base and HSLM A6

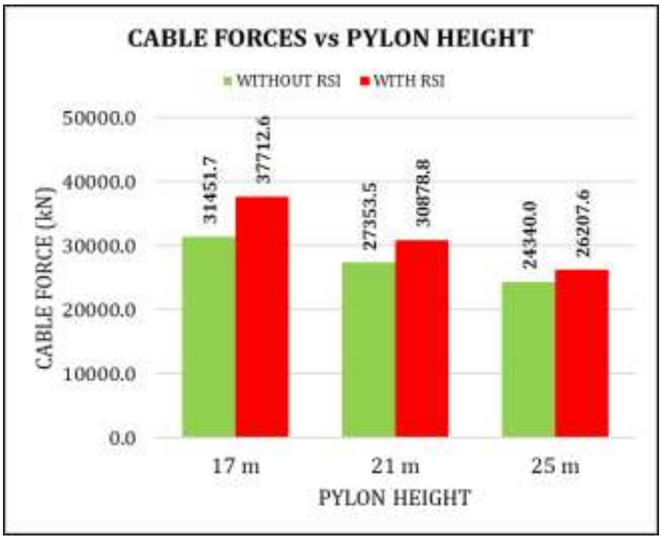

Chart -13: Cable force – Dense soil and HSLM A2

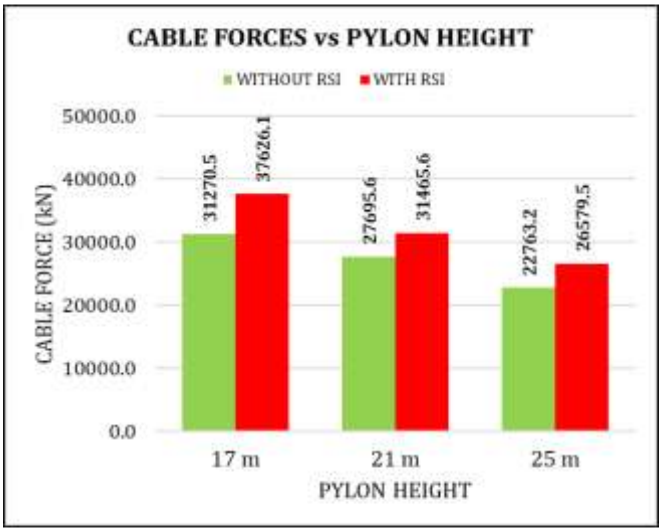

Chart -14: Cable force – Dense soil and HSLM A4

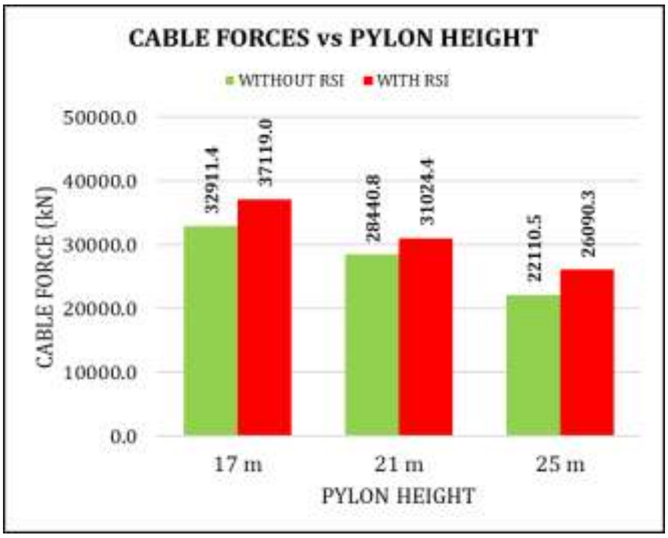

Chart -15: Cable force – Dense soil and HSLM A6

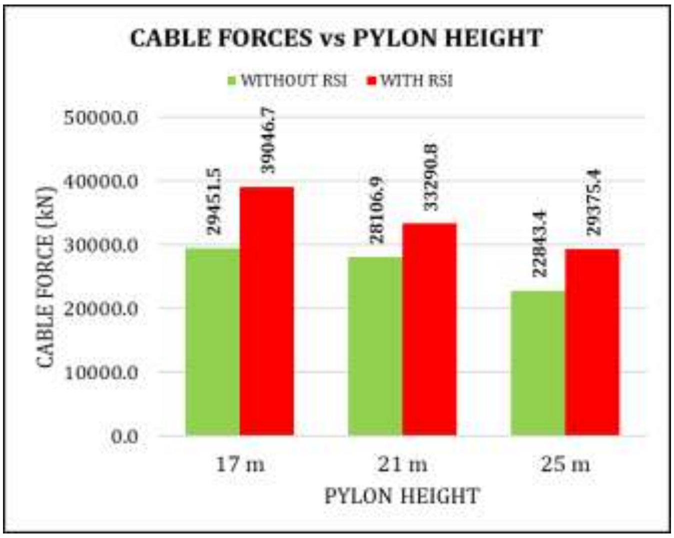

Chart -18: Cable force – Medium soil and HSLM A6

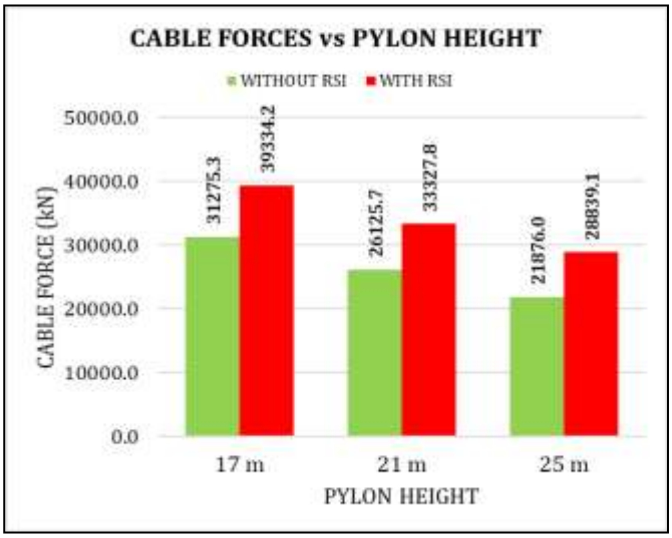

Chart -16: Cable force – Medium soil and HSLM A2

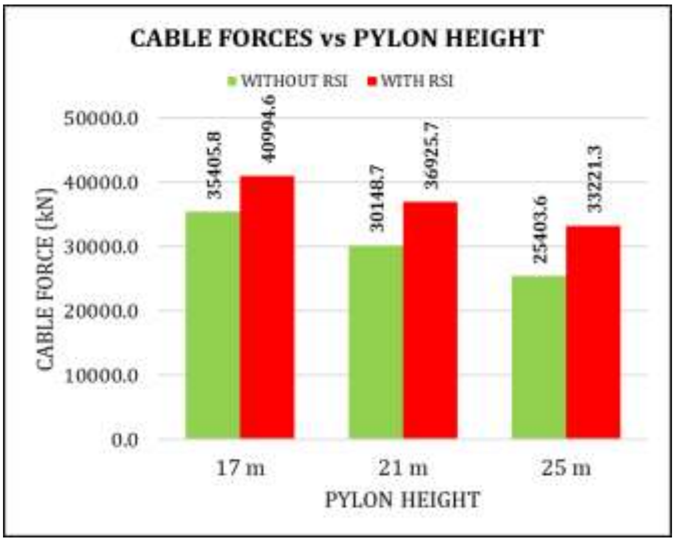

Chart -19: Cable force – Loose soil and HSLM A2

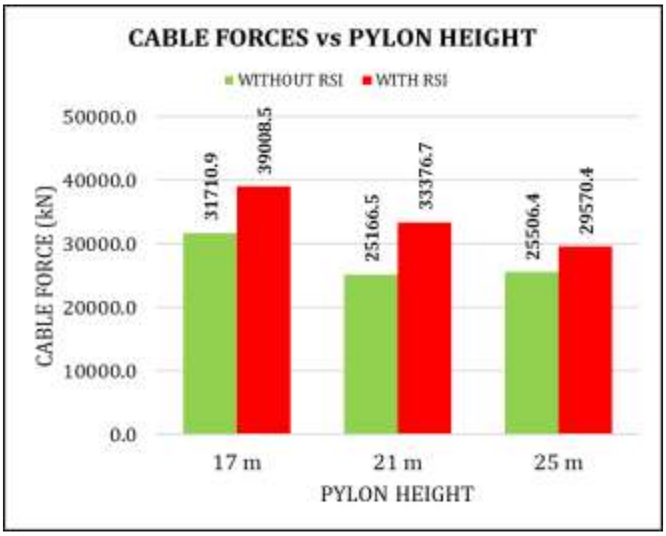

Chart -17: Cable force – Medium soil and HSLM A4

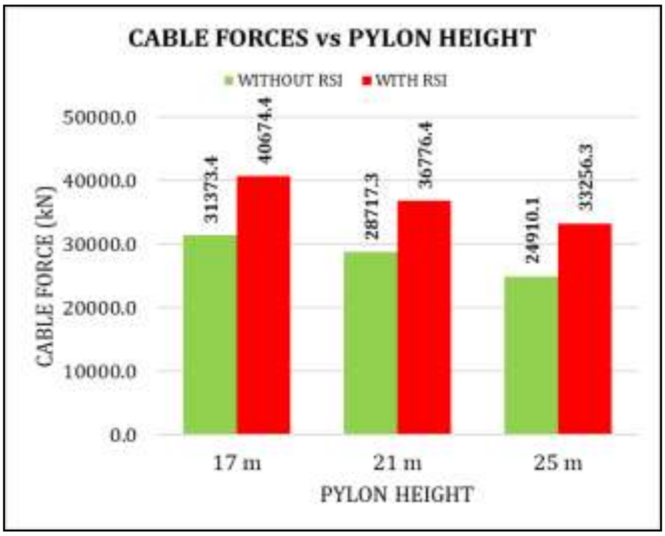

Chart -20: Cable force – Loose soil and HSLM A4

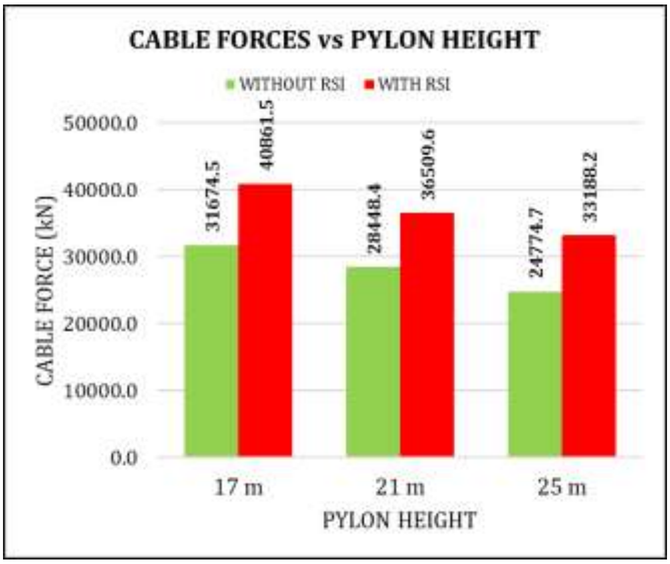

Chart -21: Cable force – Loose soil and HSLM A6

4. CONCLUSIONS

Based on the results of this study, it is concluded that for a railway extradosed bridge, there is up to 33.96 % higher design cable force to control vertical deflection so that the rail stresses due to rail-structure interaction phenomenon can be kept under the design limits as per Eurocode EN-Part 2:1991 (2003) and UIC 774-3R. Soil-structure interaction has considerable impact on the cable-forces and should always be taken into consideration for a cable supported bridge structure. Taller pylon leads to reduced cable forces in an extradosed bridge and it is recommended to provide pylon as tall as possible for the given design condition. There is increase in the consumption of concrete but as the cable forces decrease, there are savings in the material for cables which leads to overall reduction in costs.

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