Performance Evaluation of Different Types of Cable Stayed Bridges

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***Abstract* - In our country, bridges play a vital role because of undulated topography, steeper terrains and so many rivers flow. Among different types of bridges, cable stayed bridges are very popular bridge type for long span bridges. Cable stayed bridges have good stability, optimum use of structural materials, aesthetic, relatively low design and maintenance costs, and efficient structural characteristics. These are indeterminate structures which behaves as a continuous beam elastically supported by the cables, which are connected to one or two towers. This study investigates the performance evaluation of different types of cable stayed bridges by varying the pylons shapes and arrangement of cable stays. The nonlinear dynamic behavior of cable stayed bridge decks due to different load combinations and earthquake forces are done. Here the study is carried out for cable stayed bridges for four lane of total span 900 m, which includes 500 m main span and 200 m side spans. IRC Class A loading is used for the study. The superstructure of the cable stayed bridges are analyzed and designed by using SAP 2000 version 14 software. This work includes the determination of deck displacement, time period, frequencies for different types of cable stayed bridges using SAP 2000.**

Keywords- Cable stayed bridges, deck deflection, pylon, stay cables

I. INTRODUCTION

Cable stayed bridges have emerged as a dominant structure for long span bridge for the past fifty years because of their good stability, optimum use of structural materials, aesthetic, relatively low design and maintenance costs, and efficient structural characteristics. Therefore, this type of bridges are becoming more and more popular and are usually preferred for long span crossings compared to suspension bridges.

The superstructure behaves as a continuous beam elastically supported by the cables, which are connected to one or two towers. The main structural elements of a cable stayed bridges are the bridge deck, piers, towers and the stays. The deck supports the loads and transfers them to the stays and to the piers through bending and compression. The stays transfer the forces to the towers, which transmit them by compression to the foundations. The interrelation of these components makes the structural behavior of cable- stayed bridges efficient for long-span structures, in addition to providing an aesthetic pleasant solution. The cable-stayed system has become a very effective and economical system during the last century. It is mainly used to cover large spans. The development of this structural system is due to advances in materials, engineering analysis and design, and construction methodology. In terms of cable arrangements, the most common type of cable stayed bridges are fan, harp, and semi harp bridges. Typical shapes for bridge towers are H-shaped, A-shaped and Y-shaped towers.Because of their large size and nonlinear structural behaviour, the analysis of these types of bridges is more complicated than conventional bridges. Up to a span length of 1100 metres, the cable stayed system is considered as an economical solution. To achieve the increase span length and more slender girders for future bridges, accurate procedures need to be developed that can lead to a thorough understanding and a realistic prediction of the structural response to not only wind and earthquake loads but also traffic loads.

II. STRUCTURAL DESCRIPTION

The structural systems can be varied by changing tower shapes and the cable arrangements. The configurations of cable-stayed bridge are stiffening girder, cable system, towers and foundations. The stiffening girder is supported by straight inclined cables which are anchored at the towers. These pylons are placed on the main pier so that the cable force can be transferred down to the foundation system. Three basic cable arrangements are harp system, fan system and semi harp system. The role of tower or pylon is also very important in cable-stayed bridge. The towers are the most visible elements of a cable-stayed bridge. The primary function of the pylon is to transmit the force arising from anchoring the stay and these forces will dominate the design of the pylon. Many varied types of the pylon are H-type, A–type and Spread pylon Y-type are used.

The proposed bridge is a long-span cable-stayed bridge with double plane with three span. The bridge with the total length of 900 m comprises of three spans: a 500 m main span between two pylons, and two side spans each with a length of 200 m has been modeled. The bridge deck is a steel box girder 14 m wide and 3.1 m high. The cross sectional area and the modulus of elasticity of the deck are 3.36 m^2 and 1.9 x 10^8kN/m^2 respectively. There are two pylons 500 m apart consisting of hollow concrete section of 6 x 6 m, above and below the deck levels. The modulus of elasticity and area of cross section of concrete pylon are 3.35 kN/m^2 and 11 m^2 respectively. The pylons are fixed to the ground level. New parallel wire strands are used for proposed bridge models. New PWS cable with an outer diameter of 0.15m has a metallic cross-section of 0.0177 m^2 corresponding to a void ratio of 0.3 has been used. The deck section are attached to the pylons with 160 cables of varying length with 20 cables on each side of the pylon. The support ends of the bridge are hinged.

III. MODELLING

A cable stayed bridge model has been created by using the software SAP 2000. The modelling has been done by assuming the above values. And also various values are taken from the IS and IRC Codes for the modeling. Some of the IS codes used are IS 456:2000 , IS 800 : 2007 , IS 1893 : 2000 , IS 875 : 1967, IRC 6:2000 etc. Long-span cable-stayed bridge is modeled by changing the pylon shapes and the cable arrangements and analyzed by using SAP-2000 Software.

IV. ANALYSIS RESULTS

In this study, the cable stayed bridges are analyzed for four different shapes of pylon on SAP 2000 software. The models of cable stayed bridges are A - Fan Arrangement, A - Harp Arrangement, A - Semi Harp Arrangement, H - Fan Arrangement, H - Harp Arrangement, H - Semi Harp Arrangement, Y - Fan Arrangement, Y - Harp Arrangement, Y - Semi Harp Arrangement. The girder deflection is studied based on the various load conditions, load combinations, seismic load – Response spectrum and Time history Analysis and Modal Analysis. Deflection is the vertical displacement of a member subjected to loading. The allowable deflection for cable stayed bridge is L/400, where L is the main span length of proposed bridge.

A. Results due to load combinations

The displacements of the girder along the bridge length due to different load combinations are shown in their respective tables and figures.

TABLE 1 TABLE SHOWING DEFLECTIONS DUE TO DEAD LOAD +MOVING LOAD

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
0	0	0	0	0	0	0	0	0	0
100	0.0004	0.0000	0.0004	0.0004	0.0003	0.0005	0.0001	0.0003	0.0002
200	0.0004	0.0000	0.0004	0.0004	0.0004	0.0005	0.0001	0.0003	0.0002
300	0.0427	0.0974	0.0707	0.0410	0.0858	0.0667	0.0362	0.0831	0.0636
400	0.0645	0.0958	0.0726	0.0623	0.0836	0.0835	0.0562	0.0639	0.0653
500	0.0645	0.0958	0.0726	0.0623	0.0831	0.0835	0.0562	0.0648	0.0653
600	0.0427	0.0974	0.0707	0.0410	0.0853	0.0667	0.0362	0.0853	0.0636
700	0.0004	0.0000	0.0004	0.0004	0.0004	0.0005	0.0001	0.0003	0.0002
800	0.0004	0.0000	0.0004	0.0004	0.0003	0.0005	0.0001	0.0003	0.0002
900	0	0	0	0	0	0	0	0	0

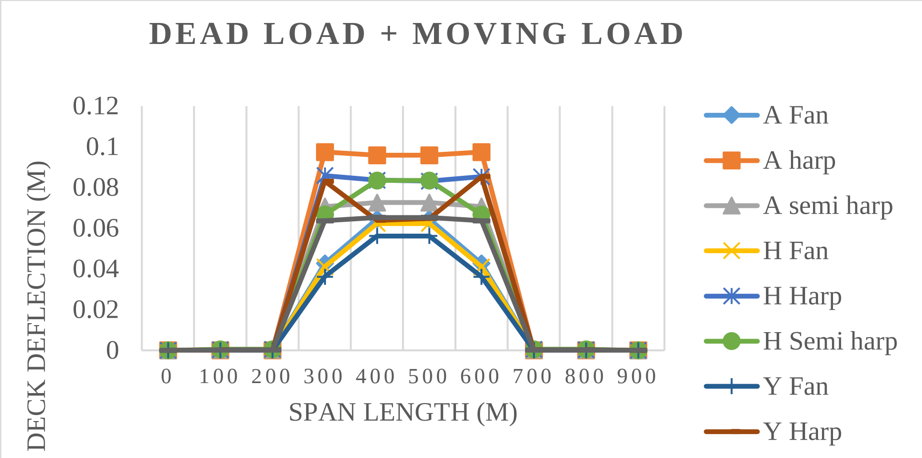

Fig.1 Graph showing deck deflections of different models

TABLE 2 TABLE SHOWING DEFLECTIONS DUE TO DEAD LOAD + LIVE LOAD

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
100	0.039	0.101	0.083	0.074	0.191	0.159	-0.103	0.124	0.070
200	0.134	-0.043	-0.010	-0.020	-0.015	-0.015	0.144	-0.013	-0.010
300	0.554	-0.518	-0.166	-0.140	-0.320	-0.250	0.706	-0.218	-0.139
400	0.982	-1.119	-0.459	-0.414	-0.858	-0.839	1.524	-0.508	-0.393
500	0.982	-1.119	-0.459	-0.414	-0.857	-0.839	1.524	-0.510	-0.393
600	0.554	-0.518	-0.166	-0.140	-0.318	-0.250	0.706	-0.222	-0.139
700	0.134	-0.043	-0.010	-0.020	-0.015	-0.015	0.144	-0.013	-0.010
800	0.039	0.101	0.083	0.074	0.190	0.158	-0.103	0.127	0.070
900	0	0	0	0	0	0	0	0	0

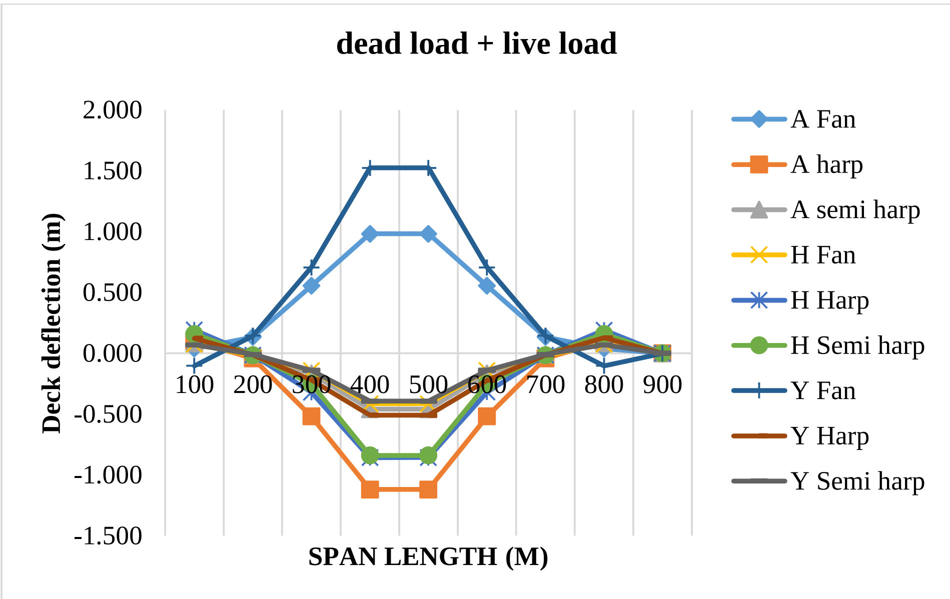

Fig.2 Graph showing deck deflections of different models

TABLE 3 DEFLECTIONS DUE TO DEAD LOAD +MOVING LOAD+WIND LOAD

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
100	0.0003	0.0000	0.0003	0.0003	0.0003	0.0004	0.0001	0.0003	0.0002
200	0.0003	0.0000	0.0003	0.0003	0.0004	0.0004	0.0001	0.0003	0.0002
300	0.0360	0.0000	0.0596	0.0346	0.0724	0.0563	0.0305	0.0701	0.0537
400	0.0544	0.0822	0.0612	0.0526	0.0705	0.0704	0.0474	0.0539	0.0551
500	0.0544	0.0809	0.0612	0.0526	0.0701	0.0704	0.0474	0.0547	0.0551
600	0.0360	0.0809	0.0596	0.0346	0.0720	0.0563	0.0305	0.0720	0.0537
700	0.0003	0.0822	0.0003	0.0003	0.0004	0.0004	0.0001	0.0003	0.0002
800	0.0003	0.0000	0.0003	0.0003	0.0003	0.0004	0.0001	0.0003	0.0002
900	0	0	0	0	0	0	0	0	0

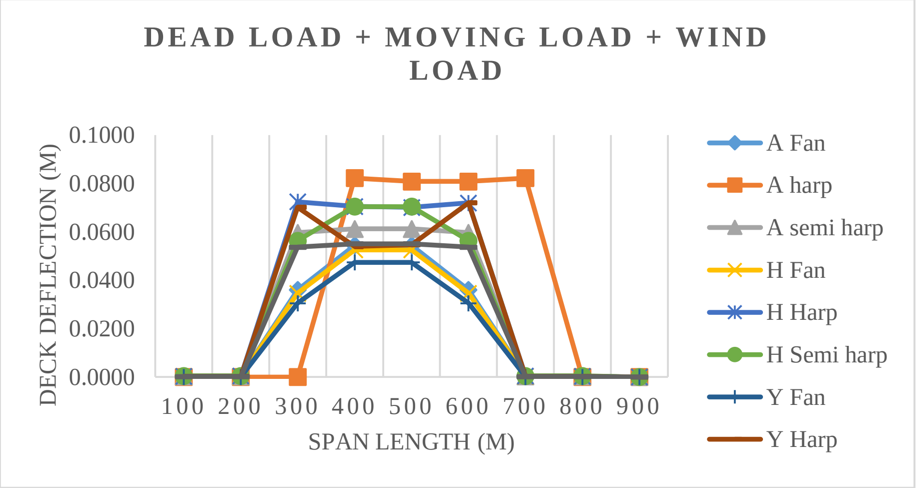

Fig.3 Graph showing deck deflections of different models

TABLE 4 TABLE SHOWING DEFLECTIONS DUE TO DEAD LOAD +MOVING LOAD + EARTHQUAKE LOAD (RS)

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
100	0.0036	0.0035	0.0052	0.0036	0.0047	0.0046	0.0033	0.0049	0.0057
200	0.0001	0.0035	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
300	0.0085	0.0001	0.0139	0.0083	0.0154	0.0129	0.0079	0.0153	0.0135
400	0.0129	0.0163	0.0146	0.0128	0.0148	0.0170	0.0126	0.0119	0.0145
500	0.0129	0.0152	0.0146	0.0128	0.0148	0.0170	0.0126	0.0114	0.0145
600	0.0085	0.0152	0.0139	0.0083	0.0153	0.0129	0.0079	0.0153	0.0135
700	0.0001	0.0163	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
800	0.0036	0.0001	0.0052	0.0036	0.0047	0.0046	0.0033	0.0046	0.0057
900	0	0	0	0	0	0	0	0	0

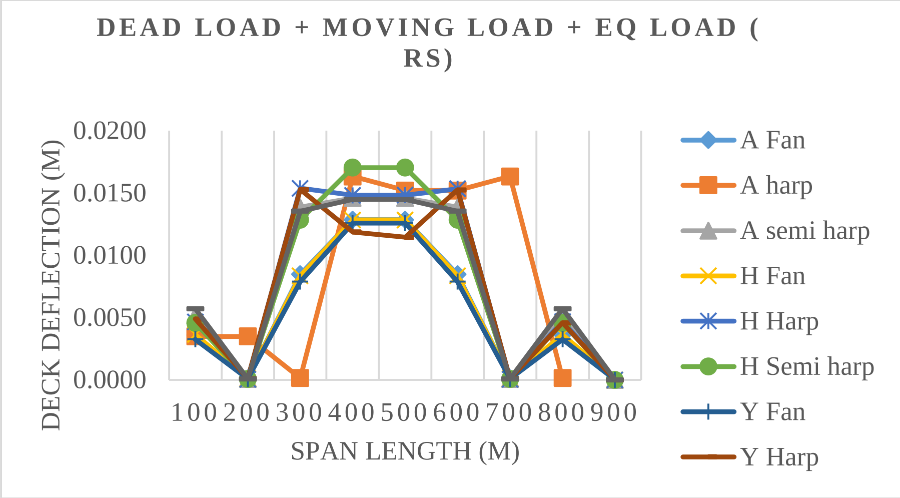

Fig.4 Graph showing deck deflections of different models

TABLE 5 TABLE SHOWING DEFLECTIONS DUE TO DEAD LOAD +MOVING LOAD + EARTHQUAKE LOAD (THA)

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
100	0.0002	0.0047	0.0128	0.0104	0.0103	0.0102	0.0075	0.0109	0.0146
200	0.0002	0.0047	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
300	0.0200	0.0002	0.0202	0.0143	0.0208	0.0196	0.0118	0.0212	0.0216
400	0.0101	0.0184	0.0254	0.0181	0.0222	0.0271	0.0179	0.0189	0.0270
500	0.0142	0.0176	0.0181	0.0199	0.0193	0.0251	0.0204	0.0155	0.0179
600	0.0185	0.0181	0.0209	0.0128	0.0209	0.0184	0.0125	0.0214	0.0218
700	0.0102	0.0196	0.0001	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001
800	0.0129	0.0002	0.0113	0.0102	0.0093	0.0112	0.0072	0.0100	0.0126
900	0	0	0	0	0	0	0	0	0

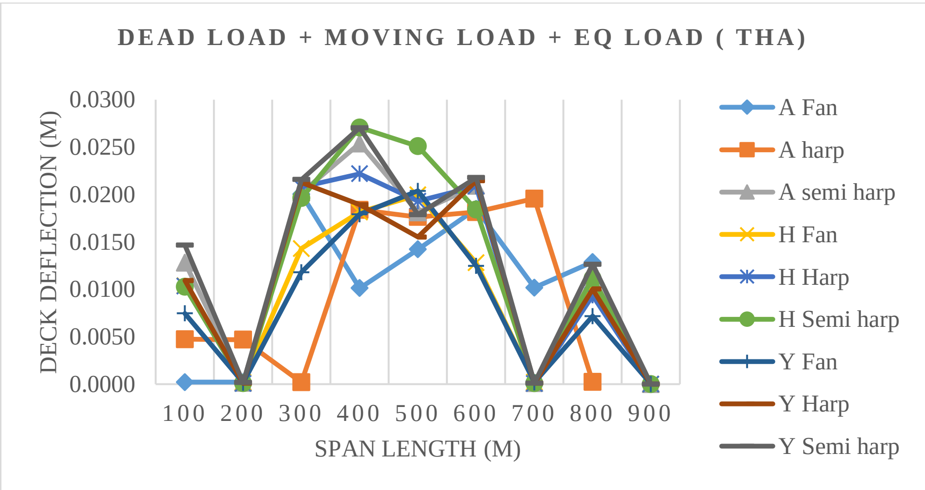

Fig.5 Graph showing deck deflections of different models

B. Results due to Seismic load – Response Spectrum Analysis

The displacements of the girder along the bridge length based on Response spectrum analysis are shown in their respective tables and figures.

TABLE 6 TABLE SHOWING DEFLECTIONS DUE TO RESPONSE SPECTRUM ANALYSIS

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
0	0	0	0	0	0	0	0	0	0
100	0.0036	0.0046	0.0045	0.0035	0.0035	0.0051	0.0032	0.0048	0.0057
200	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
300	0.0032	0.0047	0.0045	0.0031	0.0042	0.0050	0.0034	0.0049	0.0056
400	0.0051	0.0044	0.0066	0.0048	0.0032	0.0055	0.0056	0.0039	0.0063
500	0.0051	0.0044	0.0066	0.0048	0.0032	0.0055	0.0056	0.0033	0.0063
600	0.0032	0.0047	0.0045	0.0031	0.0042	0.0050	0.0034	0.0046	0.0056
700	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
800	0.0036	0.0046	0.0045	0.0035	0.0035	0.0051	0.0032	0.0045	0.0057
900	0	0	0	0	0	0	0	0	0

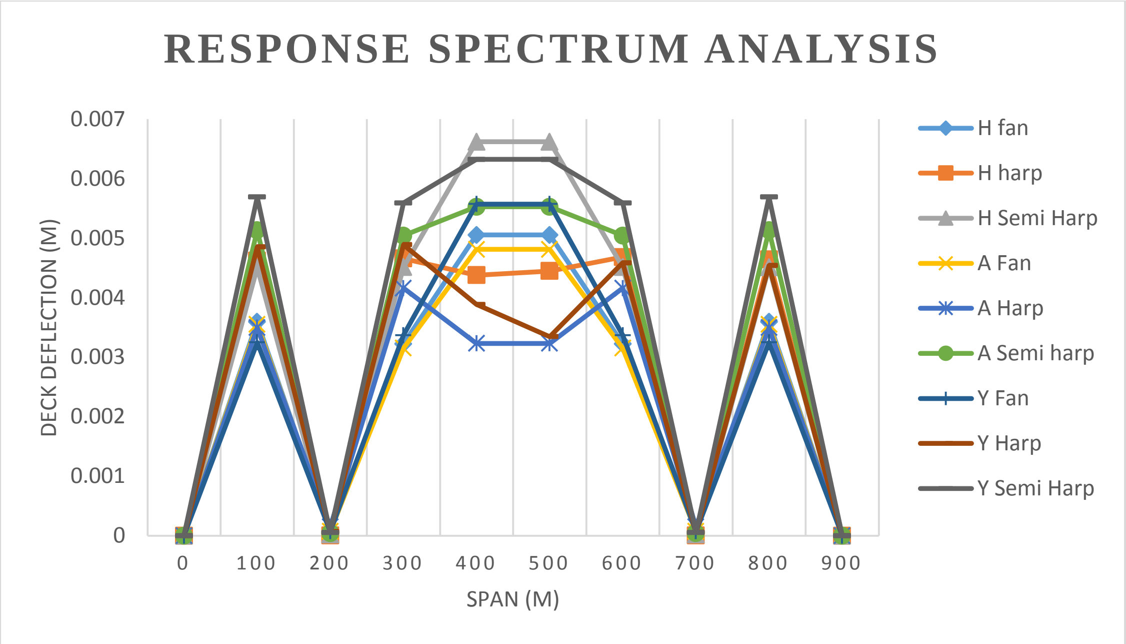

Fig.6 Graph showing deck deflections of different models

C. Results due to Seismic load – Time History Analysis

The displacements of the girder along the bridge length based on Time History analysis are shown in their respective tables and figures. Here, the values of El-Centro earhquake is taken for the analysis.

TABLE 7 TABLE SHOWING DEFLECTIONS DUE TO TIME HISTORY ANALYSIS

Span (m)	Deck deflection (m)								
	A Fan	A harp	A semi harp	H Fan	H Harp	H Semi harp	Y Fan	Y Harp	Y Semi harp
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
100	0.0103	0.0103	0.0102	0.0101	0.0047	0.0128	0.0074	0.0109	0.0146
200	0.0001	0.0000	0.0000	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
300	0.0092	0.0100	0.0113	0.0089	0.0062	0.0114	0.0073	0.0109	0.0136
400	0.0104	0.0117	0.0166	0.0104	0.0056	0.0163	0.0109	0.0109	0.0189
500	0.0122	0.0089	0.0147	0.0120	0.0062	0.0090	0.0134	0.0074	0.0097
600	0.0077	0.0102	0.0101	0.0075	0.0074	0.0121	0.0079	0.0108	0.0138
700	0.0002	0.0000	0.0000	0.0002	0.0002	0.0001	0.0002	0.0000	0.0001
800	0.0101	0.0093	0.0111	0.0101	0.0047	0.0112	0.0072	0.0100	0.0126
900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

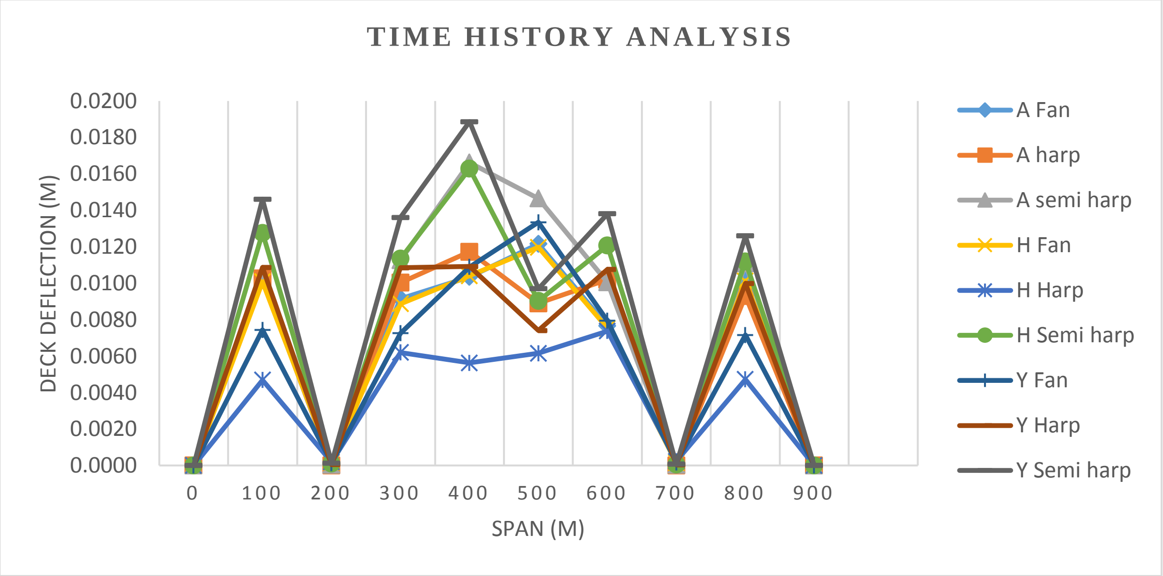

Fig.7 Graph showing deck deflections of different models

D. Results due to Modal Analysis – Period

The displacements of the girder along the bridge length based on Modal analysis are shown in their respective tables and figures. The variation of period and frequency of the 9 models are given.

TABLE 8TABLE SHOWING DEFLECTIONS DUE TO PERIOD

Mode number	Period in seconds								
	H fan	H harp	H Semi Harp	A Fan	A Harp	A Semi harp	Y Fan	Y Harp	Y Semi Harp
1	9.892	9.701	20.751	9.5	9.702	9.4	9.169	9.2103888	9.106
2	6.664	5.364	8.838	3.499	5.49	3.436	4.606	4.6073905	4.375
3	6.664	5.364	5.536	3.201	3.853	3.421	4.598	4.5237647	4.369
4	6.664	5.336	5.536	2.649	3.618	2.873	3.498	3.5506197	3.513
5	6.664	5.297	5.536	2.587	2.384	2.52	2.861	3.2635109	3.255
6	3.623	3.818	5.536	2.471	2.377	2.481	2.259	2.9551999	2.802
7	3.145	3.565	4.92	1.787	2.339	1.766	1.747	1.7439271	1.745
8	2.449	3.044	3.881	1.212	1.936	1.607	1.456	1.7267059	1.574
9	1.796	1.827	3.25	1.16	1.818	1.268	1.456	1.3594558	1.247
10	1.194	1.761	2.941	1.023	1.521	1.15	1.218	1.3421149	1.154
11	1.167	1.396	2.45	0.859	1.317	0.854	1.168	1.3157417	1.097
12	1.007	1.15	2.07	0.859	1.177	0.853	1.151	1.156899	1.097

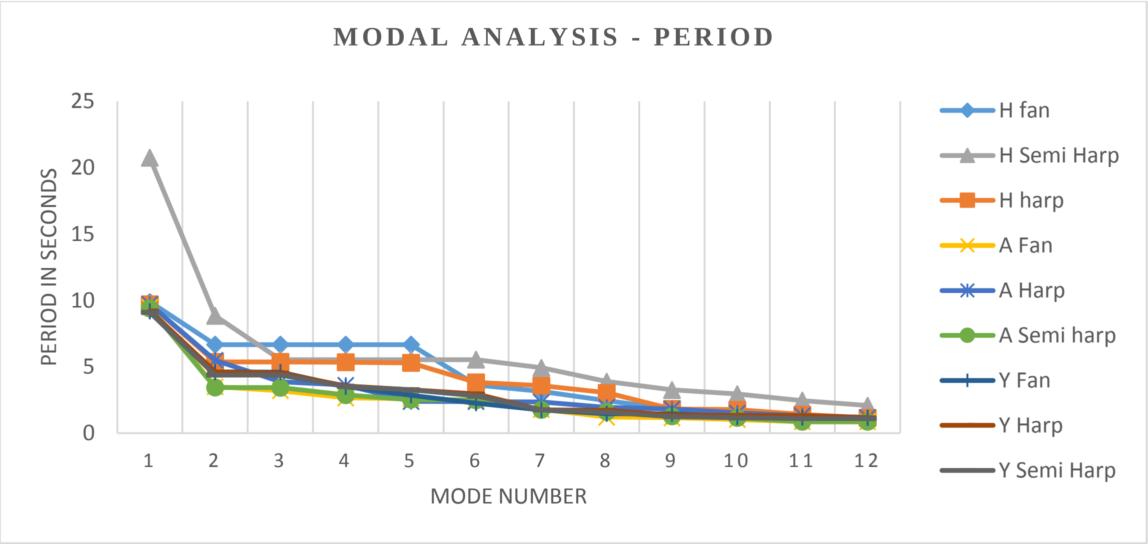

Fig.8 Graph showing deck deflections of different models

E. Results due to Modal Analysis - Frequency

TABLE 9 TABLE SHOWING DEFLECTIONS DUE TO FREQUENCY

Mode number	Frequency in Hz								
	H fan	H harp	H Semi Harp	A Fan	A Harp	A Semi harp	Y Fan	Y Harp	Y Semi Harp
1	0.101	0.103	0.048	0.105	0.103	0.106	0.109	0.108573	0.11
2	0.15	0.186	0.113	0.286	0.182	0.291	0.217	0.2170426	0.229
3	0.15	0.186	0.181	0.312	0.26	0.292	0.217	0.2210548	0.229
4	0.15	0.187	0.181	0.377	0.276	0.348	0.286	0.281641	0.285
5	0.15	0.189	0.181	0.387	0.419	0.397	0.35	0.3064185	0.307
6	0.276	0.262	0.181	0.405	0.421	0.403	0.443	0.3383866	0.357
7	0.318	0.28	0.203	0.56	0.428	0.566	0.572	0.5734185	0.573
8	0.408	0.328	0.258	0.825	0.516	0.622	0.687	0.5791374	0.635
9	0.557	0.547	0.308	0.862	0.55	0.789	0.687	0.7355885	0.802
10	0.838	0.568	0.34	0.977	0.657	0.869	0.821	0.7450927	0.866
11	0.857	0.716	0.408	1.164	0.759	1.171	0.856	0.7600276	0.911
12	0.993	0.869	0.483	1.164	0.85	1.172	0.869	0.8643797	0.912

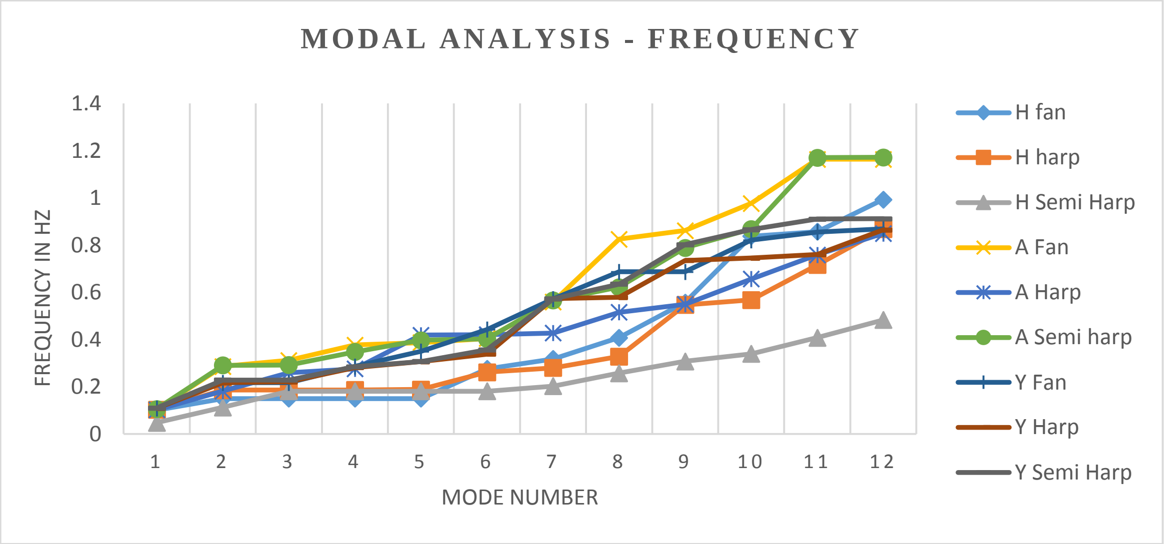

Fig.9 Graph showing deck deflections of different models

V. CONCLUSIONS

In this study, the cable stayed bridge of span length of 900m is analyzed by varying the pylons shapes and arrangement of cable stays. Therefore, this study would give some knowledge ofanalysis and design of three-span cable-stayed bridge. The analysis results conclude that the maximum deformation of the bridge deck occurs at the midpoint of the main span. Also, all the cable stayed bridges falls in the permissible range of allowable deck deflection and hence serviceability problems does not occur. The bridge models were analysed based on the different load combinations and seismic loads.

For the load combination of DL+ML, Y shaped Fan arrangement showed minimum deck deflection, for the load combination DL+ LL -Y shaped Semi Harp arrangement exhibits minimum deflection, for the load combinationDL + ML+ WL - Y shaped fan arrangement showed minimum deflection, for the load combinationDL + ML+ EQL(RS) - Y shaped fan arrangement showed minimum deflection, for the load combinationDL + ML+ EQL(THA) - A shaped harp arrangement exhibits minimum deflection at the mid point of the main span. In response spectrum analysis, H shaped semi harp arrangement exhibits maximum deflection and A shaped harp arrangement exhibits minimum deflection. In Time History Analysis, Y shaped Semi harp arrangement exhibits maximum deflection and A shaped harp arrangement exhibits minimum deflection. From the modal analysis From Modal Analysis, the period decreased from the mode number 1 to 12 and the frequency increased from the mode number 1to 12.

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