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Non-Linear Dynamic Analysis of Cable Stayed Bridge with Different Cable Arrangements

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Abstract: A cable-stayed bridge is being built more frequently every day. Cable-stayed bridges are a good option for crossing waterways or crowded metropolitan areas because they combine structural effectiveness, aesthetic perks, and urban design advantages. This work investigates the dynamic analysis of cable-stayed bridges using various cable arrangements. The reaction forces of deck are transmitted to the pylon by the cable. Pylon transfers the weight of cables to the foundation. Modelling and analysis of the cable-stayed bridge with different cable arrangements are done using the MIDAS CIVIL software. The arrangement of the cables in ‘Fan’, ‘Harp’ and ‘Semi-fan’ shapes were taken into consideration. All three bridges share the same materials and sectional characteristics, while the moving load is provided according to IRC:6-2000 loading. Three nonlinear dynamic behaviour of bridges were examined as part of the seismic analysis part using Time History data from the 1940 El Centro earthquake. Many factors are examined, including axial forces, shear forces, and bending moments. And using time history analysis, six different modes were examined. Unit pretension and optimal pretension were studied between three cable arrangements of cable stayed bridges. To understand the advantages of cable optimisation in cable-stayed bridges. According to the result, as complexity rises, structural behaviour changes. After comparing the results, it is determined which cable arrangement performs the best and most poorly. And optimization of cables plays vital role in stability of cable stayed bridge is observed.

Keywords: Fan, Semi-fan, Harp, Cable stayed bridge, Time history

I. INTRODUCTION

A bridge is a structure used in civil engineering that crosses a physical barrier, such as a river, valley, or road, to allow traffic, pedestrians, or animals to pass. Bridges are constructed to link two locations which would otherwise be split by the obstruction. They are necessary for building effective transport systems and enhancing connection between multiple regions.

The main load-bearing structure of a cable-stayed bridge is supported by cables that are fastened to one or more towers or pylons. It is a well-liked and effective bridge design that is utilised extensively around the world to cover large distances. The loads are transmitted by these cables, which are fastened to the bridge deck, to the supporting towers, which subsequently convey the forces to the ground. Cable-stayed bridges Strong, adaptable, and aesthetically appealing, cable-stayed bridges are widely known for their construction. They are frequently found in places with severe geological conditions or navigable waterways that call for huge clear spans and frequently used to span long distances.

Forces in Bridge:

- Tension in the cables: The most major driver in a cable-stayed bridge. These durable steel cables transfer weights from the bridge deck to the holding towers while supporting the deck of the bridge. The cables undergo tension, holding the weight of the deck, any additional applied weights, and living loads (such as moving vehicles and people).
- Tower Compression and Bending: As the towers carry both the weight of the deck and the tension forces generated by the cables, they are subject to compression forces. In addition, the lateral loads, such as wind and seismic pressures, cause the towers to experience bending moments.
- Bridge Deck Bending and Shear: The loads that the bridge deck supports, such as vehicular traffic and other live loads, cause it to bend and shear at various points. To keep its structural integrity, the deck needs to be built to withstand these stresses.

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- Axial Force in Pylon: In certain cable-stayed bridges, the deck between the towers may be supported by a pylon (or piers) in the centre of the bridge. Due to the compression caused by the weight of the deck and the tension in the cables, the pylon is subject to axial forces.

The period and damping of a cable-stayed bridge are impacted by changing the cable configuration, which in return affects the forces acting on bridge components and modifies the necessary dimensions. Considering this. It is obvious that changing the cable arrangement will impact both construction costs and seismic risk. Therefore, to determine the most suitable alternative, a detailed investigation of the common arrangements must be done.

Different Arrangements of Cables:

- Fan shaped arrangement: In this configuration, the cables are fastened to or span over the towers' summits. Compared to the Harp type, the cables have a smaller cross-section because of their slightly steeper slope. However, as the quantity of stay cables grows, the weight of the anchorage also grows, making it challenging to link all the stay cables at the pylon. Fan patterns are therefore only appropriate for spans with limited stay cables and moderate lengths.

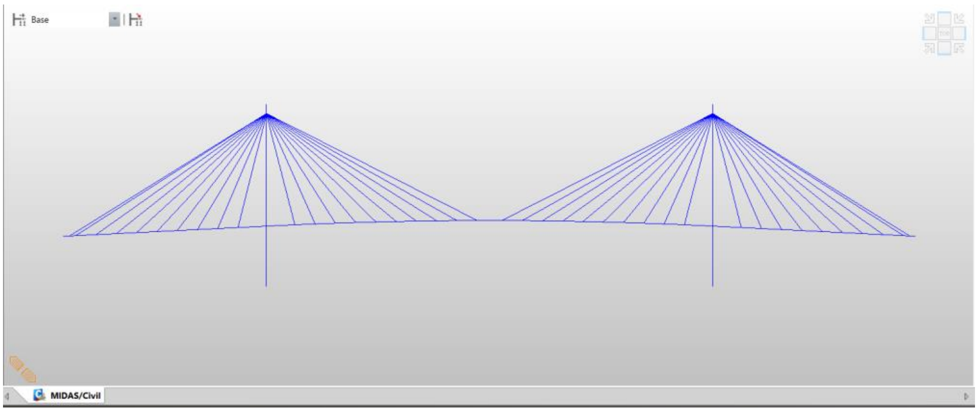

Figure -1: Fan Cable Arrangement

- Semi-fan shape arrangement: The cables in this arrangement get increasingly steeply leaned and are concentrated in the top portion of the pylon. One of the most typical arrangements is such as this. Compared to the Fan system, the cables are suitably distinct from one another in this arrangement, resulting in simpler cable maintenance and better termination.

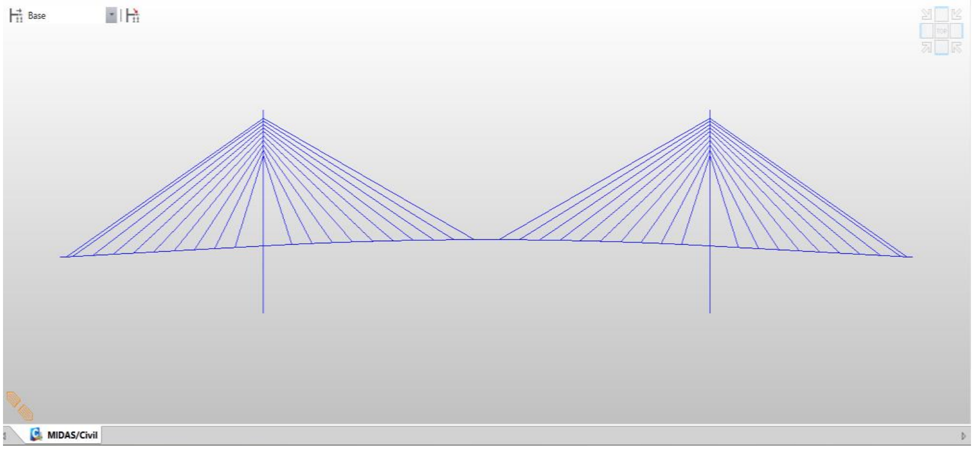

Figure -2: Semi-fan Cable Arrangement

- Harp shape arrangement: The cables in the Harp system are approximately parallel to one another, which is why it's often designated a parallel design. This arrangement is more aesthetically beautiful, but larger pylons are needed to accommodate all the cables. Furthermore, because the cables are not steeply inclined, a significant compressive force is created in the deck, which causes a greater bending moment in the pylons.

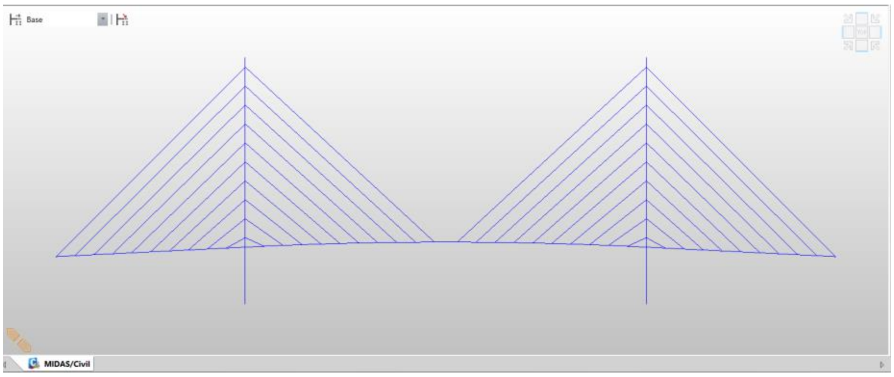

Figure -3: Harp Cable Arrangement

The present work investigates the dynamic analysis of cable-stayed bridges with various cable arrangements. In a cable-stayed bridge, the main function of cable is to give the bridge deck structural support and stability. The cables are essential for moving loads from the bridge deck to the supporting towers and, eventually, to the foundation. For the aim of this investigation, a ground motion from time history of El-Centro 1940 was taken, and a wheel according to IRC:6-2000 was provided.

It is extremely likely that software will have an impact on every industry. Working without software is challenging in any industry. In the structural field, a variety of software is employed for analysis and design. The software is still becoming better and better every day, making it easier to use. Software such as ETABS, STAAD PRO, SAP2000, and MIDAS CIVIL are frequently utilised. To analyse the bridges in the project, MIDAS CIVIL is employed.

II. LITERATURE REVIEW

Cyrille Denis Tetougueni, Paolo Zampieri, Carlo Pellegrino (2020) This study intends to assess the harm caused to a cable-stayed bridge by an unexpected load, such as blast loading., non-linear dynamic models were used to assess the structural response of three distinct cable-stayed bridge configurations and determine the possibility of short- and long-term damages while taking various loading parameters and location into account. A displacement-controlled static non-linear pushover analysis of the structure has been conducted. The research results show that the bridge's structural design and the stay arrangements have a considerable impact. The Fan cable-stayed bridge is found to be the most efficient among the configurations taken into consideration.

Yue Feng, Cheng Lan, Bruno Briseghella, Luigi Fenu and Tobia Zordan (2020) This article presents a design process for cable-stayed bridge stay cables that combines the influence matrix approach and genetic algorithms. The preliminary design of a twin tower, double-cable plane, cable-stayed bridge that would be built in Ferrara, Italy, using the design approach after that. Parallel optimisation is performed on the cable cross-sectional areas and corresponding pre-tension forces. The outcomes highlight how effective the suggested method is at designing stay cables and determining the best cross-sectional areas of stay cables under specific stress and displacement limits.

Vahid Akhoondzade-Noghabi & Khosrow Bargi (2016) A cable-stayed bridge is used as a case study to evaluate the relative dimensions and construction costs of three distinct configurations. Using the designed seismic risk assessment (DSRA) process. The suggested process involves three steps: fragility assessment, loss assessment, and cost-loss-benefit (CLB) evaluation.

It is carried out using a financial-comparative (FC) approach. By recommending benefit ratio (BR) as a profitability metric, the final decision is made. The loss due to likely earthquakes may then be studied simultaneously with the construction expenses for each configuration selected. The fan cable arrangement and the harp cable configuration, according to the results, are the best choices for cable-stayed bridges with 260 m and 100 m midspans, respectively.

A. Baldomir, S. Hernandez, F. Nieto, J.A. Jurado (2010) The cable cross section of a cable-stayed bridge is optimised in this paper while taking deck displacement and cable stress into consideration. The geometry and the mechanical qualities are susceptible to change because the bridge is still in the design process. A computer programme was built to create a model using geometrical and mechanical data and solve the optimisation problem, avoiding the need for several structural models. Two examples are provided at the end of the document to demonstrate the capabilities of the methodology.

III. OBJECTIVES

1. To study dynamic analysis of cable stayed bridge.
2. To assure the functionality, safety, and structural stability of the bridge.
3. To identify more stable type of cable arrangement for dynamic analysis.
4. To understand optimization of cables forces in cable stayed bridge.
5. To do comparative study of different types of cable stayed bridge.

IV. METHODOLOGY

1. Three span cable stayed bridge with 3 different cable arrangements are considered. Fan like, Semi-fan like and Harp like cable arrangements with the pylon height of 90m for Fan and Semi-fan cable stayed bridge while 130m height of pylon is considered for harp cable stayed bridge.
2. Self-weight, Additional dead load (SIDL), Moving loads on three span cable stayed bridge are taken as per IRC 6:2016 guidelines.
3. Class A and Class 70R vehicle moving load is applied on the bridge as per IRC 6:2016.
4. Non-linear dynamic time history analysis is used to conduct performance-based evaluation.
5. The pylon bases and cable anchorage are assumed to be fixed.
6. Nonlinear models of cable stayed bridge are prepared and time history analysis is carried out in MIDAS Civil software.

TABLE I Material Properties

Sr. No.	Particulars	Details
1	Modulus of Elasticity of steel (Es)	$2x10^7$ KN/m^2
2	Poisson's ratio of steel	0.3
3	Weight Density of steel	77.10 KN/m^3
4	Modulus of Elasticity of concrete (M60) (Ec)	38729833.5 KN/m^2
5	Poisson's ratio of concrete	0.2
6	Weight Density of concrete	24 KN/m^3

TABLE III Section Properties

Sr. No.	Section Name	Dimension (m)	Type	Cross Section Area (m^2)
1	Cable	D = 0.3	Steel	0.0707
2	Girder	W = 0.3 H = 3	Steel	0.9
3	Pylon	W = 4 H = 4	RCC	16
4	Cross beam girder	W = 3 H = 3	Steel	9
5	Cross beam pylon	W = 3 H = 3	RCC	9

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TABLE IIIII Details of Structures

Sr. No.	Particulars	Types of Structure		
		Fan	Harp	Semi-fan
1	Number of cables	80	80	80
2	Total span length of deck	420	420	420
3	Height of pylons	90	130	90
4	Slope of main span length	5%	5%	5%

- **Loading**

I. **Dead Load**: - It includes self-weight of RC and steel member. Here concrete slab having thickness 3000 mm, sizes of cross beam is 3000mm x 3000mm, size of columns 4000mm x 4000mm, Density of Concrete is 25 KN/m² and density of steel is 7710 KN/m².

II. **Additional Load (SIDL)**: -

SIDL Loads like Barriers, Footpath and kerb taking as 0.5kN/m2
Asphalt Density = 22.00 KN/m3 Assume,
Wearing Coat = 80mm SIDL Load = 22 x 0.08 =1.76 KN/m2
Total SIDL Load = 1.76 + 0.5 = 2.26 KN/m2
Total Width of Deck = 35m SIDL Load along Deck = 15.6 x 2.26 = 35.26 KN/m
Total Factored SIDL = 1.5 x 35.26 = 52.9 KN/m

III. **Moving Load**: - Class A and Class 70R vehicle loads are applied to cable stayed bridges according to with the requirements of IRC6:2016, which also specifies the type and number of vehicles for bridges.

IV. **Seismic Load**: - To conduct the time history analysis, the earthquake El Centro,1940, time history data is given. Since the earthquake is acting in all directions, the bridge can experience its impacts in different directions.

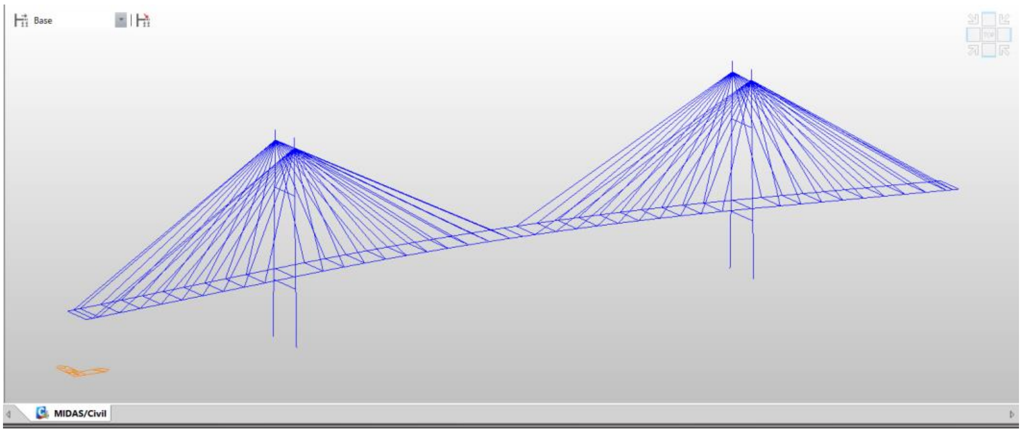

Figure -4: Fan Cable Stayed Bridge

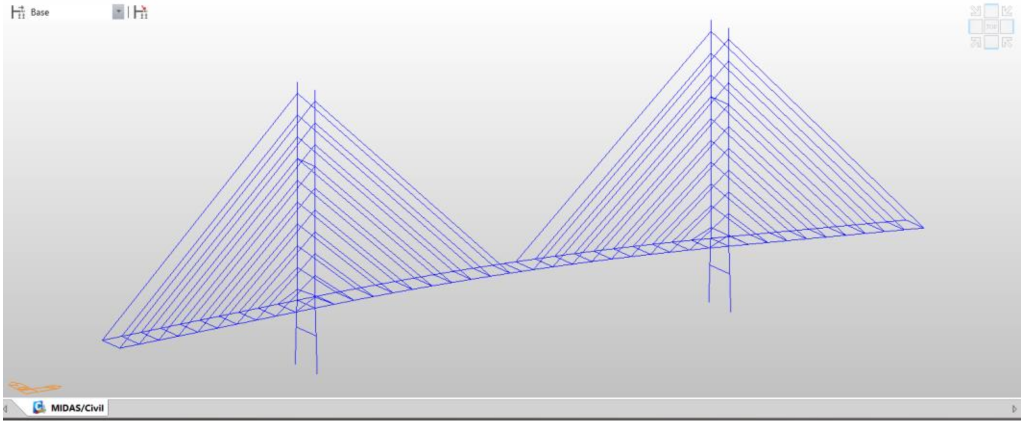

Figure -5: Harp Cable Stayed Bridge

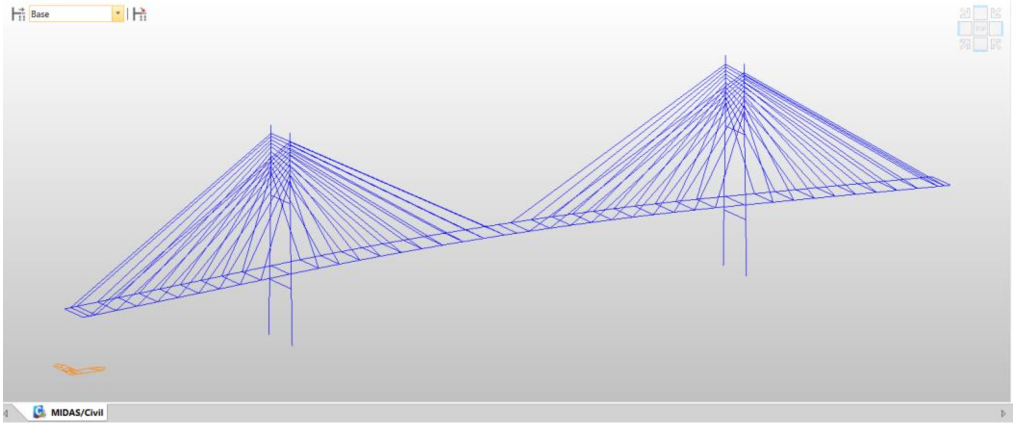

Figure -6: Semi-fan Cable Stayed Bridge

V. RESULT AND DISCUSSION

A brief discussion of results obtained from MIDAS Civil software used for evaluation of time history analysis of considered structures is as follows:

1. Bending Moment in Pylon:

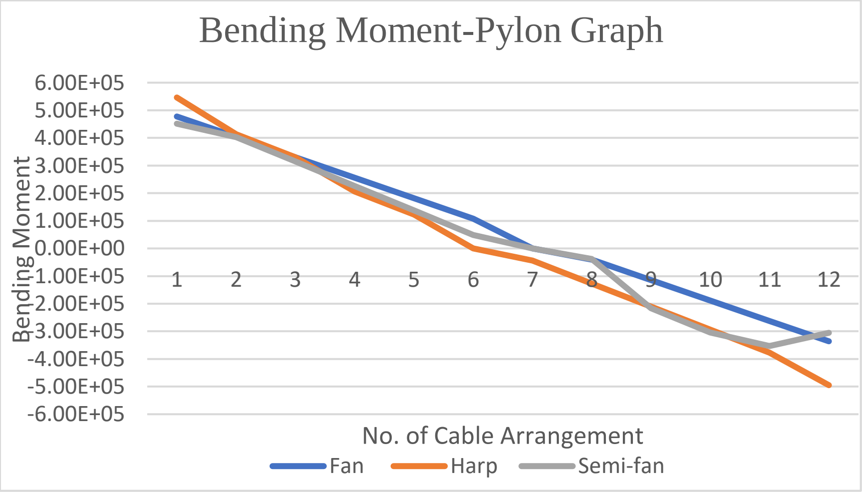

Fig.4 Bending moment on pylon

2. Bending Moment in Girder:

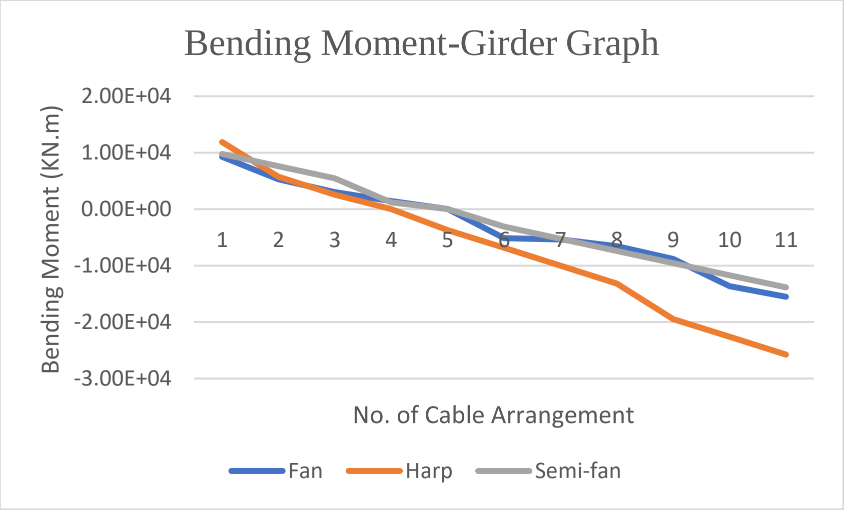

Fig.5 Bending moment on girder

3. Shear Force in Pylon:

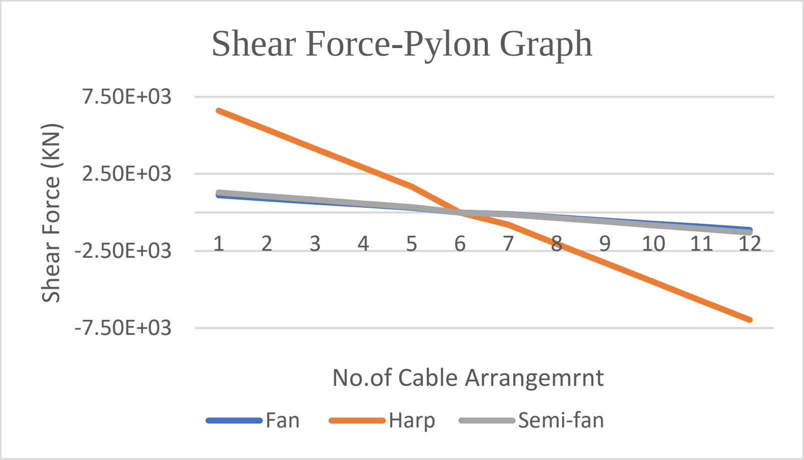

Fig.6 Shear force pylon

4. Shear Force in Girder:

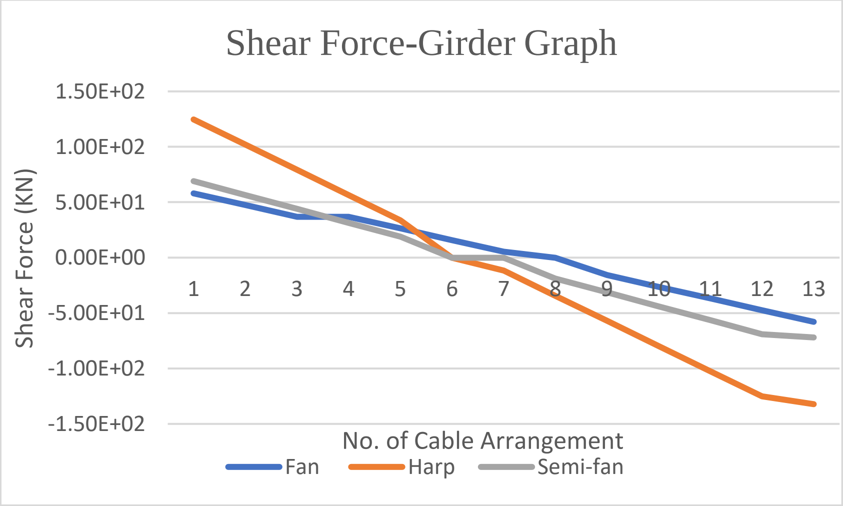

Fig.7 Shear force on girder

5. Axial Force in Pylon:

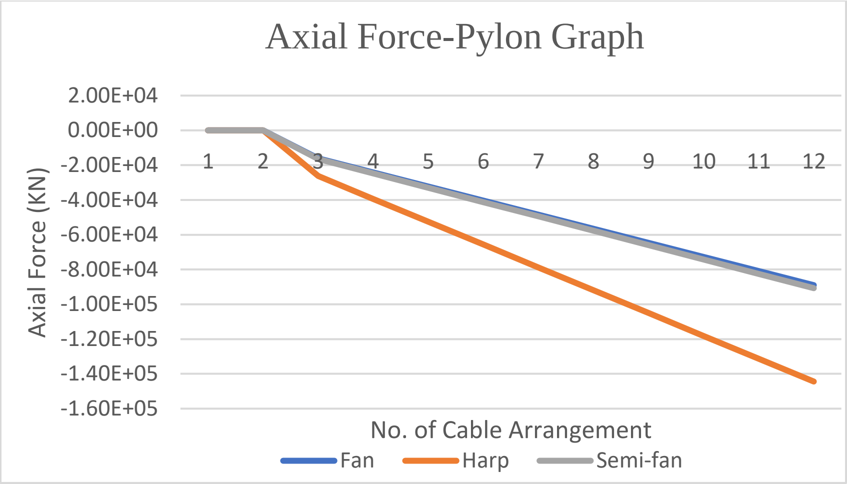

Fig.8 Axial force on pylon

6. Time Period:

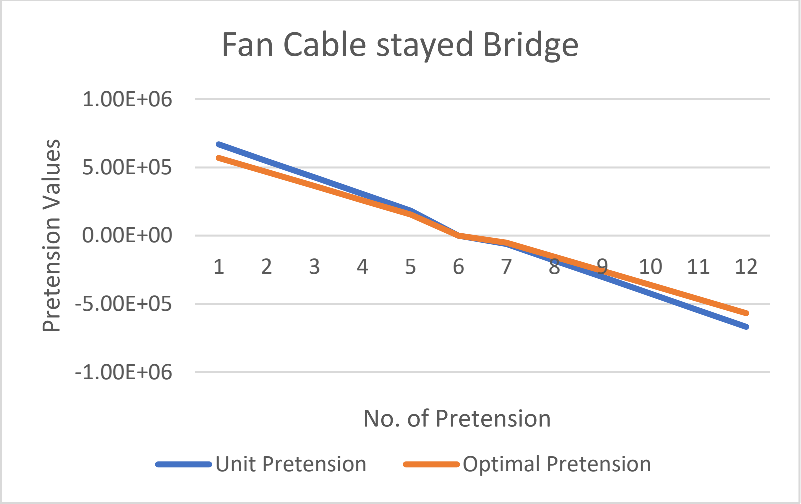

Fig.9 Time period-Mode graph

7. Frequency:

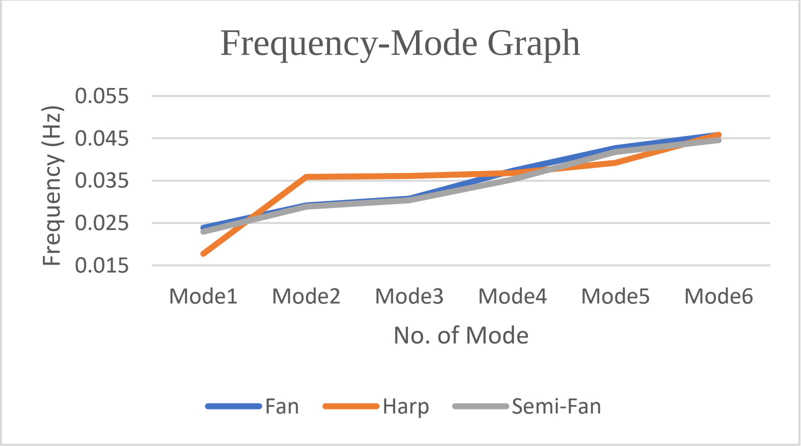

Fig.10 Frequency-Mode graph

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8. Cable Pretension in Fan cable stayed bridge:

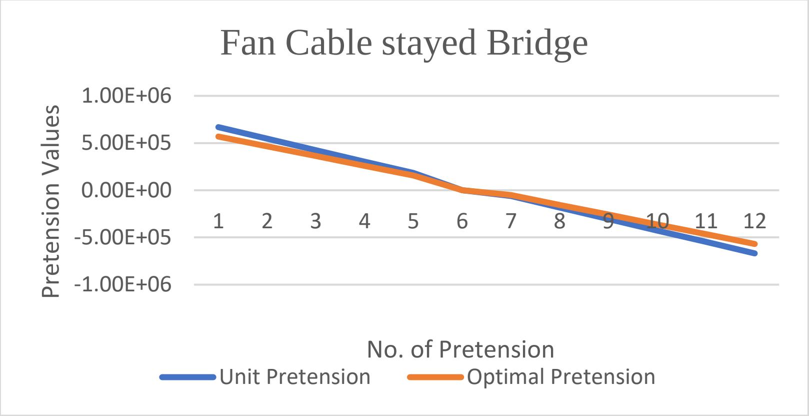

Fig.11 Fan cable stayed bridge pretension

9. Cable Pretension in Harp cable stayed bridge:

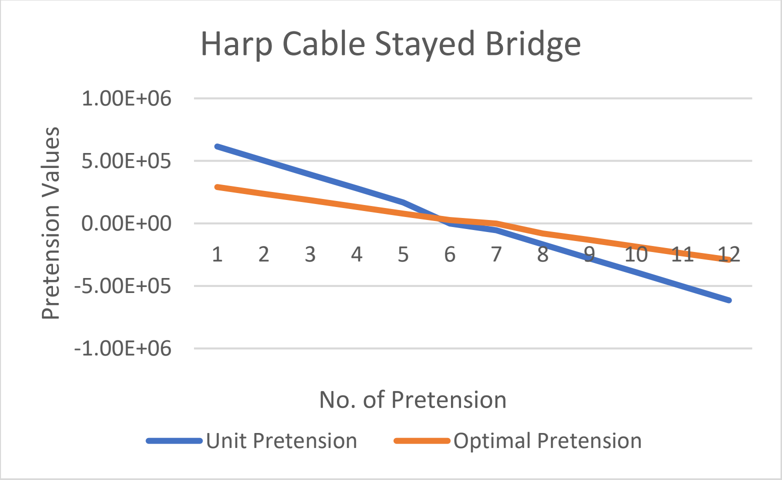

Fig.12 Fan cable stayed bridge pretension.

10. Cable Pretension in Semi-fan cable stayed bridge:

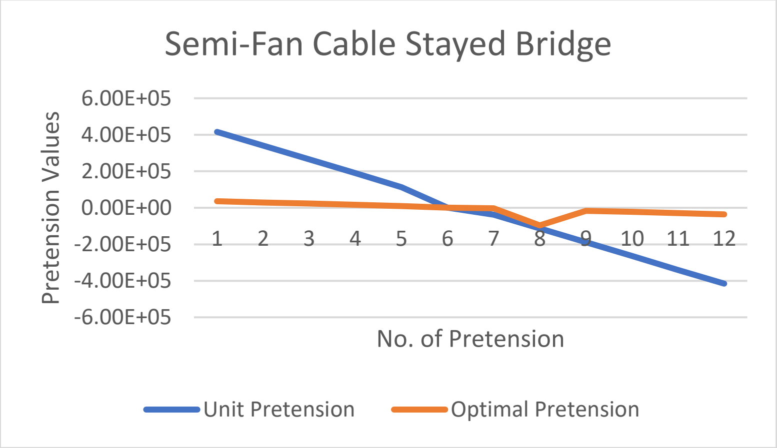

Fig.13 Fan cable stayed bridge pretension

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V. CONCLUSION

The study stated above leads to the following conclusions regarding the dynamic behavior of cable-stayed bridges with different cable arrangement patterns.

- When the possibility of dynamic behavior develops because of the complexity of the structure. The dynamic behavior of the cable-stayed bridge is complex since it is a complex structure.
- The objective of the research is to examine the dynamic behavior of the cable-stayed bridge when subjected to moving load and earthquake load. The result for different load combinations is additionally examined.
- From the values Harp shape cable arrangement cable stayed bridge shows high values of bending moment, shear force and axial force in both pylon and girder compared to Fan and Semi-fan cable arrangement cable stayed bridge.
- The Harp shape shows high frequency compared to others.
- The Fan and Semi-fan cable configuration of the cable-stayed bridge exhibits better stable characteristics in dynamic response than the Harp shape cable arrangement.
- It is concluded that the cable arrangement type, cable type, nature of the structure, and service demand all affect how the cable stayed bridge behaves.
- The highest values of the above parameters for the Harp cable arrangement makes it even less appropriate for long-spans cable stayed bridges. The visual appeal of the Harp cable arrangement is the only advantage over other cable arrangements.
- In the second study unit and optimal pretension in cables across the three various types of cable-stayed bridges Fan, Harp, and Semi-fan were compared.
- It is observed that the unit pretension cables show maximum value of Bending moment and when pretension is applied to cables bending moment reduces to the great extent.
- It is concluded that the optimal pretension cables give stability to structure, and it is important to consider optimal pretension for less bending moment.
- Minimum value of bending moment reduces the Self weight (Dead Load) of the structure, which will reduce the cost of the structure as well.

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