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Parametric Study on Axial Force in Steel and CFRP cables for a Cable-stayed bridge

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Abstract*— Man's achievement in field of Structural Engineering is evident from world's tallest structures to largest bridge spans etc. In the recent years cable stayed bridges have received more attention than any other bridges mainly, in the United States, Japan and Europe as well as in third-world counties due to their ability to cover large spans. Cable-stayed bridge can cross almost 1000m. A study is carried out to find the axial force on different types of cables on a cable stayed bridge. The different types of cables used are steel and CFRP. The study is carried out on Akkar Bridge in Sikkim which is India's first cable stayed bridge. Live loads are taken according to IRC 6:2000, IRC Class 70R vehicle load was considered. A Dynamic analysis in the form of Non-Linear Time-history is also carried out using Cape, Kobe and El Centro earthquakes. The Axial force developed in both steel and CFRP cables are represented.

Keywords—Time history analysis, axial force, cable stayed bridge, CFRP, Steel

I. INTRODUCTION

The past two or three decades has outfitted the wide application of Cable-stayed bridges in different parts of the world. Varied long span application of cable-stayed bridges has been established just recently, with the initiation of high-strength steel and FRP materials, evolution of advanced welding techniques, different deck shapes, and the advancement in structural analysis. The assortment of shapes and forms of cable-stayed bridges mesmerize even the most demanding designers, architects as well as the common people. Engineers are developing them both innovating and challenging. Cable-stayed bridges are considered as one of the most fetching recent development in the stream of bridge engineering. Increased application of these bridges among bridge engineers are often accredited to its appealing aesthetics, full and economical utilization of structural elements, augmented stiffness over long span suspension bridges, efficient and quicker mode of construction and comparatively tiny size of their substructure.

Cable-stayed bridges are best suited for spans shorter than suspension bridges and longer than cantilever bridges. The span length lies in range where a cantilever bridge would be really heavy and suspension bridge will be not practical because using large amount of cables for a shorter span bridge will be uneconomical. [7] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.

The main objective of this study is to find out the axial force developed in the steel cables of Akkar Bridge and compare them by replacing the cables using CFRP strands. The study aims to find out which of the two materials performs better under dead load, moving load and earthquake loads.

II. BRIDGE DATA

For the study Akkar bridge is considered. The Akkar Bridge at Jorethang, South Sikkim, over Rangit River is India's first cable-stayed concrete bridge (Fig.1). It was completed in 1988 and was constructed by Gammon India.

PYLON

- H Shape
- Total height: 54.6m
- Height below deck: 20.7m
- Height above deck: 33.9m
- Top section : 1.61x1.61m
- Bottom section: 2.5x2.5m

DECK

- Total width: 10m
- Width of Roadway: 2 lane 7.5m
- Depth: 0.180m
- Span: 154m

Fig.1. Akkar Bridge

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CABLES

- Cable Section: 37 H.T E450 wires (Area = 1423.9 mm^2)
- Number of Cables : 34
- Prestressing force: 2280kN

GIRDERS

- Longitudinal girder: 0.6x0.8m concrete frame element
- Cross girders: 0.45x0.8m concrete frame element at 3m intervals

CONCRETE

- Grade: M45
- Weight/unit volume: 25 kg/m^3
- Modulus of Elasticity: 33541 MPa
- Poissons ratio: 0.2

STEEL(Cables)

- Grade: E450 (Fe570)
- Weight/unit volume : 76.9729 kg/m^3
- Modulus of Elasticity: 199000 MPa
- Poissons ratio: 0.3

III. MODELING

CSi Bridge is a powerful and versatile tool for analysis and design of structures based on static and dynamic finite element analysis. Non-linear analysis can also be performed in CSi. Bridge. The analytical capabilities are just powerful representing the latest research in numerical techniques and solution algorithms. The program is structured to support wide variety of the latest national and international codes for both concrete and steel.

A. Modeling of Cables

The cable element is modeled as a linear frame. The modeling of cables is a difficult issue because of nonlinearities arises from the cable sag. The stiffness thus changes when load is applied. A prestessing force of 2280kN was applied to all the cables in order to ensure a small deformation of the deck when the self-weight is applied.

B. Properties of CFRP

- Weight/unit volume: 15.68 kg/m^3
- Modulus of Elasticity: 160000 MPa
- Poissons ratio: 0.3

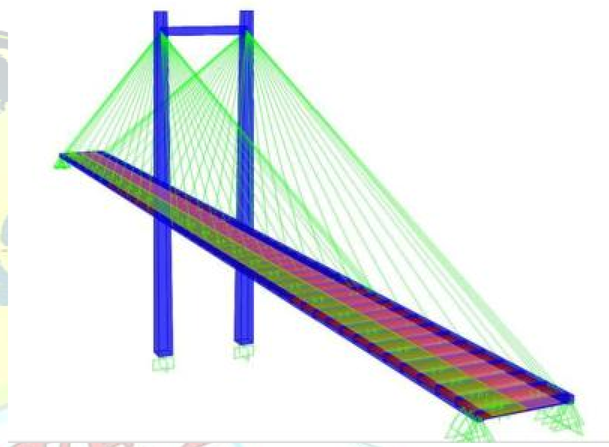

Fig. 2. 3D Model of the Bridge

C. Equivalent Area of CFRP Cables

$$E_{CFRP} \times A_{CFRP} = E_{Steel} \times A_{Steel}$$

$$1.6 \times 10^8 \times A_{CFRP} = 1.99 \times 10^8 \times 1423.9 \times 10^-$$

$$A_{CFRP} = 1.77 \times 10^{-3}\ m^2$$

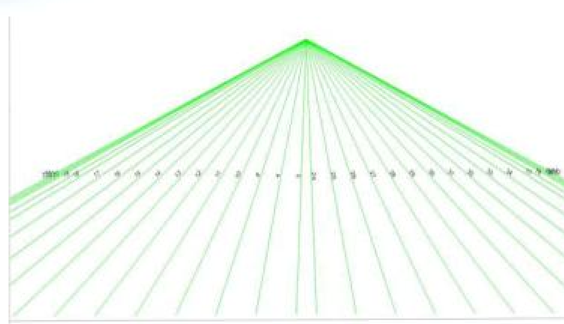

Fig. 3 .Cables

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IV. RESULTS

Steel Dead (kN)	CFRP Dead (kN)	Steel vehicle (kN)	CFRP vehicle (kN)
0.127	0.00009684	60.144	60.134
0.126	0	60.702	60.693
0.125	0	61.268	61.258
3.138	1.815	61.227	61.218
43.788	41.742	58.353	58.345
115.512	112.258	52.592	52.586
301.657	295.646	106.172	106.134
465.487	457.759	180.23	180.18
559.187	551.17	223.499	223.453
589.135	581.926	238.744	238.707
568.802	562.488	239.902	239.869
517.914	512.444	236.5	236.468
450.253	445.847	232.655	232.625
384.997	381.604	229.052	229.023
338.512	335.571	225.335	225.307
307.566	304.276	214.266	214.24
285.038	281.393	188.557	188.539
285.038	281.393	188.557	188.539
307.567	304.277	214.266	214.24
338.512	335.571	225.335	225.307
384.998	381.605	229.052	229.023
450.254	445.847	232.655	232.625
517.914	512.444	236.5	236.468
568.802	562.488	239.902	239.869
589.135	581.927	238.744	238.707
559.187	551.17	223.499	223.453
465.487	457.759	180.23	180.18
301.657	295.646	106.172	106.134
115.512	112.258	52.592	52.586
43.788	41.742	58.353	58.345
3.138	1.815	61.227	61.218
0.125	0	61.268	61.258
0.126	0	60.702	60.693
0.127	0.00009679	60.144	60.134

Table.1. Axial Force in Cables- Dead and Moving load Case (Moving Load – IRC Class 70R through one lane)

Steel (kN)	CFRP (kN)
35.223	33.679
35.86	34.309
36.516	34.959
41.184	39.774
83.786	80.951
162.029	156.418
354.723	346.162
519.451	509.057
606.49	595.818
622.662	614.644
625.605	617.498
588.047	580.405
512.3	505.925
459.095	451.055
408.529	401.263
345.828	339.999
304.624	301.602
310.201	305.876
363.248	357.554
413.996	407.313
461.011	453.658
508.765	500.936
575.286	566.525
646.11	635.833
674.4	662.832
635.536	626.189
556.508	546.697
383.72	375.787
180.132	175.55
100.115	96.881
64.179	61.574
60.49	57.973
59.53	57.029
58.596	56.109

Table.2. Axial Force in Cables- Cape EQ

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Steel (kN)	CFRP (kN)
30.314	27.364
30.759	27.796
31.216	28.239
34.614	32.994
70.092	70.74
136.997	137.011
316.811	309.461
484.439	476.082
579.804	570.539
607.584	598.9
576.179	568.619
516.436	510.632
466.569	461.227
413.113	408.693
359.901	356.281
314.526	310.169
284.197	279.909
292.003	287.369
325.87	320.782
363.758	359.111
404.21	399.267
450.17	443.713
518.899	515.412
576.929	572.802
607.139	598.548
584.493	575.315
484.472	475.757
321.894	315.984
143.403	140.006
72.87	70.622
33.737	31.941
29.142	27.466
28.719	27.047
28.308	26.638

Table.3. Axial Force in Cables- El Centro EQ

Steel (kN)	CFRP (kN)
28.108	25.722
28.312	25.917
28.518	26.113
32.756	30.27
68.213	65.109
132.098	128.277
314.285	307.671
480.04	471.203
579.275	569.919
601.745	593.115
582.641	574.166
524.161	516.867
482.149	475.542
428.051	422.768
379.084	373.834
335.444	330.106
283.63	279.583
282.967	279.296
338.418	332.913
390.116	384.688
438.075	432.199
489.738	482.901
530.709	523.311
580.431	572.19
615.631	606.482
588.942	579.298
479.807	470.922
308.723	302.011
127.085	123.238
62.562	59.446
28.328	25.733
24.344	21.834
24.202	21.703
24.059	21.572

Table.4. Axial Force in Cables- Kobe EQ

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V. Conclusion

The above study was conducted to compare the axial forces developed in steel and CFRP cables for a cable stayed bridge. Dead, moving and earthquake loads were considered for the same and in all the load cases CFRP cables showed less axial force values. This shows that for an equal area, CFRP cables performs better in both dead and moving load cases showing 5-10% reduction. The time-history analysis revealed a similar trend showing 3-5% reduction.

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