iJRASET
International Journal For Research in Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: VI Month of publication: June 2022

DOI: https://doi.org/10.22214/ijraset.2022.43805

# Response Spectrum Analysis of Suspension Cable Bridge and Tied Arch Bridge

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***Abstract—Bridges are recognition of a nation's infrastructure. Bridges play an important role in connecting people, good and transports. A bridge's close down can halt economic progress of any nation. Services those are no longer available can be simply completed with the help of bridges. Most advanced technology that are used for bridge design and construction are Building Information Modelling (BIM), Prefabrication and computer aided AI-based system. Various new construction materials are also being used as a replacement for traditional materials. A Tied-arch bridge is an arch bridge in which the outward-directed horizontal forces of the arch are borne as tension by a chord tying the arch ends, rather than by the ground or the bridge foundations. A Suspension bridge is a type of bridge in which deck is hung below suspension cables on vertical suspenders. Suspension Bridge consists of main span, side span, main cables, hanger ropes, pylons and deck. Tied arch bridge is type of bridge in which deck is below the arch and vertical suspender ropes. A tied-arch bridge is an arch bridge in which the outward horizontal forces of the arch caused by tension at the arch ends to a foundation are countered by equal tension of its own gravity plus any element of the total deck structure such great arch support. The arch have strengthened chord that run to a strong part of the deck structure or to independent tie-rods below the arch ends. This research presents the Response Spectrum analysis of Suspension Bridge and Tied-arch Bridge. The modelling is done using SAP 2000. Response Spectrum analysis is done and the deformation of both the bridges under dead load live load and earthquake load is studied. Axial force, Shear force Moment and Torsion values are observed and studied. Along with earthquake load vehicle load is also applied. According to IRC 006, vehicle loading of class 70R wheeled is applied.***
***Keywords—Suspension Cable Bridge, Tied Arch Bridge, SAP 2000, Response Spectrum Analysis***

## I. INTRODUCTION

The present work deals with Response Spectrum analysis of Suspension Bridge and Tied-arch Bridge. A Suspension bridge is a type of bridge in which deck is hung below suspension cables on vertical suspenders.

Design and analysis of Suspension cable bridge and Tied-arch bridge is done according to IS 456:2000, IS 800:2007, IS 1893:2016, IRC 006:2014. The Response Spectrum analysis is done considering that the bridges are located in zone IV. Main span of Suspension bridge is taken as 1000 m and that of Tied Arch Bridge is taken as 1800 m. The loads that are applied to the bridges are dead load, live load, super dead load, vehicle load and earthquake load.

After inserting grid, properties for various frame sections, cable sections and area sections are defined and model is created. Load patterns are assigned. After model creation the structure is analysed for dead load, live load, super dead load, vehicle load and earthquake load. Analysis results show us the deformed shape in application of dead load live load vehicle load and earthquake load. Parameters such as axial force, shear force, bending moment, can be studied and we can obtain the values on respective joints and members.

In the initial stage, a Case Study of Forth Road Bridge is taken which is a Suspension Cable Bridge in Switzerland. The design codes used for steel frame design is AISC 310-10 and design code used for concrete frame design is ACI 318-14. A Suspension cable bridge of main span 1006 m and side spans 408 m are used. The Suspension Bridge is modelled, designed and analysed for a live load of 5 $KN/m^2$ and super dead load of 1 $KN/m^2$. Super dead loads are the superimposed loads on a structure. The deformed shape of bridge under live load, dead load, is observed and axial force, shear force, and bending moment values are obtained for various members and joint.

In the final stage Suspension Cable Bridge and Tied arch bridge is designed for specific vehicle loads, earthquake load with zone factor 4, dead load and live load. Design code used for Steel frame design is IS 800:2007 and for designing concrete frame design is IS 456:2000. For Response Spectrum analysis the structure is assumed to be located in Zone IV with a zone factor of 0.24 and designed according to IS 1893(Part I):2016. Importance factor is 5 and response reduction factor is 1.5 and so the response spectrum scale factor is calculated as 2.943. According to IRC 6, Class 70 R wheeled loading is applied for vehicle load analysis. Bridges play an important role in connecting people, good and transports. A bridge's close down can halt economic progress of any nation. Services those are no longer available can be simply completed with the help of bridges. Shipping materials and good are transferred from one place to another through bridges. Therefore, Bridges need to be built strong so as to withstand its self-weight, vehicle load, seismic load, and wind load. Bridges needs to be designed for the worst case scenario for maximum strength and long life.

## II. OBJECTIVES

- To create a model of Suspension Cable Bridge using SAP 2000.
- To create a model of Tied arch Bridge using SAP 2000.
- To study the deformation of Suspension Cable Bridge and Tied arch bridge under the action of seismic loads and imposed loads.
- To study the axial force, shear force, bending moment.

Response Spectrum Analysis of Suspension Cable Bridge and Tied Arch Bridge will be done and the obtained results of bending moment and shear force will be compared to draw conclusion about which bridge is safer and economical.

## III. METHODOLOGY

### A. *Bridge dimensional Details*

| Dimensional Details | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Main span | 1000m | 1800m |
| Deck Height | 45m | 45m |
| Tower Height | 105m | 105m |
| Total Height | 150m | 150m |
| Deck Width | 12m | 12m |

### B. *Sectional Details*

| Sectional Details | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Column tube section | 120in x 120in x 1in | - |
| Cross Bearing | 96in x 36in x 1in | 96in x 36in x 1in |
| Steel Beam | 36in x 72in x 1in | 36in x 72in x 1in |
| Angle Section | 200mm x 200mm x 16mm | 200mm x 200mm x 16mm |
| Area Section | 225mm | 225mm |
| Main Cable | 590mm | - |
| Main Span Hanger Ropes | 57mm | 57mm |
| Side Span Hanger Ropes | 48mm | - |
| Arch Diameter | - | 1.8m |
| Column Support Diameter | - | 4m |

### C. *Design Parameters*

1) *Seismic Analysis-{IS 1893:2016}*
   Seismic Zone-IV
   Soil type-II
   Response Reduction factor-1.5
   Importance Factor-5
   Response Spectrum Scale Factor=I*g/R=1.5*9.81/5=2.943
2) *Vehicle Load Analysis-{IRC: 6-2014}*

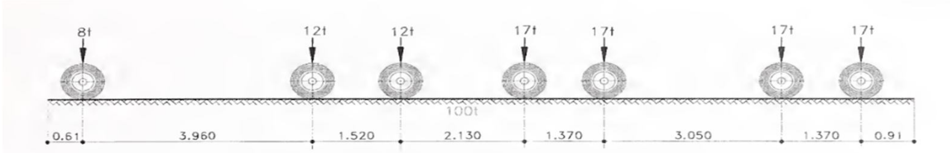


Figure 1. Class 70 R (Longitudinal Position)

Vehicle loading is taken according to IRC 6. Class 70R vehicle loading is assumed and the load on every axle at specified distance is taken as shown in above figure. The leading distance of any vehicle according to SP 2000 is taken as infinite and subsequent trailing distances are taken as per IRC 6. For every subsequent trailing distance loads in tonnes are entered in the software in vehicle class type in moving load case type. The distances are measured in meter and axle loads are measured in tonne.

*Load Cases:*
- Dead Load
- Live Load
- Super Dead Load
- Vehicle Load
- Earthquake Load
- Response Spectrum

The Bridge is modelled according to design parameters and various load cases are applied according to Indian standard and the bridge is analysed for Dead load, Live load, SDL, Earthquake load and Vehicle load. Live load of 5KN/$m^2$ and SDL of 1 KN/$m^2$ is applied and response spectrum analysis is done considering that the bridges are in zone 4 of Indian seismic zones with a zone factor of 0.24 and vehicle loading of Class 70R (wheeled). The Bridges are analysed for various load combinations and the results are obtained and compared to draw conclusion about bridges.

*Load Combinations:*
- 1.5(D+L)
- 1.2(D+L±Ex)
- 1.2(D+L±Ey)
- 1.5(D±Ex)
- 1.5(D±Ey)
- 0.9D±1.5Ex
- 0.9D±1.5Ey
- Envelope(addition of all load combinations and load cases)

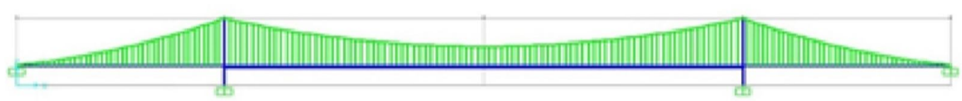

Figure 2. Modelling of Suspension Cable Bridge

Figure 3. Modelling of Tied Arch Bridge

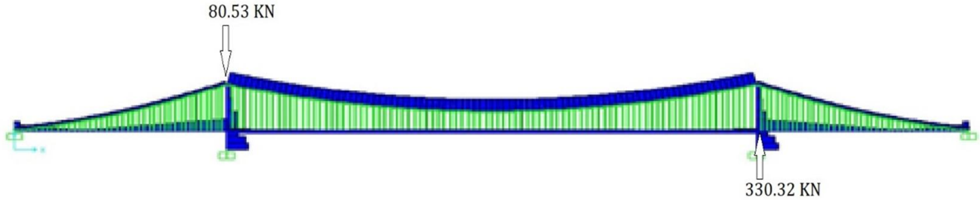


Figure 4. Axial Force Diagram of Suspension Cable Bridge due to Response Spectrum

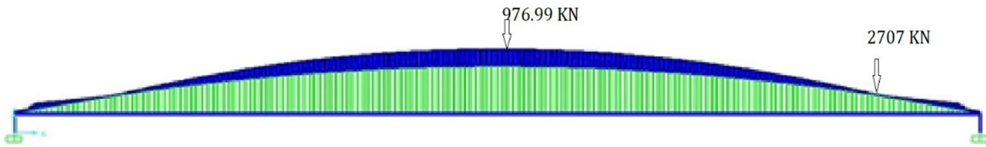


Figure 5. Axial Force Diagram of Tied Arch Bridge due to Response Spectrum

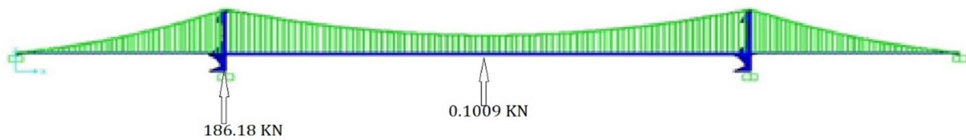


Figure 6. Bending Moment Diagram of Suspension Cable Bridge due to Response Spectrum

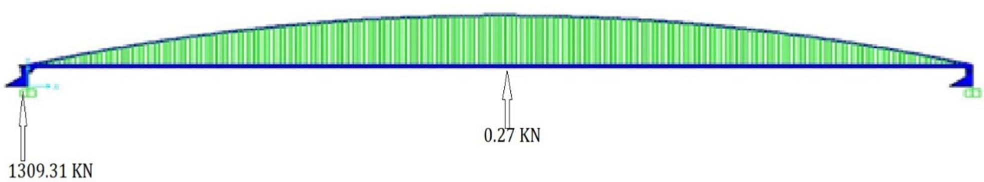


Figure 7. Bending Moment Diagram of Tied Arch Diagram due to Response Spectrum

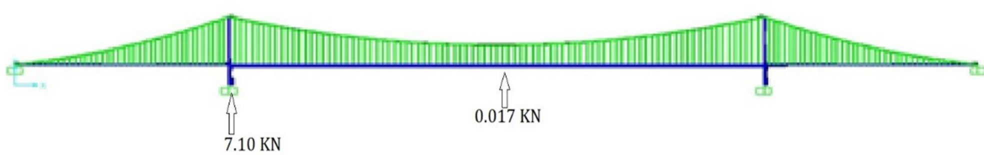


Figure 8. Shear Force Diagram of Suspension Cable Bridge due to Response Spectrum

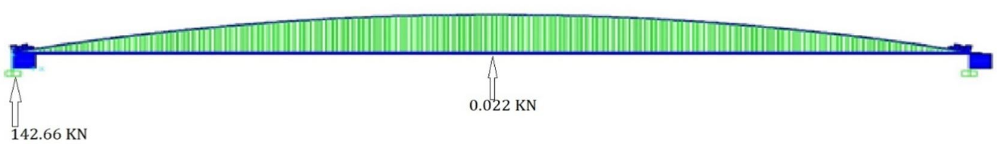


Figure 9. Shear Force Diagram of Tied Arch Bridge due to Response Spectrum

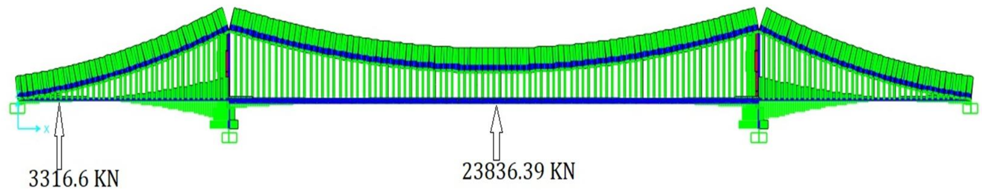


Figure 10. Axial Force Diagram of Suspension Cable Bridge due to envelope of all load cases

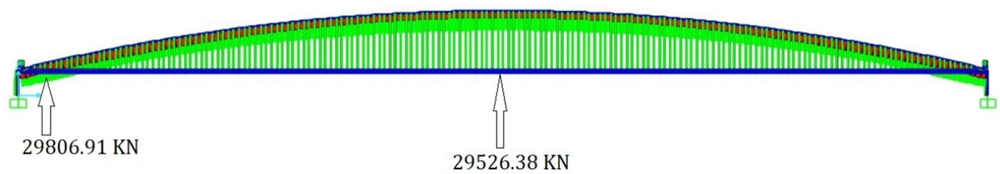


Figure 11. Axial Force Diagram of Tied Arch Bridge due to envelope of all load cases

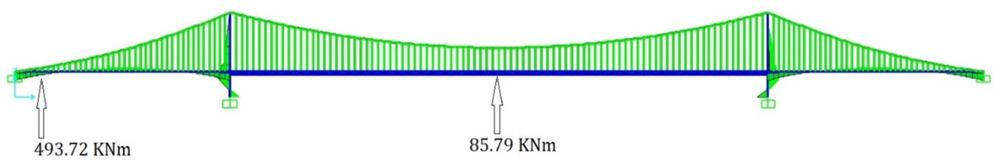


Figure 12. Bending Moment Diagram of Suspension Cable Bridge due to envelope of all load cases

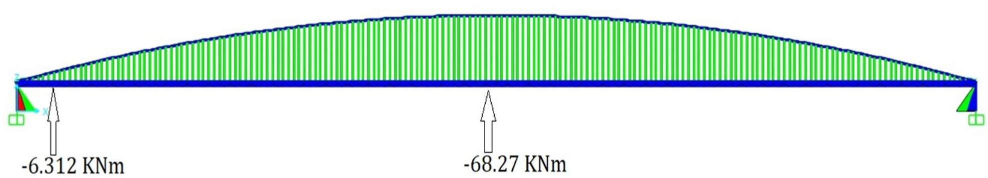


Figure 13. Bending Moment Diagram of Tied Arch Bridge due to envelope of all load cases

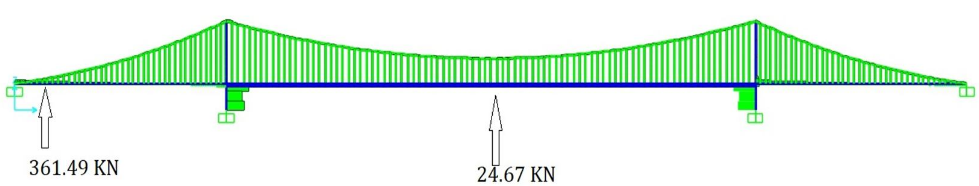


Figure 14. Shear Force Diagram due to envelope of all load cases

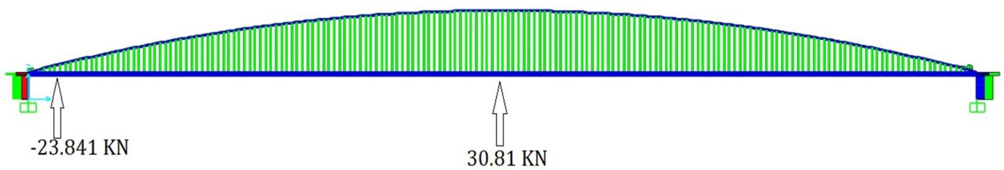


Figure 15. Shear Force Diagram due to envelope of all load cases

## IV. RESULTS

### A. *Support Values*

Table 2. Support Values - EQx

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment @ 0 m | 547.50 KN-m | 210598.00 KN-m |
| Shear Force @ 0 m | 68.823 KN | 2959.544 KN |

Table 3. Support Values - Vehicle Load Step 1

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment @ 0 m | 0.7496 KN-m | 67.5816 KN-m |
| Shear Force @ 0 m | 0.07 KN | -11.474 KN |

Table 4. Support Values - Load Combination 8{1.5(D+Ey)}

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment @ 25 m | 57724.19 KN-m | -7327088 KN-m |
| Shear Force @ 25 m | -3276.69 KN | -396046.67 KN |

Table 5. Support Values - Response Spectrum

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment @ 30 m | 186.18 KN-m | 1309.31 KN-m |
| Shear Force @30 m | 7.10 KN | 142.66 KN |

Table 6. Support Values - Envelope (Addition of all load cases and load combinations)

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment @ 50 m | 493.72 KN-m | -6.316 KN-m |
| Shear Force @50 m | 361.49 KN | -23.84 KN |

### B. *Centre span element @ 900m*

Table 7. Centre Span Element @ 900m - EQX

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment | -0.0199 KN-m | -0.0137 KN-m |
| Shear Force | -5.008E-03 KN | -6.329E-03 KN |

Table 8. Centre Span Element @ 900m - Vehicle Load Step 1

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment | 3.911E-04 KN-m | -8.5329E-03 KN-m |
| Shear Force | -1.0262E-04 KN | -1.422E-04 KN |

Table 9. Centre Span Element @ 900m - Load Combination 8{1.5(D+Ey)}

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment | -21.147 KN-m | -31.24 KN-m |
| Shear Force | 8.581 KN | -22.045 KN |

Table 10. Centre Span Element @ 900m - Response Spectrum

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment | 0.1009 KN-m | 0.2679 KN-m |
| Shear Force | 0.017 KN | 0.022 KN |

Table 11. Centre Span Element @ 900m - Envelope (Addition of all load cases and load combinations)

| Parameters | Suspension Cable Bridge | Tied Arch Bridge |
|---|---|---|
| Bending Moment | 85.79 KN-m | -68.27 KN-m |
| Shear Force | 24.67 KN | 30.81KN |

## V. CONCLUSIONS

Response Spectrum analysis of Suspension Cable Bridge and Tied Arch Bridge is carried out using SAP 2000. Bending moment, Shear force and Axial force at every point within the element can be easily obtained from the output of software once the program is analysed.

The Bending Moment and Shear force values for various loads and load combinations are obtained for both the bridges and they are compared to draw conclusion about which bridge is safer and economical.

From observing the above result tables for Bending Moment and Shear Force of both Suspension Cable Bridge and Tied Arch Bridge under Response Spectrum and Envelope of all load cases and Combinations following conclusions can be drawn:

1) At support due to Response Spectrum, Bending Moment of Tied Arch Bridge is 7.03 times more than that of Suspension Cable Bridge. Hence Suspension Cable Bridge is safer and economical.
2) At support due to Response Spectrum, Shear Force of Tied Arch Bridge is 20.1 times more than that of Suspension Cable Bridge. Hence Suspension Cable Bridge is safer and economical.
3) From left at a distance of 50 m due to Envelope, Bending Moment of Tied Arch Bridge is -6.316 KN-m. As point of contra flexure is obtained the bridge needs to be redesigned for new sections to achieve safety and economy. Suspension Cable Bridge is preferred.
4) At Centre Span at a distance of 900 m due to Response Spectrum, Bending Moment of Tied Arch Bridge is 2.6 times more than Suspension Cable Bridge. Hence Suspension Cable Bridge is safer and economical.
5) At Centre Span at a distance of 900 m due to Response Spectrum, Shear Force of Tied Arch Bridge is 1.3 times more than Suspension Cable Bridge. Hence Suspension Cable Bridge is safer and economical.
6) At Centre Span at a distance of 900 m due to Envelope, Bending Moment of Tied Arch Bridge is -68.27 KN-m. . As point of contra flexure is obtained the bridge needs to be redesigned for new sections to achieve safety and economy. Suspension Cable Bridge is preferred.
7) At Centre Span at a distance of 900 m due to Envelope, Shear force of Tied Arch Bridge is 1.24 times more than Suspension Cable Bridge. Hence Suspension Cable Bridge is safer and economical.
8) From above it is clear for equal bridge spans, width, height and similar sections having same material properties Suspension Cable Bridge is safer than Tied Arch Bridge and it is also more economical than Tied Arch Bridge.

## VI. ACKNOWLEDGEMENT

"I take this opportunity to thank Prof. Dr. V. R. Rathi my guide who has been a constant source of inspiration and also took interest in each step of the project development. I am also thankful to Dr. P. K. Kolase, Head, Department of Civil engineering for his timely guidance regarding the finalization of topic. I am also thankful to our college principal Dr. S. M. Gulhane and the staff of department of civil engineering for providing support throughout this work."

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