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SEISMIC BEHAVIOR OF CABLE STAYED BRIDGES BY USING SAP2000

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Abstract: Among the few basic types of bridges viz., Girder bridges, Arch bridges, and Trussed bridges, Cable stayed bridges have 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.

There are many types of cable arrangements among that we chose Fan type, Semi Fan type and Harp type arrangements. The bridge is analyzed for these cables arrangement by using SAP2000 software. The objective of this work is to assist the seismic behaviour of cable stayed bridge, for determining the design parameters (displacements and axial forcesetc). In this work an attempt is made to predict the behaviour of Cable Stayed Bridges under Static Loads and Dynamic Loads. The response of bridges in terms of Bending Moments, Shear Forces is determined under static loading. The dynamic characteristics such as Displacement and Base Reactions are also determined by the Non Linear Time History Analysis.

INTRODUCTION

1.1 GENERAL

During the past decade cable-stayed bridges have found wide applications in large parts of the world. Wide and successful application of cable-stayed systems has been realized only recently, with the introduction of high-strength steel, orthotropic type decks, development of welding techniques and progress in structural analysis. The variety of forms and shapes of cable-stayed bridge intrigue even the most demanding architects as well as common citizens. Engineers have found them technically innovating and challenging. Modern cable-stayed bridges are at present considered to be the most interesting development in bridge design. The increasing popularity of these contemporary bridges among bridge engineers can be attributed to its appealing aesthetics, full and efficient utilization of structural materials, increased stiffness over suspension bridges, efficient and fast mode of construction and the relatively small size of their sub structure.

HISTORY OF DEVELOPMENT OF BRIDGE

Early nineteenth century gave rise to the concept of long span bridges using steel. Towards the end of nineteenth century, reinforced concrete was first used in bridges followed by composite construction with steel and concrete, and pre-stress concrete being successfully used first in1959. Mid twentieth century saw the revival of the cable-stayed bridge, which in concept, dates back to seventeenth century Venice but is generally credited to Loscher (1784) in the form of a complete timber bridge.

TRANSFORMATIONS IN BRIDGE STRUCTURE

The following information shows the development in bridge construction over the years:

600. The An-chi bridge at Chao Chou is designed and built by Ch’un. The 117ft span features arch shaped openings on the walls of the bridge.

1400. The Romans innovative design for an aqueduct bridge is built in Nimes, France. It is used to transport water from the Gard River to the town of Nimes. It is unique design consists of three types of arches. It is extremely strong so that it can withstand the weight of water.

COMPONENTS OF BRIDGE

The bridge structure comprises of the following parts.

- **Superstructure or Decking**

  This includes slab, girder, truss, etc. This bears the load passing over it and transmits

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the forces caused by the same to the substructures.

- **Bearings**

  The bearings transmit the load received from the decking on to the substructure and are provided for distribution of the load evenly over the substructure material which may not have sufficient bearing strength to bear the superstructure load directly.

- **Substructure**

  This comprises piers and abutments, wing walls or returns and their foundation.

  - **Piers and Abutments**

    These are vertical structures supporting deck/bearing provided for transmitting the load down to the bed/earth through foundation.

  - **Wing walls and Returns**

    These are provided as extension of the abutments to retain the earth of approach bank which otherwise has a natural angle of repose.

  - **Foundation**

    This is provided to transmit the load from the piers or abutments and wings or returns to and evenly distribute the load on to the strata.

1.5 CLASSIFICATIONS OF BRIDGES

Bridges may be classified based on the flexibility of superstructure as fixed span bridges or movable bridges,inter-span relations as simple, continuous or cantilever bridges,form or type of superstructure,materials of construction used for superstructure.

Some of the classifications are illustrated below

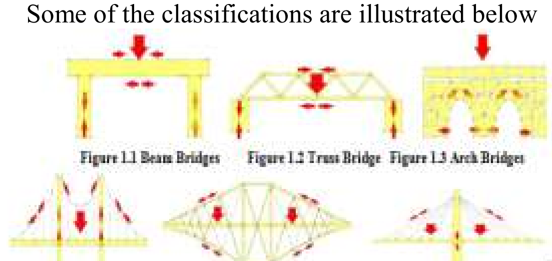

Figure 1.1 Beam Bridges Figure 1.2 Truss Bridge Figure 1.3 Arch Bridges

Fig 1.4 Suspension Bridge Fig 1.5 Cantilever Bridges Fig 1.6 Cable –stayed Bridge

According to the various longitudinal arrangements, cable-stayed bridges can be divided into three basic systems – radial, harp and fan pattern . However, except in very long span structures, cable configuration does not have a major effect on the behavior of the bridge.

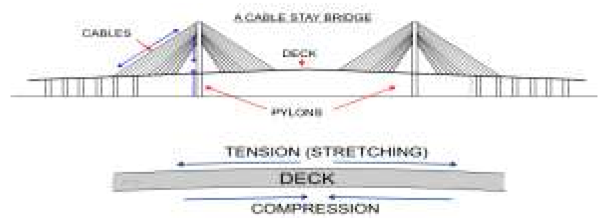

Figure1.7Notations InCable Stayed Bridge

Main Girders and Trusses

The three basic types of main girders or trusses presently being used for cable-stayed bridges are

1. Steel girders
2. Trusses
3. Reinforced or Pre-stressed concrete girders.

1.7 NOTABLE CABLE STAYED BRIDGES

A list of the India's prominent cable-stayed bridges constructed in various locations and their salient features (in decreasing order of their main span length) are listed below,

Table1.1 India's Prominent Cable Stayed Bridges

Rank	Name of the Bridge	Location	Height of Pylon	Longest Span	Year	Pylons
1	VidyasagarSetu	Kolkata	128m	457.2m	1992	2
2	Kota Chambal	Kota	125m	350.5m	2017	2
3	New Yamuna	Allahabad	154m	260m	2004	2
4	Bandra-Worli Sea Link	Mumbai	126m	250m	2010	2
5	NiveditaSetu	Kolkata	14m	350.5m	2007	2
6	Akkar Bridge	Akkar	54.60m	150m	1988	2

SEISMIC DESIGN CRITERIA

A Seismic analysis method in which the dynamic behaviour of a structure during an earthquake is obtained considering dynamic characteristics of the structure and characteristics of the ground motion by solving the equations of motion of the structure. Seismic

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design criteria for highway bridges have been improving and advancing based on research findings and lessons learned from past earthquakes.

LOADING DETAILS

Road bridges shall be divided into classes according to the loadings they are designed to carry.

- **IRC Class 70R Loading**

This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. Bridges designed for Class 70R Loading should be checked for Class A Loading also as under certain conditions, heavier stresses may occur under Class A Loading.

- **IRC Class AA Loading**

This loading is to be adopted within certain municipal limits, in certainexisting or contemplated industrial areas, in other specified areas, and along certain specifiedhighways. Bridges designed for Class AA Loading should be checked for Class ALoadingalso, as under certain conditions, heavier stresses may occur under Class A Loading.

OUTLINE OF THESIS

In this work, an attempt is made to study the seismic behaviour of cable stayed bridge with different cable arrangements under static and dynamic loads. The response of cable stayed bridges in terms of Bending moments, Shear Forces is determined under static loading. The dynamic characteristics such as displacement and axial forces are also determined by the nonlinear time history. The objective of this work is to assist the seismic behaviour of cable stayed bridge, for determining the design parameters (displacements and axial force) at Uttarkashi Location in Uttarakhand State, India.

LITERATURE REVIEW

9. **Agarwal, T.P.,** "Cable Stayed Bridges - Parametric Study", Journal of bridge engg, pp. 61-67, May 1997. The investigation shows that maximum cable tension decreases rapidly with the increase in the number of cables. In general, the effect of length of the central panel on the sagging moment is significant; on the hogging moment, the effect of length is not appreciable.

10. **Domenico Bruno, Fabrizio Greco, Paolo Lonetti, "**Static and Dynamic Nonlinear Modelling Of Long-Span Cable-Stayed Bridges" Vol. 1, No. 1, (2013), pp. 3-27. Sensitivity analyses are proposed in terms of dynamic impact factors, emphasizing the effects produced by the external mass of the moving system and the influence of both "A" and "H" shaped tower typologies on the dynamic bridge behavior.

11. **OluremiOlamigoke, "**Structural Response Of Cable-Stayed Bridges To Cable Loss"The effect of the cable loss due to blast and fire on the remaining cables, cable-deck connection, cross beam, longitudinal girder, deck and pylon were examined and compared to the code recommended method. The relationship between cable loss time and the natural period of the bridge was also investigated.

CONCEPT OF CABLE STAYED BRIDGES

The basic idea of a cable-stayed bridge is the utilization of high strength cables to provide intermediate supports for the bridge girder so that the girder can span a much longer distance. This introduces high compressive stresses in both the bridge girder and the towers. Technically this is an excellent design concept and aesthetically, this has a very soothing effect on the land scape because of its extreme slender appearance. "A cable-stayed bridge is a statically indeterminate structure with a large degree of redundancy.

3.1 BEHAVIOUR OF CABLE STAYED BRIDGE GENERAL

Because of having large dimensions and also great flexibility, cable-stayed bridges have long periods. Therefore, these types of bridges are different than other structures and this matter affects stayed bridges dynamic behavior. One of the items that influence the flexibility and the dynamic characteristics of the stayed bridges is the form of the cable's placement in vertical and horizontal positions. In general, cable-stayed bridges have many degrees of indeterminacy from static and dynamic points of view which are the result of the tension forces in the cables.

Cables are the most important elements in cable-stayed bridges; they carry the load from the superstructure to the tower and to the back stay cable anchorages. In addition to high tensile strength, they must also have high fatigue resistance and corrosion protection.

Usually these cables are used spiral with strands in cable bridges. Three types of strands (shown in Fig.) used in such bridges are:

1) Parallel wire strand

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2) Helically-wound strand
3) Locked coil strand

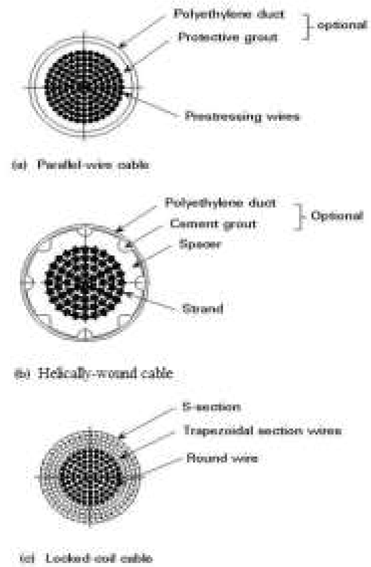

Figure 3.1 Types of strands

- **Fan System:**

With the fan configuration, all the cables connect to the top of the tower. This is a convenient cable configuration because all the cables have their maximum inclination; therefore the amount of material required in the girder is reduced. However, this configuration may cause congestion problems and the detailing may be complex (figure 3.2).

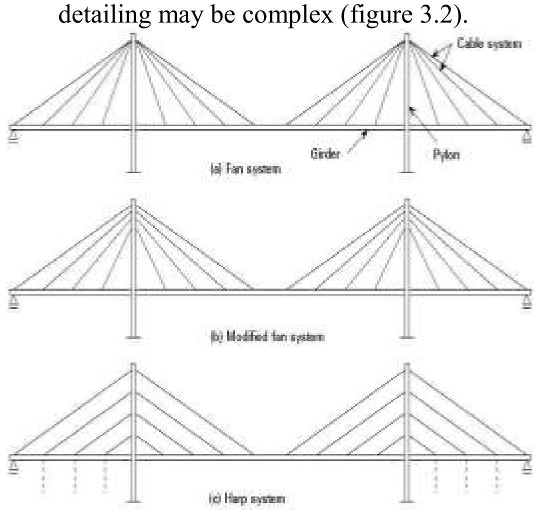

Figure 3.2 Types of Cable System

- **Single-plane system:**

This system is composed of a single cable layout along the longitudinal axis of the superstructure. This kind of layout is governed by torsional behaviour. The forces are created by unsymmetrical loading on the deck. The main girder must have adequate torsional stiffness to resist the torsion force.

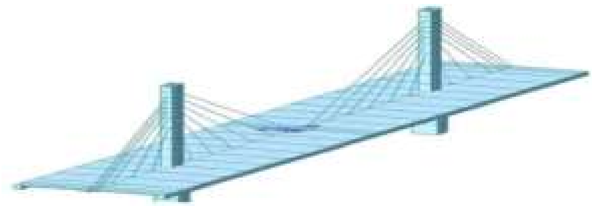

Figure 3.3 Single-Plane System

- **Two-plane system:**

If the tower is of the shape of an H-Tower, the layout is a two-plane vertical system. If only one tower is provided in the middle of the superstructure, then the layout is a two-plane, inclined system. The transverse layout has two options for the anchorage. The anchorage is located either outside of the deck structure or inside the main girder.The spacing of the cables varies according the chosen layout and the aesthetics requirements. The current trend is to employ many cables. Increasing the number of cables reduces the required stiffness of the girders, and results in more slender superstructure sections. Consequently, the load in each cable decreases, and the construction process is simplified.

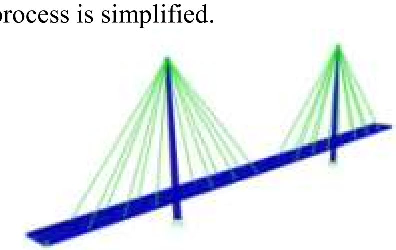

Figure 3.4 Two-Plane System

Deck systems are chosen according to the cable layout, the span dimensions, the material utilized, and the special requirements of the bridge. The most common types of deck are shown in figure 3.5. The qualities required for the deck also depend on the nature of the structure and its service requirements (Road or Rail Bridge).

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Of the deck types shown in figure, the most frequently used deck system is the box section deck because it provides convenient anchorages, and has significant torsional properties. It is common to utilize diagonal bracing and frame-type diaphragms to increase the rigidity of the box section. When selecting a deck, it is also important to consider maintenance and deflections limits.

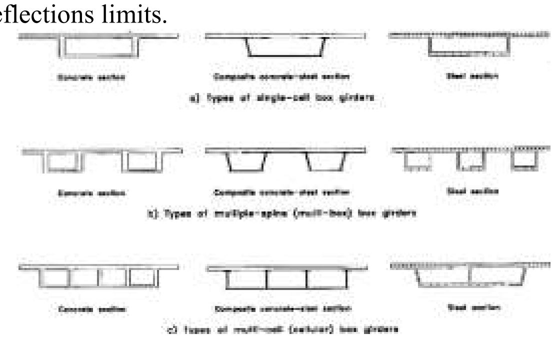

Figure 3.5 Types of decks

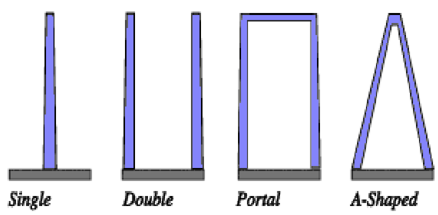

Figure 3.6 Types of Pylons

Components Of Cable Stayed Bridge

The following figure shows components of cable stayed bridge

Figure 3.7Components of Cable Stayed Bridge

EFFECTS AND DAMAGES

In many cases, the cause of damage can be understood only after detailed analysis, and, even then, the actual causes and effects may be elusive.In past earthquakes, the nature and extent of damage that each bridge suffered have varied with the characteristics of the ground motion at the particular site and the construction details of the particular bridge.

- No two earthquakes or bridge sites are identical.
- Despite these uncertainties and variations, one can learn from past earthquake damage, because many types of damage occur repeatedly.
- An effort is made to distinguish damage according to two classes, as follows:

➢ **Primary damage**

Damage caused by earthquake ground shaking or deformation that was the primary cause of damage to the bridge, and that may have triggered other damage or collapse.

➢ **Secondary damage**

Damage caused by earthquake ground shaking or deformation that was the result of structural failures elsewhere in the bridge, and was caused by redistribution of internal actions for which the structure was not designed.

The following sections are organized according to which element in the overall set of contributing factors appears to be the primary cause of the bridge damage

i. Effects of Site Conditions
ii. Effects of Structural Configuration
iii. Unseating at Expansion Joints
iv. Damage to Superstructures
v. Damage to Bearings
vi. Damage to Foundation

MODELLING OF CABLE STAYED BRIDGES

OVERVIEW OF SOFTWARE (SAP2000)

Modeling, analysis and design of bridge structures have been integrated into SAP2000 to create the ultimate in computerized engineering tools. The ease with which all of these tasks can be accomplished makes SAP2000 the most versatile and productive software program available on the market today.

CONSIDERATIONS

1. **<u>Bridge Geometry</u>**
   - Span length : 160 m
   - Bridge width : 8 m
2. **<u>Deck</u>**

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- Outside depth : 1m
- Outside width : 8m
- Flange Thickness : 0.2m
- Web Thickness : 0.3m

3. **Edge beam:**
   - Material : M45
   - Depth : 1m
   - Width : 1m
4. **Pylon**

   Pylon Bottom
   - Material : Fe345
   - Section type : Tube
   - Outside diameter : 2.4m
   - Wall thickness : 0.5m

   Pylon Top
   - Material : Fe345
   - Section type : Tube
   - Outside diameter : 1.2m
   - Wall thickness : 0.5m
5. **Stay Cables**
   - Material : Fe345
   - Diameter : 0.04m

Time History Function Used

The Uttarkashi Earthquake

Location : Tehri Region, Himalaya

Year : 20th Oct, 1991

Magnitude : 6.8 (on Richter scale)

Duration : 6.22 sec

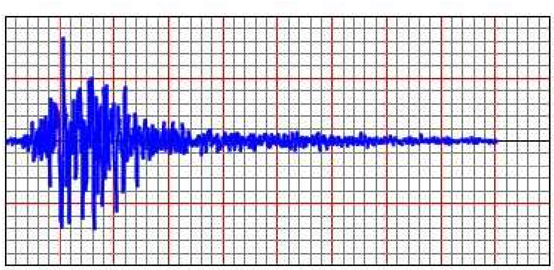
Excitation type : Short

Number of steps : 1996

Step size : 0.02

Time history type : Modal

Occurrence of maximum acceleration: 1.481 sec



Graph 4.1Shows the Dynamic behaviour of the ground motion in Uttarkashi

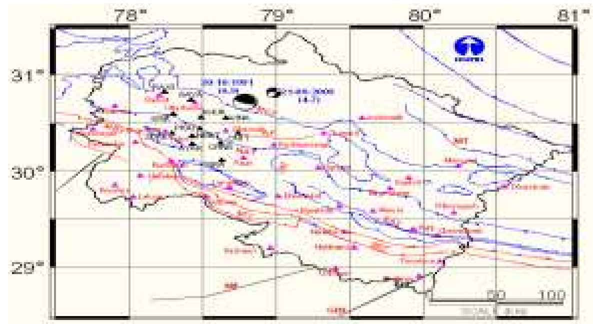


Figure 4.1 Seismotectonicmap of Uttrakhandalong with the location of instruments, strong motion (mangenta triangles) and short period (black triangles)

RESULTS AND DISCUSSIONS

5.1 GENERAL

To understand the static non-linear behaviour of (Fan, Semi Fan, Harp)cable-stayed bridges, the bridge models have been subjected to dead load , vehicle load and load combinations and their responses are studied. The parameters studied are – Bending moments and shear forces of beams for static loads. Similarly, dynamic behaviour has been investigated by applying load time histories of Uttarkashi (1991) to the above models. The parameters observed in this case are - maximum displacements in beams and maximum axial forces in cables

5.2 STATIC ANALYSIS OF CABLE STAYED BRIDGE

The static analysis is done for three types of cable stayed bridges. The table 5.1 to 5.3 shows variations in the forces and moments for the models.

Table 5.1 Shows Maximum Bending Moment, Shear Forces For Fan Arrangement

Beam No.	Shear Force (KN)		Bending Moment (KN-m)	
	Max.	Min.	Max.	Min.
51	314.160	313.299	1237.563	1230.713
50	-194.530	-195.345	1590.017	1582.246
49	-342.023	-342.905	1212.731	1205.251
48	-544.998	-545.398	-5831.906	-5836.934
47	496.906	496.012	-2317.572	-2353.415
46	399.195	398.268	2493.582	2485.956
45	352.647	351.673	3883.262	3874.851

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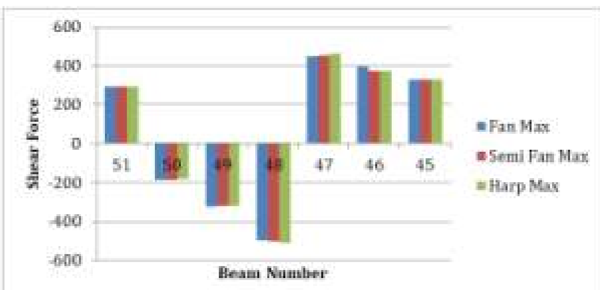
Table 5.2 Shows Maximum Bending Moment, Shear Forces For Semi Fan Arrangement

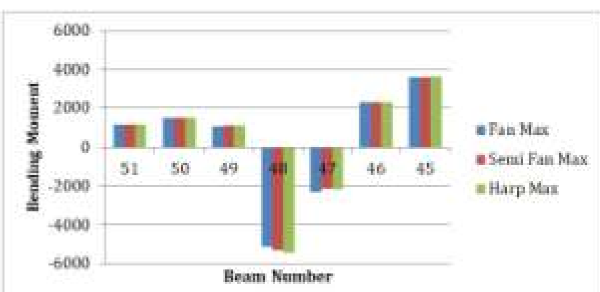
Beam No.	Shear Force (KN)		Bending Moment (KN-m)	
	Max.	Min.	Max.	Min.
51	315.030	314.220	1245.078	1238.284
50	-197.729	-198.542	1584.994	1577.284
49	-341.951	-342.828	1192.970	1185.589
48	-538.071	-538.461	-5680.019	-5684.914
47	485.054	484.167	-2312.982	-2318.776
46	400.980	400.054	2434.778	2427.225
45	352.647	351.675	3823.527	3815.183

Table 5.3 Shows Maximum Bending Moment, Shear Forces For Harp Arrangement

Beam No.	Shear Force (KN)		Bending Moment (KN-m)	
	Max.	Min.	Max.	Min.
51	313.948	313.148	1236.180	1229.470
50	-197.731	-198.543	1575.298	1567.774
49	-345.725	-346.597	1181.534	1174.420
48	-533.370	-533.748	-5488.119	-5492.870
47	483.150	482.269	-2484.322	-2490.161
46	423.165	422.232	2452.747	2445.248
45	352.647	351.678	3825.945	3817.620



Graph 5.1 Maximum Shear Force For Fan, Semi Fan And Harp Type Arrangements



Graph 5.2 Maximum Bending Moment For Fan, Semi Fan And Harp Type Arrangements

(a) Variation In Bending Moments

From above results we can say that maximum bending moment (M3) about horizontal axisoccurs in Harp type arrangement and minimum bending moment in Fan type arrangement.

(b) Variation In Shear Force

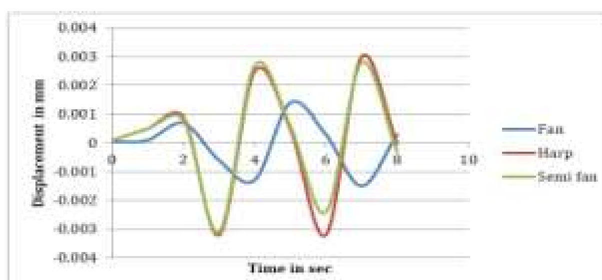
The absolute maximum shear force(V_2) about horizontal axis occurs in Harp type arrangement and minimum shear force in Fan type arrangement.

5.3 DYNAMIC ANALYSIS OF CABLE STAYED BRIDGE FOR DIFFERENT CABLE ARRANGEMENTS

The Non-linear Time-History analysis is done for Cable stayed bridge with different cable arrangements.Uttarkashi Earthquake ground motions have been considered in the analysis. From the analysis, displacement values and axial forces for cables are evaluated for the three models.

The Non-linear time history analysis gave the maximum and minimum displacement of the bridge. Below graphs shows the displacement of the structure.

5.3.1 JOINT DISPLACEMENTS



Graph 5.3 Time vs Displacement Longitudinal Displacement at joint 56

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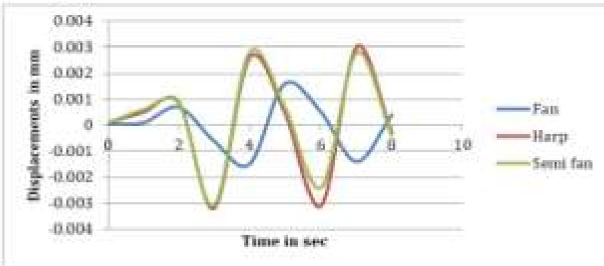


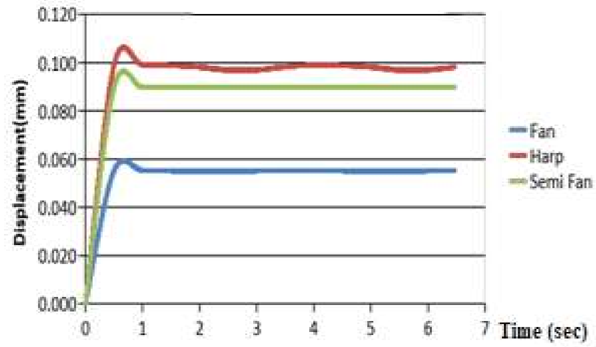
Graph 5.4 Time vs Displacement Longitudinal Displacement at joint 45

The response has been plotted with zero end at the roller supports and the 160 m at other end of the roller supports of the girder. From the following graphs, it can be ascertained that the edge beam displacements is minimum at the ends and maximum displacements are seen at the middle span for the 3 cable type arrangements.

5.3.2 MAXIMUM DISPLACEMENTS

Table 5.4Maximum displacements for 3 models

Harp	Semi Fan	Fan
0.09901	0.08972	0.05523
0.09901	0.08972	0.05521
0.09879	0.08972	0.05508
0.0981	0.08972	0.05486
0.09695	0.08972	0.05486
0.09699	0.08972	0.05508
0.09822	0.08972	0.05522
0.09901	0.08972	0.05521
0.09879	0.08972	0.05508
0.0981	0.08972	0.05486
0.09695	0.08972	0.05486
0.09699	0.08972	0.05508
0.09822	0.08972	0.05522

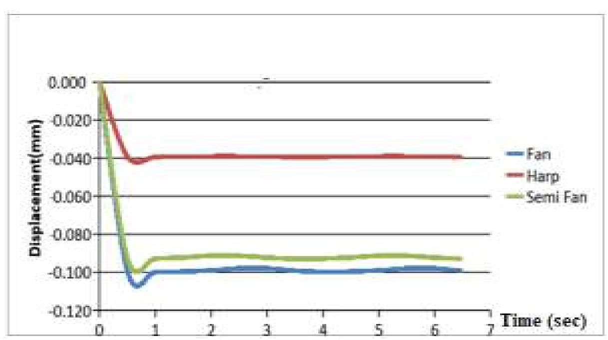


Graph 5.5 Overall Maximum Displacements

5.3.3. MINIMUM DISPLACEMENTS

Table 5.5 Minimum displacements for 3 models

Fan	Semi Fan	Harp
-0.09981	-0.08972	-0.03923
-0.09981	-0.08972	-0.03921
-0.0996	-0.08972	-0.03911
-0.09897	-0.08972	-0.03893
-0.09793	-0.08972	-0.03893
-0.09796	-0.08972	-0.03912
-0.09908	-0.08972	-0.03923
-0.09981	-0.08972	-0.03921
-0.0996	-0.08972	-0.03911
-0.09897	-0.08972	-0.03893
-0.09793	-0.08972	-0.03893
-0.09796	-0.08972	-0.03912
-0.09908	-0.08972	-0.03923



Graph 5.6 Overall minimum displacements

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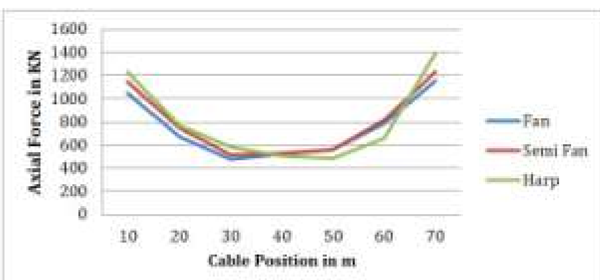
From the above graphs the maximum and minimum displacements are observed under Uttarkashi earthquake.Hence the displacement is more in Fan than Semi Fan and least in Harp arrangement.

5.3.4 AXIAL FORCES IN CABLES

The models were also checked for axial forces present in the stay cables. The response has been plotted with the outermost cable at the roller support end of the girder numbered one and subsequently increasing as we move towards the other end. The total number of cables in one plane is 12 with equal spacing of 10m throughout the length of the deck.

Table 5.6 Axial Forces for Three models

Cable Position	Axial Force in KN		
	Fan	Semi Fan	Harp
10m	1051	1147	1230
20m	676	752	772
30m	481	519	586
50m	558	563	484
60m	789	821	660
70m	1157	1233	1390



Graph 5.7 Axial Forces of three types of Cable arrangement

Cables which are the ones closest to the pylon and of the shortest length are having minimum axial force (tensile in nature). Cables which are away from the pylon and of the longest length are having maximum axial force.

Hence from the above graph Fan type cable stayed bridge have maximum Axial Forces than semi fan and Harp type arrangement.

CONCLUSIONS

6.1 GENERAL

In this study, an implementation of three types of cables arrangement for the design of the cable-stayed bridges have been considering Fan ,Semi Fan and Harp arrangements. The shear force, bending moment, displacements and axial forces for three types of cable-stayed bridges are compared with each other and the result of comparisons.

6.2 CONCLUSIONS

Seismic behaviour of cable stayed bridges with cable arrangements is a complicated subject study and requires extensive investigation. However, based on the limited study conducted in this work, the following conclusions could be drawn.

- Under static loads, Fan type cabled bridges were superior to the other models from the point of bending moment and shear force.
- In the result of Non-linear dynamic loads the smallest displacement on edge beams was in Fan type models and the biggest one was in Harp type models. In three cases, the maximum displacement is occurred at the mid-span of the structure.
- Total Axial forces happened in cables of Fan type model was 2% less than Semi-fan type model and 3% less than Harp type. Hence cables of different lengths experience varying axial forces depending upon their relative positions.
- From the results, we can infer that, the most efficient, out of all these three arrangements indicated that the Fan arrangement is more efficient than two other arrangements i.e. Semi fan type and Harp type.
- Fan type model is more efficient in withstanding the pressure effected by the ground motion i.e. seismic criteria and it offers more stability in terms of Axial forces and Displacements than the other two models i.e. Semi-fan type and Harp type.

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SEISMIC BEHAVIOR OF CABLE STAYED BRIDGES BY USING SAP2000

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