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# "A STUDY ON EFFECTS OF EARTHQUAKE AND WIND LOADING ON A CABLE STAYED BRIDGE WITH DIFFERENT CABLE ARRANGEMENTS"

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## ABSTRACT

In recent years construction industry is being revolutionized with modern technology and innovations. Cable stayed bridges are designed to provide free space between two piers for easy and faster navigation through rivers. Analyzes the performance of various cable location patterns installed at different location of the structure in terms of their efficiency and structural weight. For the in vestigation purpose medium wind zone was preferred. The same structure is investigated for four different cable profiles for performance of the structure against the seismic and wind forces. Analysis work are performed with the help of structural design software STAAD. Pro by Bentley. Graphs and tables are used to finalize the best and economical model of all.

## 1. INTRODUCTION

In ancient times people used to cross water bodies with the help of a cable attached with wooden block. It is considered birth of cable stayed and suspension bridge. But cable stayed bridge was developed in 1595 and used for utility purpose in 19th century. At those times Cable Bridge constructed with both the suspension bridge and cable stayed bridge. In 1808 an American inventor named James used two cables over the top of many towers and fastened these cables on the either side of bridge structure.

### 1.1 Resultant of Cable Stayed Bridge

**Main Cables**

Cables are primary resultant of cable stayed bridge which are in the form of bunch of wires. These are connected with deck of bridge and different locations on vertical tower. Cables act as an inter-connection and load transfer resultant to the vertical tower from the bridge deck. The SF produced on the deck due to dead load of bridge itself and live load induced due to the movement of vehicles is transferred to the foundation with the help of these cables via towers.

**a. Parallel Wire Cables**

Parallel wire cable arrangement is commonly used in cable stayed bridge. This cable system consists of many numbers of wires which are placed straight and parallel to each other throughout the cable.

**b. Spiral Cable**

In spiral cable all the wires of cable profile are twisted around a central wire to produce a cable profile of rounded shape. Two adjacent layers are directed in opposite direction to each other. This twisting of cable wires reduces the stiffness by 15-25% in respect to the parallel wire combination. The stiffness, E of a spiral wire cable profile is nearly150MPa.

**c. Locked Coil Cable**

This cable profile has resemblance to the spiral cable profile consisting wires of cable profile are twisted around a central wire to produce a cable profile of rounded shape but in locked coil profile the final layer consists of Z shaped wires. These wires are inter-locked into each other to produce a smooth outer surface.

**i.Parallel System**

In the parallel cable system cables are to be arranged parallel to each other and hence cables are tied at different heights on the bridge tower. Parallel cable system provides best aesthetical view but it also requires a tower of great height compared of all other cable arrangements.

**ii.Fan System**

This fan cable system somewhat similar to the previous cable system but differs as in fan cable system the cables are connected equidistant to each other on tower while in parallel cable system these are not at equidistantly connected on tower.

**iii.Radial System**

In the radial system of cable arrangement all the cables are connected at a single top most point of the bridge tower. In this system inner cables are at their largest inclination to the tower which increases the girder stiffness. Analyzing bridge with radial system is relatively difficult.

**Deck**

The deck is that element of bridge which is most commonly used for the purpose of movement of vehicles and people. Bridge deck is composed of many numbers of steel trusses.

**Tower**

It is a structural element which holds the cables attached to it to create the perfect shape with other tower in order to maintain the cables in position. Aesthetical view plays a very important role in selecting suitable shape of bridge towers.

**Tower Foundation**

It is the basic structural element of the bridge. Foundation either is rested on ground surface or under water. Foundations which are to be constructed under water requires a lot of time and effort for its successful placements.

Dead Load
Live Load
Impact Loading
Wind Load
Seismic (Earthquake) Load
Force due to curvature of deck

## 2. LITERATURE REVIEW

**[H.J.Kang,*et-al*.,2013]**Investigated a cable suspension bridge supported by arch. Author explained static condition of arch bridge with long span in both terms experimentally and in tern of numerical analysis also. This is explained by a model analysis of suspension bridge having two pylon and deck of bridge is supported by cable attached with arch of mild steel section frame.

**[Huu-Tai Thai, e*t-al*.,2013** Author gave the numerical method for pre calculation of ultimate strength of bridge under the subject of dead load only. Geometrical nonlinearities are calculated by using centenary element in form of cable sag effect. The accuracy of the method is finding out by numerical example. Shape analysis is used for determine deformation or sag in cable.

**[Vernerstraupe*et-al*., 2013]** Presented a mathematical model for the analysis of interaction of element of cable stayed bridge. All element of cable stayed bridge are observed in the terms of physical, geometrical and mechanical parameter.

**[TatjanaGrigorjeva*et-al*.,2013]** Proposed the theoretical and numerical analysis of the suspension bridge with the simulation of rigid cable. He proposed that the major disadvantage of suspension bridge is the continuous increment in deformability of bridge and solution of this problem is to provide certain bending stiffness to cables.

**[Qinghua Zhang *et-al*.,2013]** All results are presented in terms of frictional resistance distribution of side surface between main cable and saddle. Largest deviation between experimental and FEM results is approximate 6.2%. Total frictional resistance and nominal COF is increased when we increased number of vertical friction plate. Vertical friction resistance is increased half of vertical frictional plate increment so it is prove that vertical plate is effectively improve the frictional resistance.

**[P.Lonetti, A.Pascuzzo et-*al*., 2014]** This paper proposed a methodology for optimized cable dimension with post tensioning force using iterative method for optimized design. In this paper it is focus on material utilization under the best load combination and bridge design proposed for stress in largest bad condition is equal to largest stress and also use performance factor that is based on secant iterative method.

**Strengths of Research Work Reviewed**

- The dominant modes frequencies of the deck decreases by 6 to 12% and there were nearly no change in motion of the tower.
- The bridge modal frequency is decreased by nearly 12%during retrofitting of the structural which take place due to change in the hanger configuration.

## 3. METHODOLOGY

In depth analysis of review papers reflects advantages of various solution approaches and also the shortcomings of study. This is to be noted that further work can be done on minimizing the largest BM and SF in cable arrangement of a cable stayed bridge by rearranging cables and geometry of tower analysis of different model in STAAD. Pro.

To obtain this target, problem statement and objective are defined as below: -

**Problem Statement**

"A study on effects of earthquake and wind loading on a cable stayed bridge with different cable arrangements: analytical approach".

**Objectives.**

The prime purpose of the dissertation is to analyses different cable profiles in cable stayed bridge and geometry of tower to find the best possible shape and arrangement of cables. To achieve the said aim, the below listed objectives are considered:

- Study on effects of earthquake and wind loading on a cable stayed bridge with different cable arrangements.
- To have comparison of different cable profiles with BM and SF in vertical plane.
- To have comparison between braced model and unbraced model with lowest value of BM and SF.
- To figure out the most economical cable arrangement for design.
  - **Steps in analyzing a structure in STAAD. Pro**

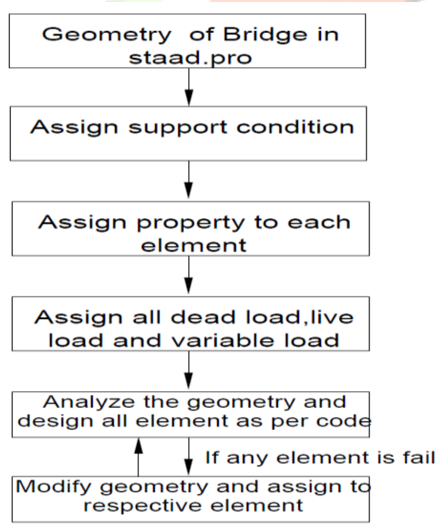



Fig. Flow Chart in STAAD. Pro of Cable Stayed Bridge.

1. **BM Calculation of Deck Slab**
2. **Vehicle Loading Calculation**

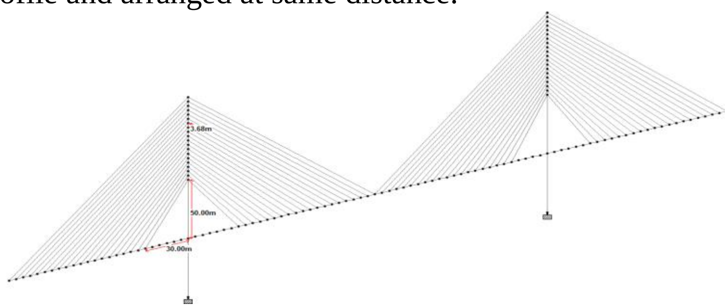
# 4. MODELS FOR ANALYSIS

### 4.1 Modeling of Model M1

Lowest inclination angle of cables is $43.83^0$ and largest inclination degree is $63.5^0$. Number of cables in both the models is same. Vertical distance on pylons between cables is increased whereas the horizontal distance between the cables remains the same.

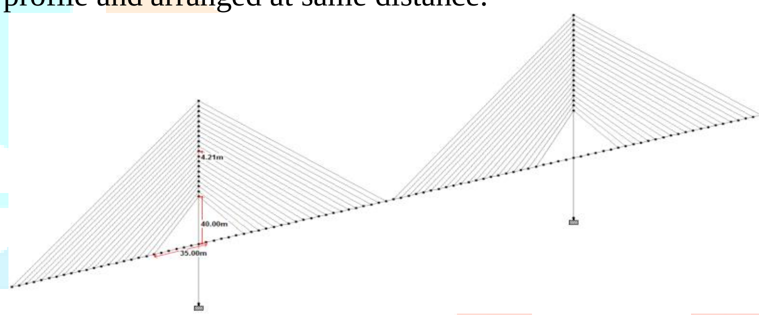
### 4.2 Modeling of Model M2

Model M2 has similarity to model M1 with basic difference between model M1and M2 is as in model M1 cables are arranged in fan profile and arranged at same distance.




### 4.3 Modeling of Model M3

Model M3 has similarity to model M1 with basic difference between model M1and M3 is as in model M1 cables are arranged in fan profile and arranged at same distance.




### 4.4 Modeling of Model M4

Model M4 has similarity to model M1 with basic difference between model M1and M4 is as in model M1 cables are arranged in fan profile and arranged at same distance. Lowest inclination angle of cables is $43.83^0$ and largest inclination degree is $45^0$.

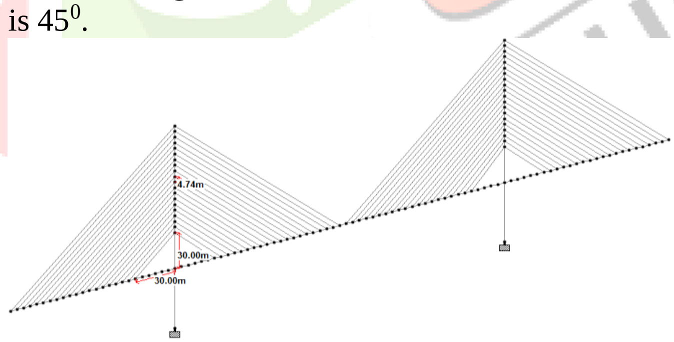



Figure - Layout Plan of model M4

### 4.5 Modeling of Model M5

Model M5 has similarity to model M1 with basic difference between both model M1and M5 is as in model M1both towers are connected at top and intermediate point where the top cable is connected to the towers but in model M5 both towers are connected with cross bracing.

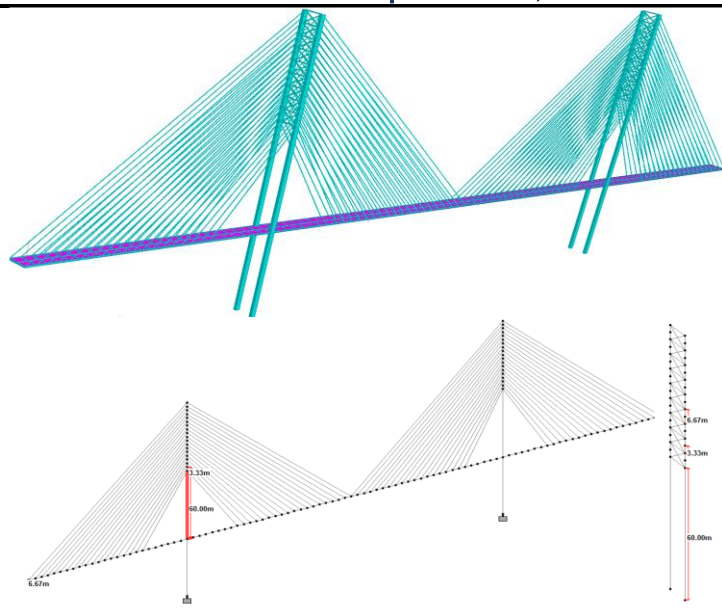



Figure - Layout Plan of model M5

## 4.6 Modeling of Model M6

Model M6 has similarity to model M2 with basic difference between both model M2 and M6 is as in model M2 both towers are connected at top and intermediate point where the top cable is connected to the towers but in model M6 both towers are connected with cross bracing.

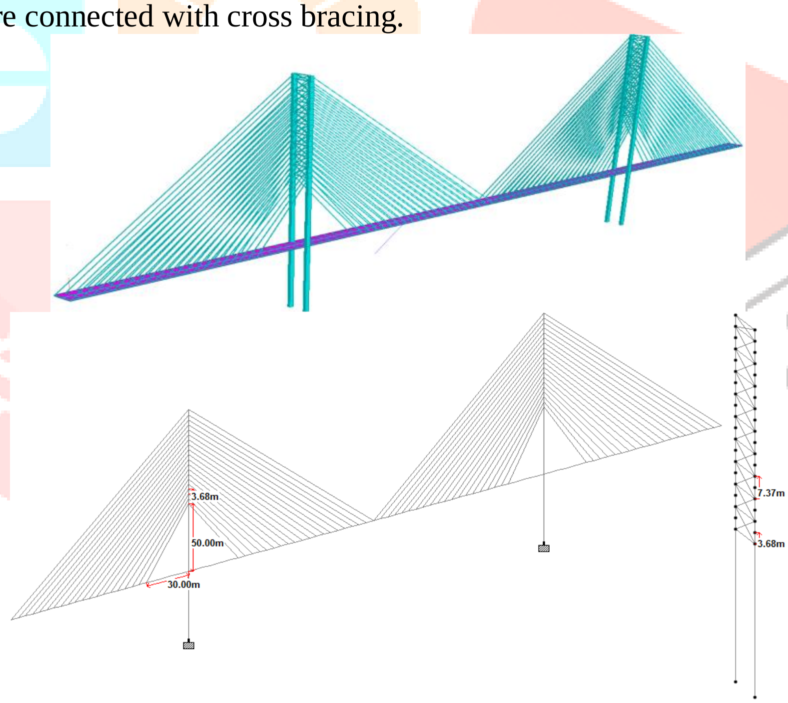



Figure - Layout Plan of model M6

## 4.7 Modeling Of Model M7

Model M7 has similarity to model M3 with basic difference between both model M3 and M7 is as in model M3 both towers are connected at top and intermediate point where the top cable is connected to the towers but in model M7 both towers are connected with cross bracing.

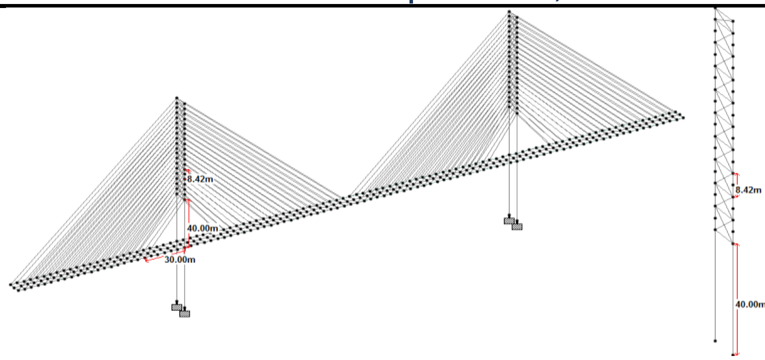



Figure - layout Plan of model M7

### 4.8 Modeling Of Model M8

Model M8 has similarity to model M4 with basic difference between both model M4 and M8 is as in model M4 both towers are connected at top and intermediate point where the top cable is connected to the towers but in model M8 both towers are connected with cross bracing.

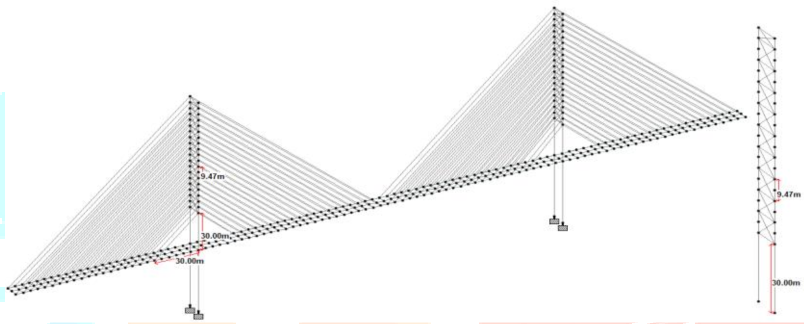



Figure - layout plan of model M8

## 5. ANALYSIS, RESULT AND DISCUSSION

In previous chapters of this dissertation methodology, model generation, loads acting and various load combinations are introduced. All models in the previous chapter are modalised in STAAD. Pro software and also load and their possible combinations are presented as per Indian standard code IS code.

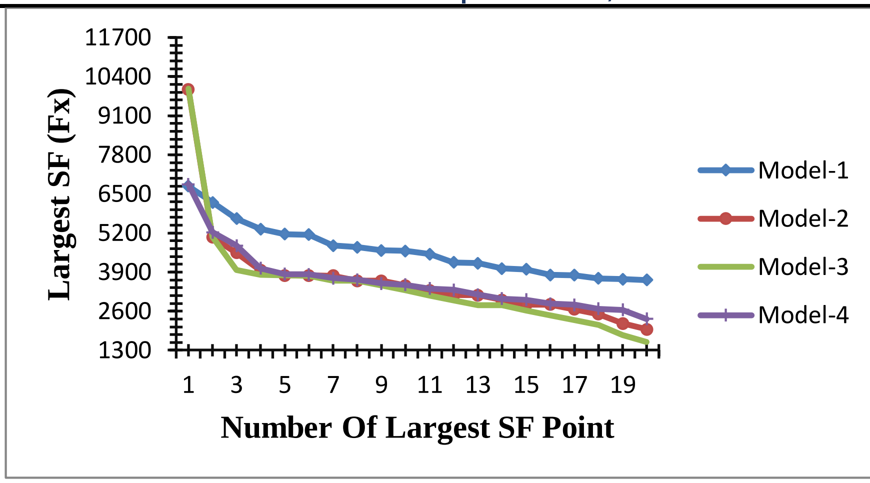
### 5.1.Analysis and Result of Side Span of Bridge

In this section all models are analyzed and compared for their different parameters of side span of the cable stayed bridge. All parameters are then collected in the form of graphs and tables which are then compared with the help of graphs and tables until final results are obtained.

### 5.2.SF Comparison of Cable (Side Span)

#### 5.2.1. Horizontal SF (Fx) Comparison

In cable stayed suspension bridge numbers of cables are used as an effective load transfer medium between bridge deck and tower. All cables in the bridge are then subjected to SF so it is a major matter of concern as how to reduce the SF in cables for an economical and efficient cable stayed bridge design.

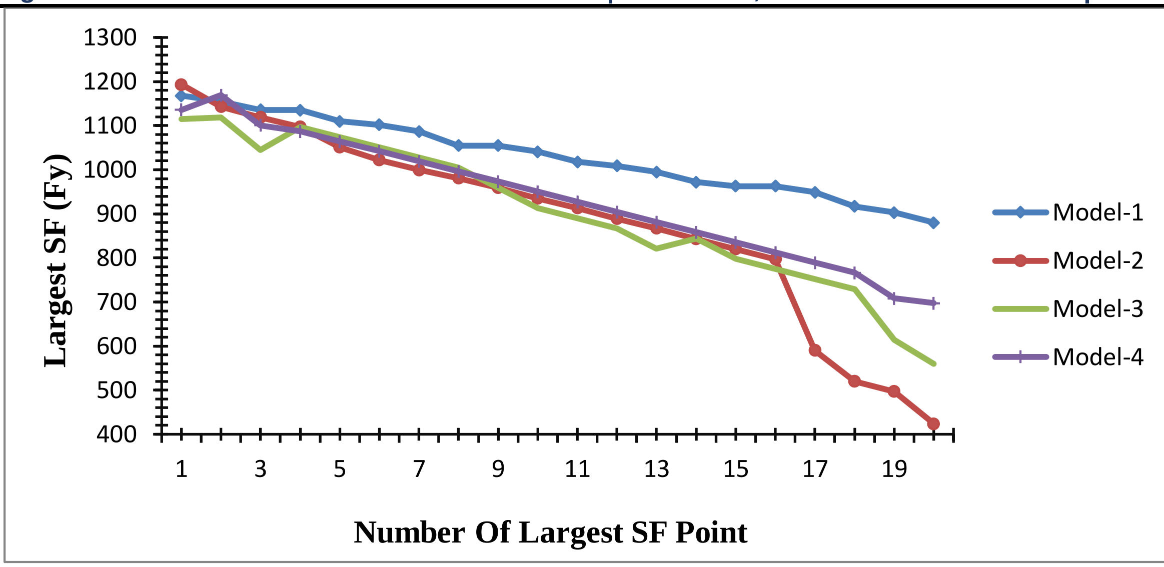



Graph-5.1SF (Fx) for Side Span

**Table 5.1 Horizontal SF (Fx) resultant for side span**

| S. N. | M1 | M2 | M3 | M4 |
|---|---|---|---|---|
| 1 | 6772 | 9912 | 10010 | 6799 |
| 2 | 6305 | 5065 | 5075 | 5225 |
| 3 | 5677 | 4542 | 3969 | 4612 |
| 4 | 5321 | 3956 | 3803 | 4030 |
| 5 | 5162 | 3789 | 3795 | 3833 |
| 6 | 5140 | 3786 | 3782 | 3824 |
| 7 | 4776 | 3774 | 3614 | 3701 |
| 8 | 4725 | 3610 | 3611 | 3648 |
| 9 | 4616 | 3608 | 3450 | 3523 |
| 10 | 4602 | 3451 | 3286 | 3478 |
| 11 | 4500 | 3293 | 3121 | 3355 |
| 12 | 4223 | 3135 | 2957 | 3312 |
| 13 | 4194 | 3134 | 2795 | 3145 |
| 14 | 4017 | 2975 | 2792 | 3018 |
| 15 | 3988 | 2821 | 2627 | 2977 |
| 16 | 3803 | 2817 | 2467 | 2848 |
| 17 | 3772 | 2664 | 2298 | 2809 |
| 18 | 3685 | 2502 | 2121 | 2679 |
| 19 | 3664 | 2190 | 1806 | 2642 |
| 20 | 3672 | 1981 | 1499 | 2365 |

Graph reflects that largest value of horizontal resultant of SF is in model M1 for middle cables but model M3 give lowest SF values for mid cables. However model M3givehigherSFinitially in outer cables and after which it decreases but Model M4 gives better results of SF in initial and final stages of different cables arrangement so it is obvious that it is the best arrangement of cable profile in respect to SF distribution in the horizontal direction. Model M4 give linear distribution of SF in cables. SF in outer cables is high and it is decrease according to the cable. Cable that has less distance from pylon had less SF as compared to outer cable.




Graph-5.2SF (Fy) Comparison for Side Span

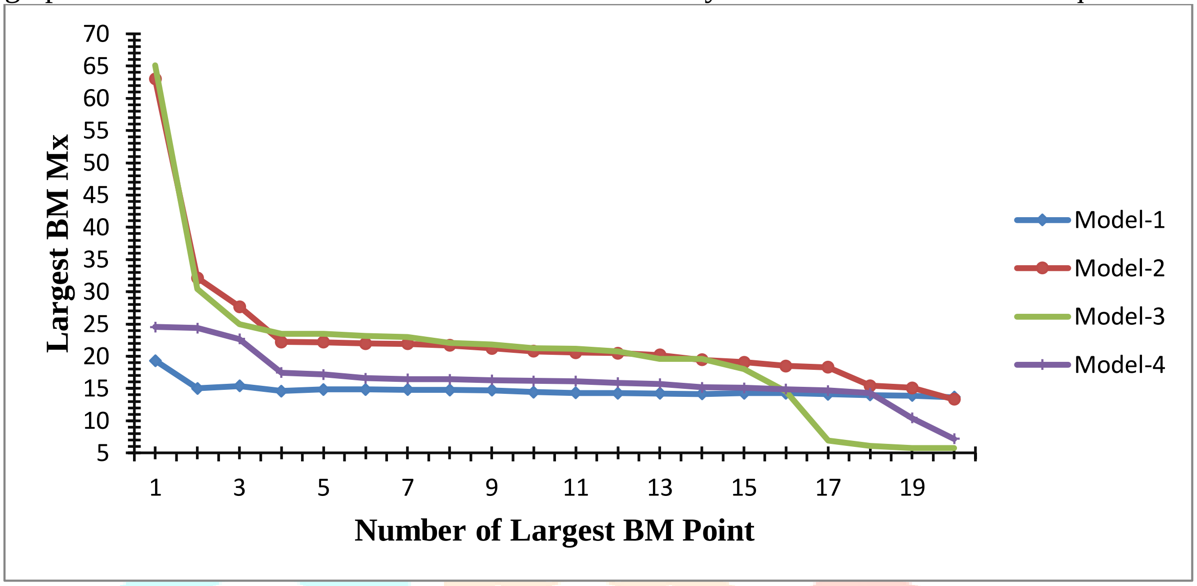
**Table 5.2Vertical SF Resultant for Side Span**

| S. N. | M1 | M2 | M3 | M4 |
|---|---|---|---|---|
| 1 | 1168 | 1193 | 1115 | 1136 |
| 2 | 1155 | 1143 | 1119 | 1169 |
| 3 | 1136 | 1119 | 1045 | 1101 |
| 4 | 1135 | 1097 | 1097 | 1087 |
| 5 | 1110 | 1051 | 1074 | 1064 |
| 6 | 1102 | 1022 | 1051 | 1042 |
| 7 | 1087 | 1000 | 1028 | 1019 |
| 8 | 1055 | 981 | 1005 | 996 |
| 9 | 1055 | 959 | 959 | 973 |
| 10 | 1041 | 935 | 913 | 950 |
| 11 | 1018 | 913 | 890 | 927 |
| 12 | 1009 | 889 | 867 | 904 |
| 13 | 995 | 867 | 821 | 881 |
| 14 | 972 | 843 | 844 | 858 |
| 15 | 963 | 820 | 798 | 835 |
| 16 | 963 | 797 | 775 | 812 |
| 17 | 949 | 590 | 752 | 789 |
| 18 | 917 | 520 | 729 | 766 |
| 19 | 903 | 497 | 614 | 708 |
| 20 | 880 | 424 | 560 | 697 |

## 5.3. BM Comparison of Cables (Side Span)

### 5.3.1. Horizontal BM (Mx) Comparison

When cables are subjected to SF then BM develops in the cables and this is the prime need of any designer to minimize the BM and to give economical design with keeping the safety in mind for cable stayed bridge. Below graph shows BM in cables and this data is used to analyse the structure to obtain required results.




Graph-5.3BM (Mx) Comparison for Side Span

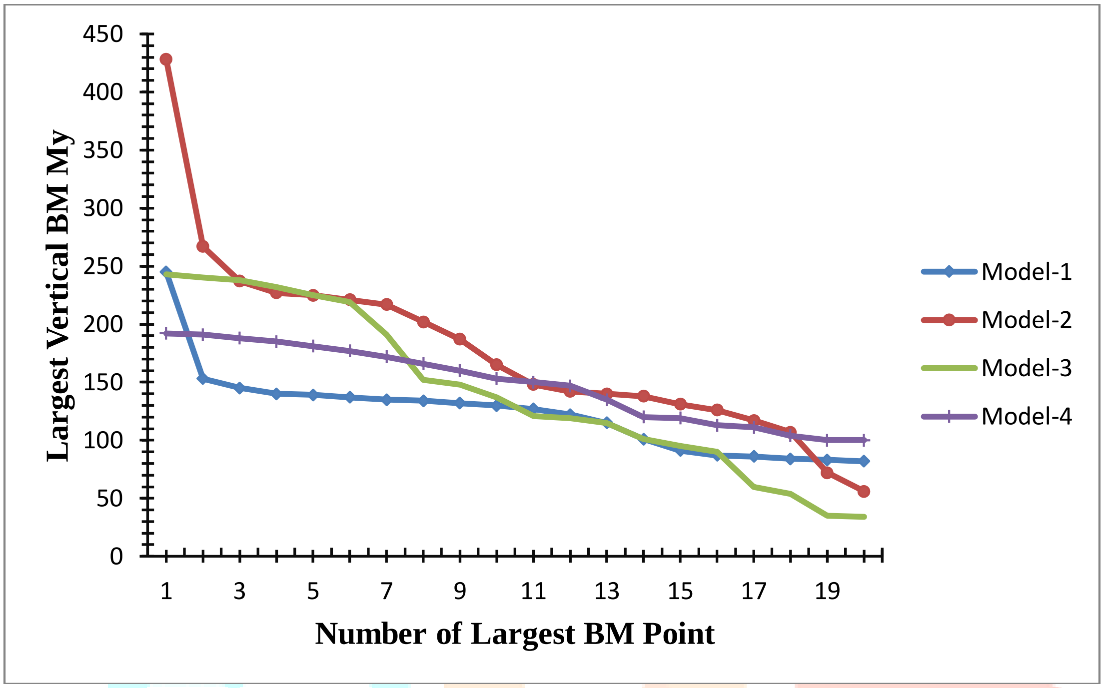
**Table 5.3 Horizontal BM (Mx) for Side Span**

| S. N. | Model-1 | Model-2 | Model-3 | Model-4 |
|---|---|---|---|---|
| 1 | 19.33 | 63 | 65.15 | 25.54 |
| 2 | 15.01 | 32.16 | 30.42 | 25.37 |
| 3 | 15.4 | 27.68 | 25.95 | 22.66 |
| 4 | 15.59 | 22.22 | 23.49 | 17.46 |
| 5 | 15.85 | 22.17 | 23.46 | 17.17 |
| 6 | 15.83 | 21.98 | 23.16 | 16.59 |
| 7 | 15.79 | 21.94 | 22.96 | 16.48 |
| 8 | 15.76 | 21.68 | 22.09 | 16.43 |
| 9 | 15.74 | 21.24 | 21.78 | 16.31 |
| 10 | 15.42 | 20.78 | 21.23 | 16.16 |
| 11 | 15.29 | 20.56 | 21.15 | 16.11 |
| 12 | 15.26 | 20.47 | 20.75 | 15.88 |
| 13 | 15.24 | 20.2 | 19.58 | 15.72 |
| 14 | 15.15 | 19.45 | 19.56 | 15.17 |
| 15 | 15.25 | 19.07 | 18.02 | 15.09 |
| 16 | 15.25 | 18.48 | 15.53 | 15.88 |
| 17 | 14.09 | 18.27 | 6.96 | 15.67 |
| 18 | 13.97 | 15.42 | 6.1 | 15.26 |
| 19 | 13.91 | 15.09 | 5.77 | 10.43 |
| 20 | 13.64 | 13.32 | 5.77 | 7.17 |

Table 5.3 reflects that there is nearly same magnitude of BM values for model M1 and M4 having approximately same mid values of BMs. In model M2 and M3initiallyBM is large but there is sudden decrement in BM value as presented in graph5.3.

#### 5.1.1. Vertical BM (My) Comparison

Graph reflects that largest value of vertical BM(My) is given by model M2 and M3. However for modelM2SF is high initially for two cables which then decreases but the Model M4 gave near about linear values of vertical BM.




Graph-5.4 Vertical BM (My) Comparison for Side Span

**Table 5.4 Vertical BM (My) for Side Span**

| S. N. | Model-1 | Model-2 | Model-3 | Model-4 |
|---|---|---|---|---|
| 1 | 245 | 428 | 243 | 192 |
| 2 | 153 | 267 | 240 | 191 |
| 3 | 145 | 237 | 238 | 188 |
| 4 | 140 | 227 | 232 | 185 |
| 5 | 139 | 225 | 225 | 181 |
| 6 | 137 | 221 | 219 | 177 |
| 7 | 135 | 217 | 191 | 172 |
| 8 | 134 | 202 | 152 | 166 |
| 9 | 132 | 187 | 148 | 160 |
| 10 | 130 | 165 | 137 | 153 |
| 11 | 127 | 148 | 121 | 150 |
| 12 | 122 | 142 | 119 | 147 |
| 13 | 115 | 140 | 115 | 135 |
| 14 | 101 | 138 | 101 | 120 |
| 15 | 91 | 131 | 95 | 119 |
| 16 | 87 | 126 | 90 | 113 |
| 17 | 86 | 117 | 60 | 111 |
| 18 | 84 | 107 | 54 | 104 |
| 19 | 83 | 72 | 35 | 100 |
| 20 | 82 | 56 | 34 | 100 |

Table 5.4reflects that for initial values of BM in y-direction My model M4 is efficient as compared to models M1, M2 and M3. Model M1 and M3 is has similar values initially but for modelM3 BM values decreases more as compared to model M1. So model M1 is efficient model for cable arrangement.

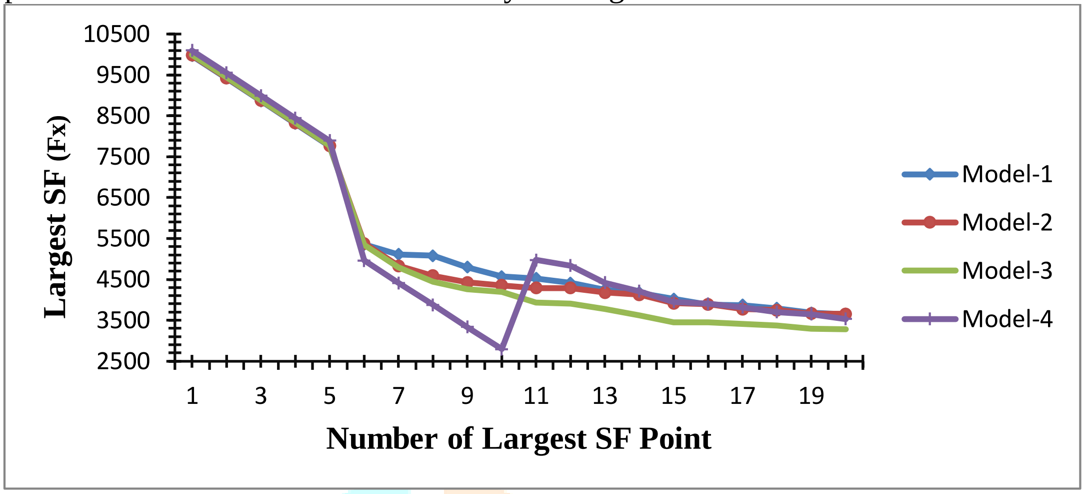
### 5.1.Analysis Result for Main Span of Bridge

In this section we attempt to analyze all models and to compare them for all the parameter for main span of cable stayed bridge. All parameter are taken in the form of graphs and tables to compare their results and to study to obtain the final results.

### 5.2. SF Comparison of Cable for Main Span Bridge

#### 5.2.1. Horizontal SF (Fx) Comparison

All the above presented graphs and tables are generated for the side span of the structure with changing the position the cables of the said cable stayed bridge.




Graph-5.5SF (Fx) Comparison for Main Span

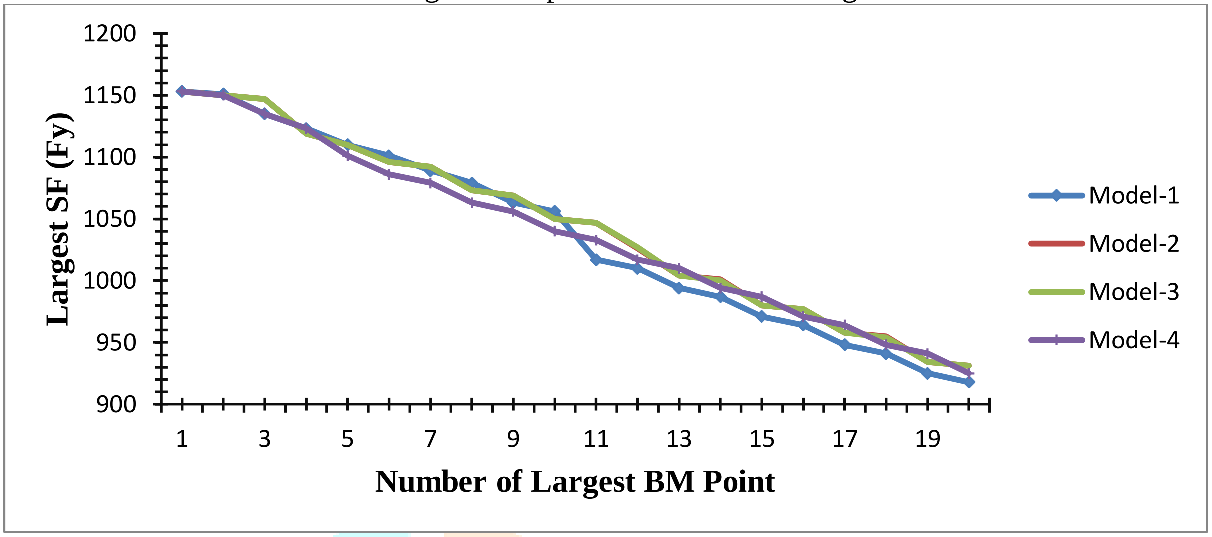
**Table 5.5 Horizontal SF Resultant for Main Span**

| S. N. | M1 | M2 | M3 | M4 |
|---|---|---|---|---|
| 1 | 9970 | 9982 | 9990 | 10101 |
| 2 | 9417 | 9429 | 9436 | 9548 |
| 3 | 8864 | 8876 | 8883 | 8995 |
| 4 | 8311 | 8323 | 8330 | 8442 |
| 5 | 7758 | 7770 | 7777 | 7889 |
| 6 | 5352 | 5377 | 5343 | 4959 |
| 7 | 5111 | 4833 | 4800 | 4414 |
| 8 | 5076 | 4586 | 4442 | 3875 |
| 9 | 4799 | 4423 | 4257 | 3334 |
| 10 | 4566 | 4355 | 4195 | 2795 |
| 11 | 4523 | 4289 | 3929 | 4976 |
| 12 | 4411 | 4289 | 3909 | 4837 |
| 13 | 4246 | 4180 | 3781 | 4422 |
| 14 | 4169 | 4125 | 3621 | 4211 |
| 15 | 4020 | 3915 | 3454 | 3948 |
| 16 | 3881 | 3888 | 3448 | 3904 |
| 17 | 3872 | 3773 | 3416 | 3816 |
| 18 | 3791 | 3745 | 3376 | 3700 |
| 19 | 3683 | 3664 | 3289 | 3649 |
| 20 | 3646 | 3654 | 3285 | 3530 |

However initial SF for model M4 is slightly higher in outer cables and after that it decreases and more number of cables reflects lower values of tension so it is most effective arrangement of cable with respect to SF distribution in x-direction.

#### 5.1.1. Vertical SF (Fy) Comparison

Graph 5.6 gives overall analyses idea between all the four models. This graph reflects not too much variation in vertical tension resultant for bridge main span for this cable arrangement.




Graph-5.6SF (Fy) Comparison for Main Span

**Table 5.6 Vertical SF Resultant for Main Span**

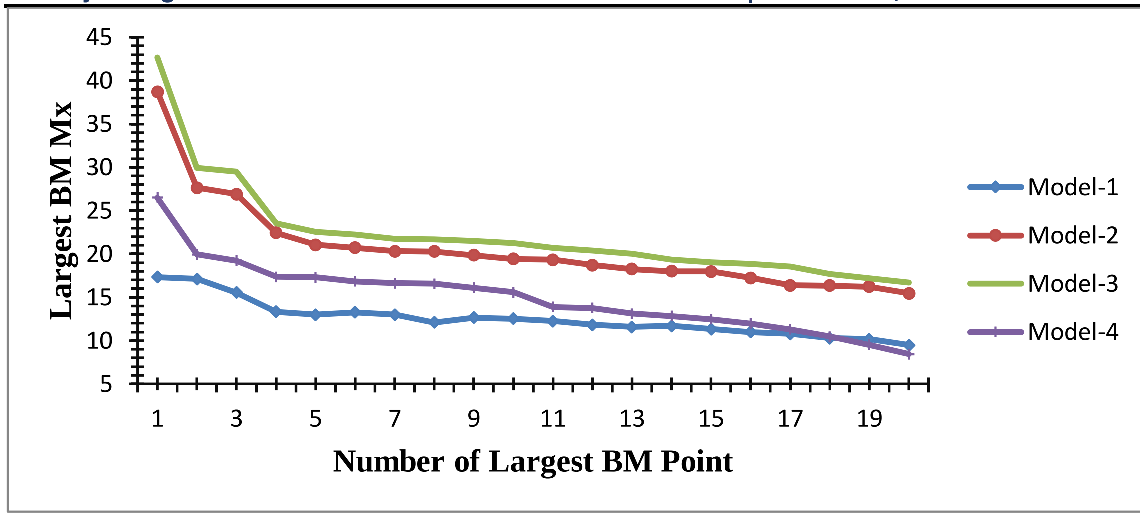
| S. N. | M1 | M2 | M3 | M4 |
|---|---|---|---|---|
| 1 | 1153 | 1153 | 1153 | 1153 |
| 2 | 1151 | 1150 | 1150 | 1150 |
| 3 | 1135 | 1147 | 1147 | 1135 |
| 4 | 1123 | 1119 | 1119 | 1123 |
| 5 | 1110 | 1110 | 1110 | 1101 |
| 6 | 1101 | 1096 | 1096 | 1086 |
| 7 | 1089 | 1092 | 1092 | 1079 |
| 8 | 1079 | 1073 | 1073 | 1063 |
| 9 | 1063 | 1069 | 1069 | 1056 |
| 10 | 1056 | 1050 | 1050 | 1040 |
| 11 | 1017 | 1047 | 1047 | 1033 |
| 12 | 1010 | 1026 | 1027 | 1017 |
| 13 | 994 | 1004 | 1004 | 1010 |
| 14 | 987 | 1001 | 1000 | 994 |
| 15 | 971 | 980 | 980 | 987 |
| 16 | 964 | 977 | 977 | 971 |
| 17 | 948 | 958 | 958 | 964 |
| 18 | 941 | 955 | 954 | 948 |
| 19 | 925 | 934 | 934 | 941 |
| 20 | 918 | 931 | 931 | 925 |

### 5.4. BM Comparison of Main Span Cables

#### 5.4.1. Horizontal BM (Mx) Comparison

Graph reflects that largest value of BM in horizontal direction (Mx) is for model M2 and model M3 and these models have nearly the same magnitude. Model M1 reflect slowest BM in horizontal direction and model M4have little more BM but has less BM then model M2 and M3. So there are two suitable arrangement of cable in terms of model M1 and M4.

Table 5.7reflects that model M1 and M4 shows nearly same BM values. Mid BM values is also approximately same in these two models. Intial value of BM is large for model M2 and M3 but it decreases suddenly as presented below in graph5.7.




Graph-5.7LargestBM (Mx) Comparison for Main Span

## CONCLUSIONS AND FUTURE SCOPE

In previous chapters of this dissertation, BM&SF of all structural models are compared and best design model of all the studied models are presented with minimal SF and BM with the help of graphs and table. In this chapter it is also given the future scope needed for future work extension. All analysis results are summarized as follows.

- After in depth analysis of 4 cable profiles of cable stayed bridge it is concluded that the cable arrangement at the inclination from horizontal deck surface of about 45$^o$ is best suited. Model M3 give the most economical cable arrangement profile with upper-half of the pylon length attached with cables.
- Bracing neither reduce SF nor BM too much in the cables. Bracing is playing role in reducing only deflection in pylons.
- Bridge designed for less number of cables will be difficult in managing the anchor failure. So the number of cables is increased to manage the anchor failure easily.
- Inclination of cable affects height of tower which is near about 45$^o$ to t deck of the bridge.

## REFERENCES

1) H.J. Kanj, Y.Y. Zaho, Y.X.Jin"Static behavior of a new types of cable arch bridge" ELSEVIERJournals& Magazines 2013.
2) H.Erogan, E.Gulal"The application of time series analysis to describe the dynamic behavior of suspension bridge" ELSEVIERJournals& Magazines 2009.
3) Samir N.Shoukry, MuradY.Riad"Longterm sensor based monitoring of an LFRD design steel girder bridge" ELSEVIERJournals& Magazines 2009.
4) Yuxin Pan, Carlos E. Ventura, Moe M.S Cheug "Performance of highway bridge subjected to the blast loading ELSEVIER Journals & Magazines 2017.
5) B.Mokrani, Z.Alaluf, F.Meng, A.Perumount "Passive damping of suspension bridge using multi-degree of freedom tuned mass damper" ELSEVIER Journals & Magazines 2017.
6) P.Lonetti , A. Pascuzzo "Optimum design of hybrid cable stayed suspension bridge" ELSEVIER Journals & Magazines 2014.
7) Chen Chang-song"Self-adapted construction control analysis of long span pre-stressed concrete cable stayed bridge " IEEE Journals & Magazines 2008.
8) A.M.B.Martins ,L.M.CSimoes "optimization of cable forces on concrete cable-stayed bridges including geometrical nonlinearities ELSEVIER Journals & Magazines 2015.
**9)** Huu-tai Thai, Dong-Ho Choi "Adavanced analysis of multi-span suspension bridge"EURODYN Journals & Magazines 2013.
**10)** OyvindWiig Petersen, Ole Oiseth, Eliz-Mari Lourens "Esimation of dynamic response of a slender suspension bridge using measured acceleration data"ELSEVIERJournals & Magazines 2017.