FATIGUE LIFE ESTIMATION OF STEEL ARCH BRIDGE BY USING S.N CURVE METHOD

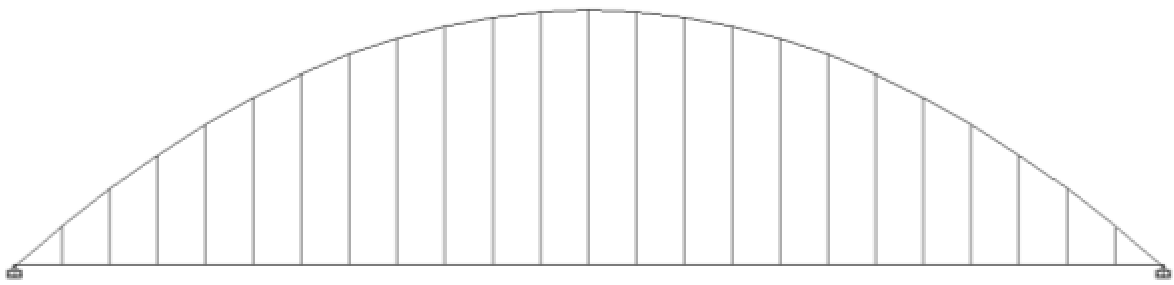
[1]K.PRUDHVI, [2]Y.NAGENDRA BABU, [3]N. VENU, [4]V.UMA MAHESH, [5]V.YESWANTH, [6] Y.SANTOSH

[1]ASSISTANT PROFESSOR, [2,3,4,5,6] B.Tech Student Scholar
DEPARTMENT OF CIVIL ENGINEERING, MVRCOE, PARITALA.

***Abstract*— Fatigue is the effect of alternating stresses acting for a long time over structural members. Such phenomenon is very common in bridges. In one passage of vehicle, generated stress may be very small but its cumulative effect will reduce the life span of the structure. In the present study fatigue life estimation of steel arch bridge with various hanger arrangements has been studied considering the passage IRC 70 vehicles. Finite Element Model of the steel arch bridge has been created in SAP2000 and stresses in the vulnerable members have been determined for different velocity of the vehicle. The approach is based on Miner's hypothesis of damage accumulation.**

I. INTRODUCTION

An arch is sometimes defined as a curved structural member spanning an opening and serving as a support for the loads above the opening primarily by the axial compression which is eventually transferred to abutments or ties depending on type of arch bridge. Usually arch bridges are subjected to multiple loads (dead, live, wind and temperature loads, etc.) which will produce bending stresses in the arch rib that are generally small compared to axial compressive stresses. The damage (or) failure of materials under cyclic loads in engineering applications is called fatigue damage. Fatigue failure generally take place at stress much lower than ultimate stress(yield stress)-at a stress which is safe on the basis of static failure analysis. The failure is due primarily to the repeated stress from a maximum to a minimum. The fatigue strength is the stress level that a material can endure for N cycles. A plot of fatigue strength versus the number of cycles to failure gives an S-N curve. Bridge structures that have long service years or long spans, or that are frequently subjected to heavier loadings than their design loads, are greatly affected by heavy traffic induced vibrations. The most important parameters influencing the dynamic stresses in the bridge are: the frequency characteristics of bridge structures (i.e., the length, mass, and rigidity of individual members), the frequency characteristic of vehicles, weight of the vehicles, the damping in bridges and in vehicles, the velocity of vehicle movement, the track irregularities, and so on.The vehicles affect the bridges not only by vertical forces, but also by movements which generate longitudinal and transverse horizontal forces. This results in an increase or decrease of bridge deformations when compared to that due to static forces. Many bridge engineers treat such vibration problems by considering only impact factors, which state how many times the static effects must be multiplied in order to cover the additional dynamic loads, specified in their current design codes, even though the vibrations may depend on such factors as vehicle and bridge dynamic characteristics, vehicle speeds, and deck conditions.In general, two different methods can be used in order to carry out a fatigue assessment, namely, the S-N method and the fracture mechanics method. The former, which is based on the S-N curve of the fatigue detail in question, is used in conjunction with Miner's rule (Miner 1945). By contrast, the latter method considers explicitly the growth of fatigue cracks and for this reason, it is more appropriate in cases where a fatigue crack has been detected. Since crack detection is mostly case-specific, most of the fatigue assessment methodologies that have been developed for railway bridges are based on the S-N approach.



Front view of arch bridge with parabolic profile

II. MODELLING OF ARCH BRIDGES

Test model

An arch bridge of span 120m is tested for different rises with different profiles of arch and hanger arrangements in SAP2000. The rise-span ratio is varying from 0.1 to 0.25 (1/10 to 1/4). First dead load analysis is carried out. Then in every case it is loaded by an IRC70R, wheeled single lane load. Combined effect of dead load and live load has been found. The ends of the arch rib are

fixed and stringers are simply supported on both sides over RCC abutment. The width of the deck is 7m out of which 5.1m is carriage way. The spacing between stringers is 1.725m. Thickness of deck is 250mm uniform.
The main components of bridge are arch rib, stringers, cross beams, bottom chord lateral bracing, hangers or verticals and top chord lateral bracing.

S.no	Type of properties	Dimensions (mm)
1	**Stringer-1**	Top flange -220x12 Web -476x10 Bottom flange - 220x12
2	**Stringer-2**	Top flange -220x12 Web -476x10 Bottom flange-220x12
3	**Cross girder-1**	Top flange -450x16 Web -464x16 Bottom flange -450x20
4	**Cross girder-2**	Top flange -280x12 Web -476x12 Bottom flange -280x25
5	**Bottom bracing-1**	Bottom flange -100x12 Web -100x12
6	**Bottom bracing-2**	Bottom flange -75x10 Web -75x10
7	**Top bracing**	Top flange -200x20 Web -270x10 Bottom flange-200x20
8	**Hanger-1**	Top flange -300x16 Web -348x10 Bottom flange -300x16
9	**Hanger-2**	Top flange -300x12 Web -356x10 Bottom flange-300x12

10	**Channel**	Top flange -50x20 Web -160x15 Bottom flange-50x20
11	**Arch-1**	Top flange -760x20 Web -1262x40 Bottom flange-760x20
12	**Arch-2**	Top flange -760x12 Web -1248x20 Bottom flange-760x12
13	**Arch-3**	Top flange -680x32 Web -1224x40 Bottom flange-680x32

Finite element modeling of bridge

Finite element model has been widely accepted as powerful tool in the engineering world for accurate physical representation of structure. The Finite Element modelling of bridge and modelling assumptions have been developed using *SAP2000*, which is used to determine the response of bridge structures due to the weight of its components and vehicle live loads with different constant speed. The bridge to be analysed is modelled with Frame elements representing the superstructure, substructure and other components of interest. Frame-element internal forces due to the influence of Vehicle live loads are determined. Other element types (shells and links) are used depending on the requirements.Frame element is defined with two nodes and it activates all the six degrees of freedom at each node. And Shell elements with 4 nodes are considered. The Finite Element modelling of parabolic steel arch bridges with different rises (rise-span ratio varying from 1/4 to 1/10) and having span 120m have been developed using SAP2000. A circular steel arch bridge with different rise-span ratio having span 120m has been developed in SAP2000 using Finite Elements. The materials are M30 grade concrete and FE250 steel.

Analysis of Bridge

Three basic analyses has been performed, static, modal and dynamic analysis using sap 2000 version 15.

Static analysis

Static analysis of steel arch bridge has been performed using SAP2000 version 15. The loading considered in the study is of type: IRC 70 R wheeled vehicle. The static analysis has been done to obtain the effect of dead load by assigning material properties of each component.

Modal analysis

Modal analysis has been performed to determine the vibration modes of a structure and its natural frequencies. These modes are useful to understand the dynamic behaviour of the structure under dynamic loading. The modal analysis has been carried out using eigenvector analysis which has the basic equation as follow:

$$[K - \Omega^2 M]\phi = 0$$

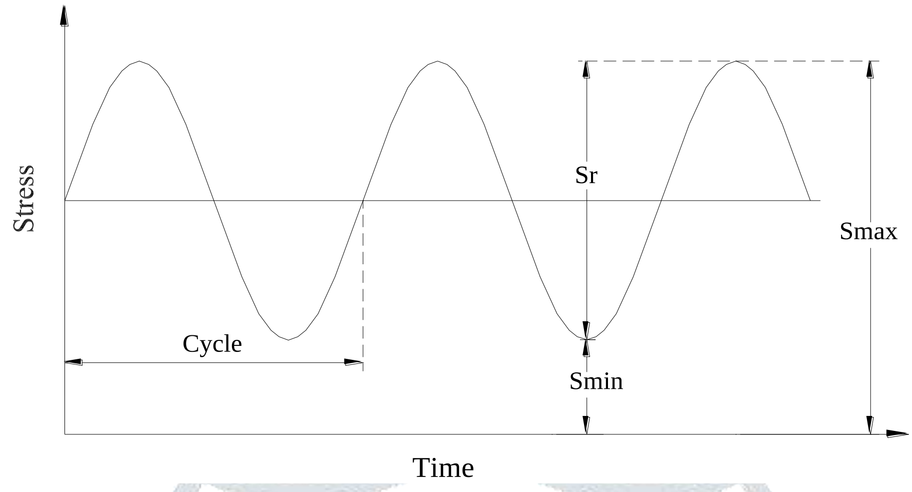
In which K is the stiffness matrix, M is the diagonal mass matrix, Ω^2 is the diagonal matrix of eigenvalues, Φ is the matrix of corresponding eigenvectors (mode shapes).

Dynamic analysis

The most important factor to cause structural fatigue damage is stress fluctuation, which mainly induced by traffic loading. In order to obtain accurate and reliable stress time histories, structural characteristics must be well identified. The following procedures are used for the present dynamic analysis of bridge.

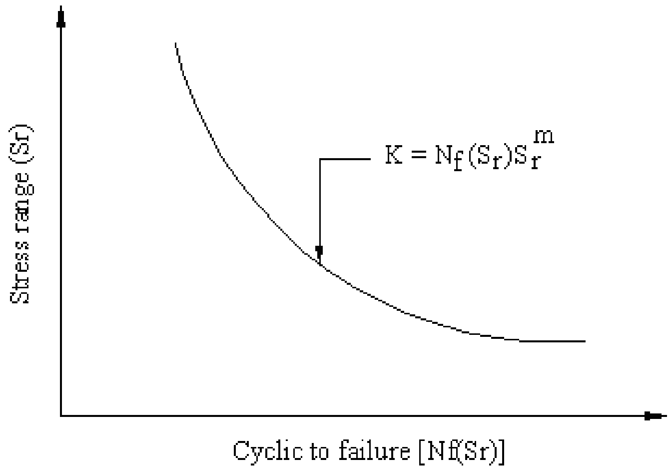
In dynamic analysis of bridge, loading, IRC 70 R wheeled vehicle was employed. The linear time-history due to a constant different vehicle speed in the range of 60 Kmph to 100 Kmph were obtained. In the present work, Rainflow cycle counting method has been applied to identify the stress cycles responsible for damage accumulation in the structure. Standard algorithm has been used to calculate the expected Rainflow cycles, which are used for fatigue life evaluation.

We used the term fatigue to describe damage accumulation, which is measured by damage function D (t). This has been used to describe progress toward failure whether or not that progress is observable. The damage function D (t) is presumed to start zero value for new structure and is normalized to be unity when failure occurs. Furthermore, it is a non decreasing function of time. If some function goes monotonically from zero at t=0 to 1 at t=T (T is the failure time), then f (t) is one possible choice of damage function. However, $f^n(t)$ for any positive n also satisfies the condition of damage function.



A typical stress history for the constant amplitude loading

Thus the result of a constant amplitude fatigue test is often described by two bits of information. The stress range, which is denoted by Sr and number of cycles to failure, denoted by N_f. A typical experimental investigation of constant amplitude fatigue for a specimen of given configuration and material involves a large number of tests. The test results are usually presented in the form of S-N curve with the stress range on the ordinate and the number of cycles on the abscissa.



S-N curve

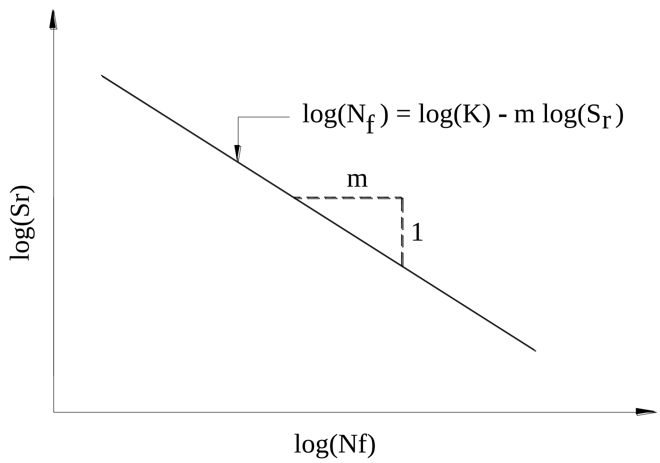
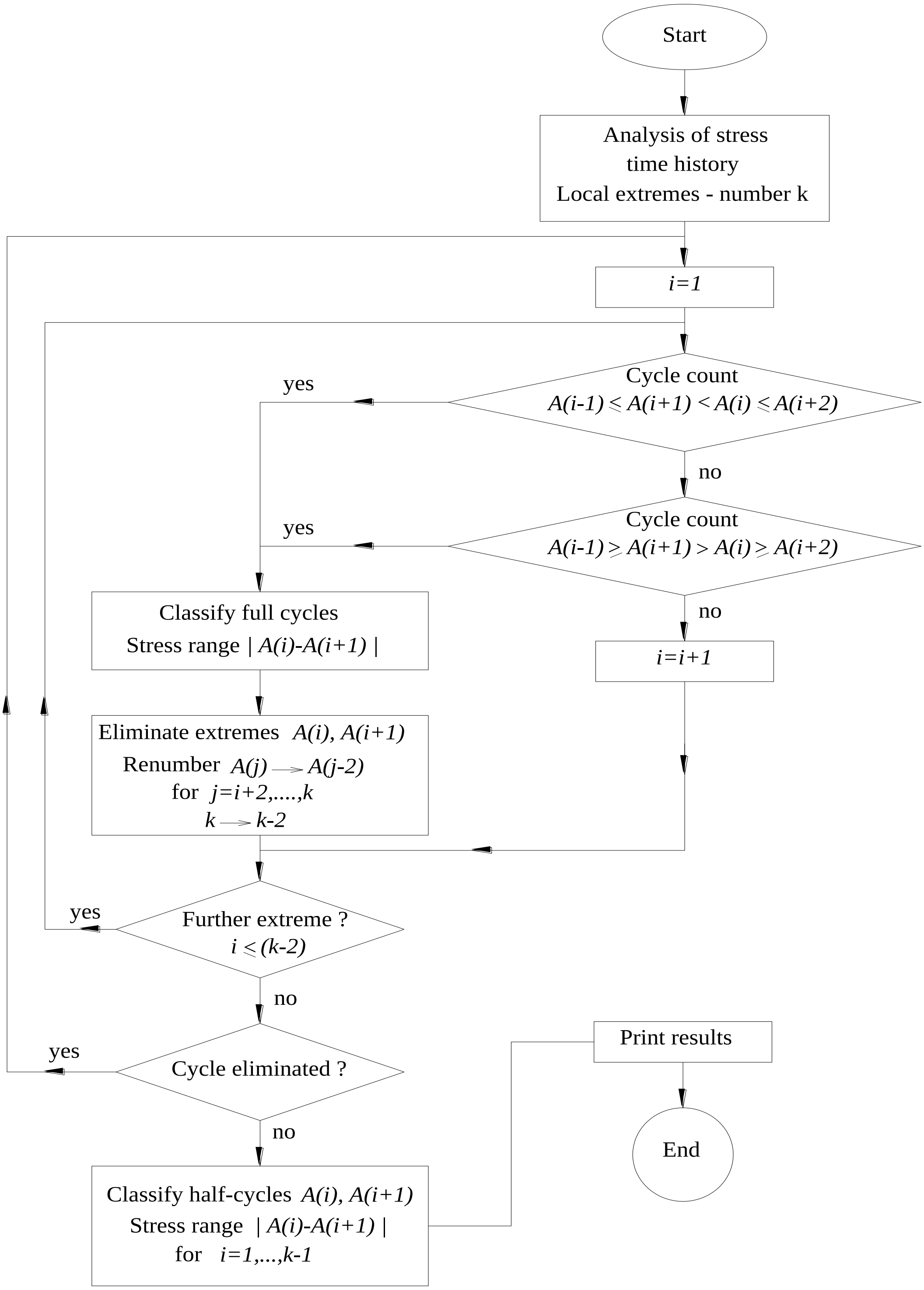


Figure 3.1 S-N Curve on log-log plot

The flow diagram of the computer program for the “Rainflow Counting” method is illustrated in Figure

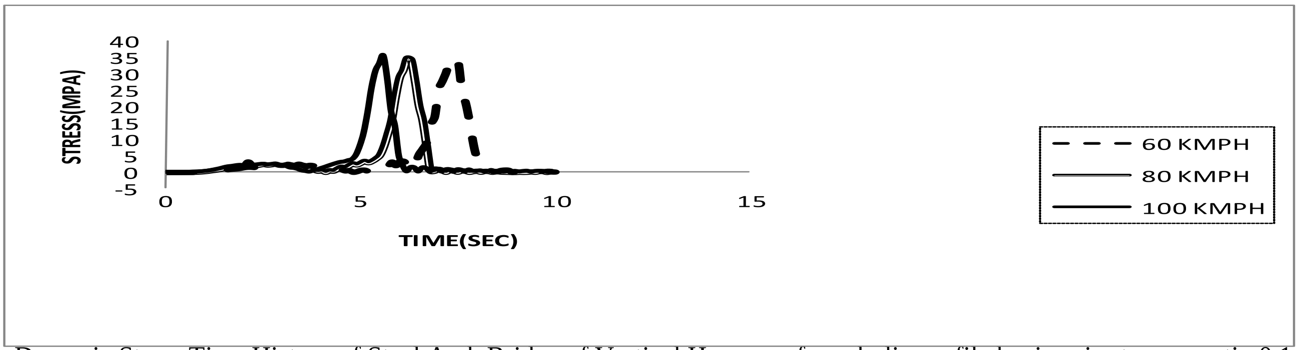


Flow diagram of the computer program for the Rainflow counting method

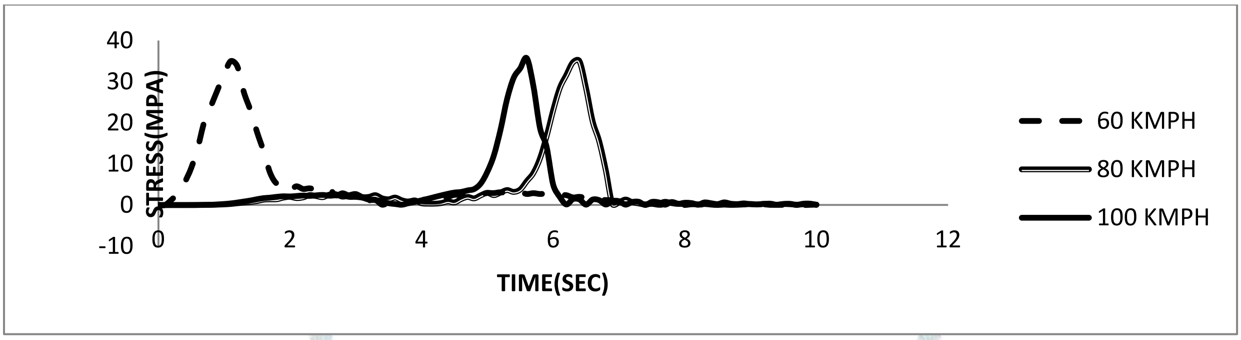
III. FIGURES AND TABLES

Dynamic Force Time Histories

Flexural stress time history of the critical hanger of the bridge has been considered for the evaluation of fatigue damage. The time-history is obtained by direct integration. The speed of the vehicle has been considered in the range of 60 km/h to 100 km/h. The vehicle loading employed here for determination of stresses are IRC 70 R wheeled loading. Force time history for vertical frame elements of steel arch bridge of different profiles having vertical hanger arrangements obtained from the dynamic analyses are shown in the following figures.



Dynamic Stress Time History of Steel Arch Bridge of Vertical Hangers of parabolic profile having rise to span ratio 0.1.



Dynamic Stress Time History of Steel Arch Bridge of Vertical Hangers of circular profile having rise to span ratio 0.1.

In order to determine the amount of damage suffered by the bridge section over a specified time period, a stress range frequency histogram is to be found from stress time history. For the fatigue of bridges, it is important to know the number of individual stress ranges due to traffic loads per unit of time, e.g. per day or per year. For this purpose, the stress ranges are classified into several classes and the number of stress ranges or stress cycles is ascertained in every class. In this way the histogram of stress range frequency or stress spectrum is obtained.

FATIGUE LIFE

Fatigue life of the bridge is evaluated using approache.

1. Miner's Damage criteria using S-N curve approach

Fatigue life of steel arch bridge of vertical hanger of parabolic profile having rise to span ratio 0.1.

Velocity (Kmph)	Fatigue life in years (m=4)	Fatigue life in years (m=4.1)	Fatigue life in years (m=4.2)
60	294.05	150.86	125.51
80	190.23	124.74	104.75
100	152.52	104.95	101.11

Fatigue life of steel arch bridge of vertical hanger of parabolic profile having rise to span ratio 0.25.

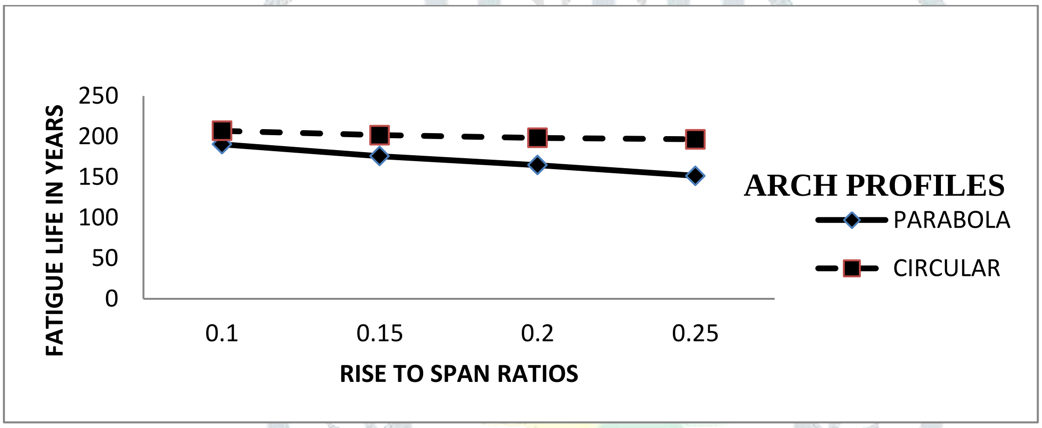
Velocity (Kmph)	Fatigue life in years (m=4)	Fatigue life in years (m=4.1)	Fatigue life in years (m=4.2)
60	217.6	194.02	168.06
80	151.41	144.31	121.02
100	137.83	114.64	110.51

Fatigue life of steel arch bridge of vertical hanger of circular profile having rise to span ratio 0.10.

Velocity (Kmph)	Fatigue life in years (m=4)	Fatigue life in years (m=4.1)	Fatigue life in years (m=4.2)
60	304.99	253.74	211.21
80	282.23	234.82	195.45
100	253.78	211.15	175.75

Fatigue life of steel arch bridge of vertical hanger of circular profile having rise to span ratio 0.25.

Velocity (Kmph)	Fatigue life in years (m=4)	Fatigue life in years (m=4.1)	Fatigue life in years (m=4.2)
60	390.87	325.21	270.69
80	337.96	281.19	235.23
100	291.92	242.88	202.16



Fatigue life of vertical hangers having different profiles for various rise to span ratios at 80 kmph.

CONCLUSION

1.The estimated fatigue life using S-N curve approach in the vertical hanger having parabolic profile of steel arch bridge from 101-294 years with rise to span ratio in between 0.1-0.13, 100-271 years with rise to span ratio in between 0.15-0.19, 120-251years with rise to span ratio 0.2, 110-217 years with rise to span ratio 0.25 for two types of loading and three vehicle speeds considered in study.

2.The estimated fatigue life using S-N curve approach in the vertical hanger having circular profile of steel arch bridge from 101-285 years with rise to span ratio in between 0.1-0.13, 116-271 years with rise to span ratio in between 0.15-0.19, 102-257years with rise to span ratio 0.2, 106-242 years with rise to span ratio 0.25 for two types of loading and three vehicle speeds considered in study.

3.In case of vertical hanger arrangement, increase in rise to span ratio results decrease in fatigue life for parabolic and circular arch profiles, circular profile shows more fatigue life..

4. Fatigue life decreases with increase in the vehicle weights and velocities.

5. The fatigue constant ‘m’ appearing in S-N curve relationship plays a significant role in estimation of life. A small variation of the constant m (from 4 to 4.2) has been significant to alter the fatigue life.

REFERENCES

[1] Fryba, L., “Dynamics of railway bridges”, Thomas Telford, Czech Republic.
[2] Hahin. C., South. M.J., Mohammadi. J.,“Accurate and rapid determination of fatigue damage in steel bridges” Journal of Bridge Engineering ASCE Vol.119, pp150-168,1993.
[3] Miner, M. A. “Cumulative Damage in Fatigue.” Journal of Applied Mechanics, Vol. 12, No. 3, 1945, pp. 159–164.

[4] Zwerneman, F.J., and Frank, K.H., “Fatigue damage under variable amplitude loads” Journal of Structural Engineering ASCE, Vol.114, pp 67-83, 1993.

[5] Mohammadi, J., and Polepeddi, R.,’ Bridge Rating with Consideration for Fatigue Damage from Overloads ‘, Journal of Bridge Engineering, Vol. 5, pp 259-265,2000.

[6] Yen, B., Hodgson, I., Zhou, Y., and Crudele, B. (2013). “Bilinear S-N Curves and Equivalent Stress Ranges for Fatigue Life Estimation.” Journal of Bridge Engineering. Vol 18(1), pp 26–30, 2011

KOTA PRUDHVI has received his B.TECH degree from Amara Engineering College , narasaroapet and M.TECH degree from BAPATLA Engineering College. At present he is working as assistant professor in M.V.R. College of Engineering, Paritala, Krishna dt, A.P. He is a life member of international association of engineers (IAENG).

Y. Nagendra Babu was born in nakkalam peta in 1993. He is currently pursuing B.Tech Degree in the stream of civil engineering in M.V.R college of engg & tech, paritala.He is member in IGS

N.Venu was born in chowtapalli in 1995. He is currently pursuing B.Tech degree in the stream of civil engineering in MVR College of engg & tech, paritala**.** He is member in IGS

v.Uma Maheswara rao was born in Atkuru in 1995 . He currently pursuing his B.Tech degree in the stream of civil engineering in MVR college of engg & tech ,paritala**.**

Y.YESWANTH was born in moguluru in 1995. He is pursuing B.Tech final year in the stream of civil engineering in MVR college of engg& tech, paritala.

Y.SANTOSH was born in vijayawada in 1995. He is purusing his final year in the stream of civil engineeri ng. in MVR college of engg and tech , Paritala.