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Fatigue Analysis of 74M Open Web Girder Truss

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Abstract: As the population in the country is increasing with each day and specially in the metropolitan city the population is far beyond expected with the resources increasing very gradually which cannot meet the present demand at any cost. Roads are one of the essentials for metropolitan city. Hence the road should be such designed that it should meet the demand of the population for at least 50 years from the date of construction .Since traffic movement is continuous on the Road over bridges, it requires to be checked for fatigue criteria which is a very important parameter when continuous heavy traffic movement throughout the day is witnessed. It has been seen that the cracks develop at the supports in case of road over bridges because of heavy vehicular traffic movement throughout the day. Hence designing the structure after consideration of fatigue criteria becomes very essential for long life of the foot over bridge.
Keywords: Open Web girder, Truss, Road Over Bridge, manual, Stress, Stress Range, fatigue criteria, Fatigue Analysis.

I. INTRODUCTION

It includes introduction of the topic, defines research problem and relevant required parameters, states objectives and future scope of the study.

A. Open web Girder

It is generally a steel truss structure which is open from top. Open web girder is most probably a truss type of structure. The general view of open web girder is as follows.
This open Web Girder is generally used in Road over bridges and Rail over bridges.

Fig 1. General appearance of Open Web Girder

B. Fatigue

Fatigue in metals is the process of initiation and growth of cracks under the action of repetitive tensile loads. If crack growth is allowed to go on long enough, failure of the member can result when the uncracked cross-section is sufficiently reduced such that the member can no longer carry the internal forces for the crack extends in an unstable mode. The fatigue process can take place at stress levels that are substantially less than those associated with failure under static loading conditions. The usual condition that produces fatigue cracking is the application of a large number of loads Cycles.
Fatigue failures may be classified as high-cycle and low-cycle fatigue failures. Under high cycle fatigue, the material deforms primarily elastically, and the number of cycles for failure, or the failure time, is characterized in terms of the stress range. Low-cycle fatigue can be characterized by the presence of macroscopic cyclic plastic strains as evidenced by a stress–strain hysteresis loop. Depending on the material strength and ductility, the upper limit of the low-cycle fatigue regime may be from 100 to 100,000 cycles or more. For common ductile structural materials, the Low-cycle fatigue regime is generally limited to less than 50,000 cycles.
Crack growth in metals requires two existing conditions: existing flaws and tensile stresses. This crack growth can be delineated into three distinct regimes: initiation, steady-state propagation and unstable fracture.

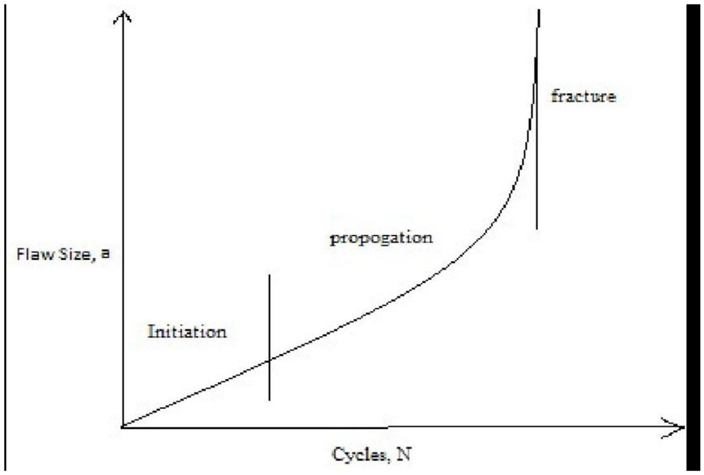

Fig. 2 – Fatigue Regimes

The process of fatigue failure starts with dislocation movements, eventually forming persistent slip bands that nucleate short cracks. The essential conditions for fatigue failure are cyclic tensile loads, stress levels above a threshold value, and a flaw in the material.

C. Necessity for Fatigue Assessment

1) Members supporting lifting or rolling loads
2) Member subjected to repeated stress cycles from vibrating machinery,
3) Members subjected to wind induced oscillations of a large number of cycles in life, and
4) Members subjected to crowd induced oscillations of a large number of cycles in life

The phases of fatigue are as follows

a) Crack initiation
b) Crack growth
c) Crack propagation
d) Final rupture.

D. Factors affecting Fatigue Life

1) Material defects
2) Surface roughness and surface treatments
3) Imperfection in assembly or functionality requirements in design
4) Size
5) Loading type
6) Harsh environments
7) Damage in service
8) Poor maintenance and improper repair
9) The number of cycles of loading
10) The stress range at the location

E. Fatigue Strength

The fatigue strength of the standard detail for the normal or shear fatigue stress range, is given below

Normal stress range

when Nsc ≤ 5 X 106

When 5 x 106 ≤ Nsc ≤ 108

$$f_f = f_{fn} \sqrt[3]{5 \times 10^6 / N_{sc}}$$

F. Fatigue Assessment

The design fatigue strength for Nsc life cycles may be obtained from the standard fatigue strength for Nsc cycles by multiplying with correction factor, for thickness and dividing by partial safety factor given in code.

where

Ymft & Yfft = Partial safety factors for strength and load respectively and

f = actual fatigue stress range for the detail.

$$N_{sc} \le 5 \times 10^6 \left(\frac{27/\gamma_{mft}}{\gamma_{fft}\, f} \right)^3$$

G. Using S-N Method to Evaluate Fatigue Life

Several S-N methods are available for estimating the fatigue life of welded components: nominal stress method, structural hot spot stress method, notch stress method, notch stress intensity method, and notch strain method (Fricke 2003). Fatigue assessment according to the nominal stress method uses several S-N curves together with detail classes of basic joints. This is the simplest and most Common method adopted for estimating the fatigue life of structural joints and elements. The Euro code 3-1993, Canadian code CAN/CSA-S.16.1, 2001, and the Indian code IS: 800 are based on this method. The fatigue strength in IS: 800 is defined by a series of log ff – log N or log tf – log N curves, each applying to a typical detail category. Each category is designated by a number which represents the reference value ffn (normal fatigue stress range) at 2 million cycles, i.e., the number of stress cycles, Nsc = 2 x 106. The values are rounded values. Detail types and their fatigue categories are provided in Table 26(a) to table 25 (d) of the code.

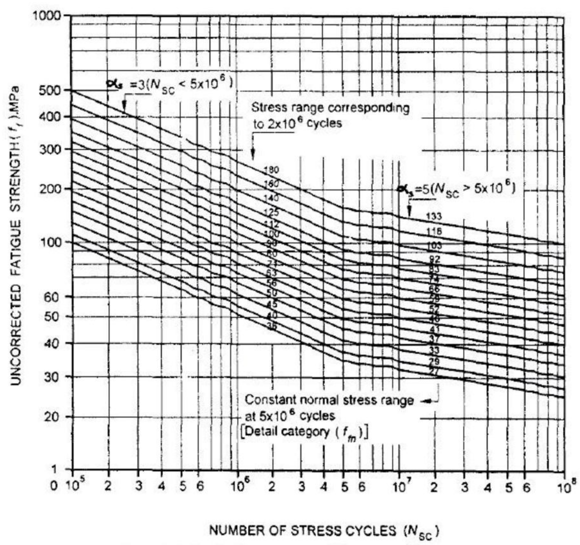

FIG. 22 *S-N* CURVE FOR NORMAL STRESS

Fig. 3 S-N Cureve for Normal stress

II. OBJECTIVES

A. Design of 74 m open Web girder manually.
B. Calculating the Axial force in each members of truss.
C. Check the stress induced in the structure due to various loading such as dead load, SIDL and Vehicular Live load.
D. Predicting the safety of the structure depending upon the stress induced.
E. Check the fatigue criteria for the same loading conditions mentioned above.

III. METHODOLOGY

A Truss of 12.8m width and 74m span and 9m height is considered for calculations of axial force for various members such as bottom chord members, top chord members, diagonal members and vertical members. The fatigue criteria is been considered and the structure is checked for fatigue stress.

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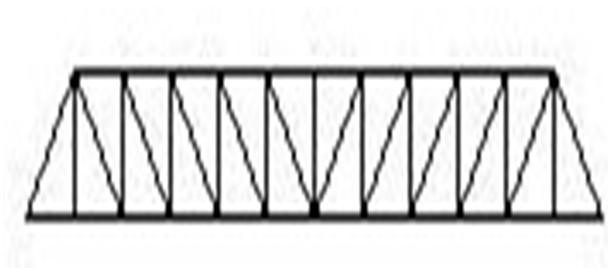
IV. INPUT CRITERIA

Nos of Traffic Lanes-2
Span (c/c of piers) - 74.5m
Effective Span - 74m
Clear span - 72m
Height at midspan - 9m
No of panels – 12
c/c of truss – 12m
Type of structure – Truss

V. GENERAL ARRANGEMENT OF SUPERSTRUCTURE

The superstructure is a funicular arch truss consisting of RC deck slab at the bottom level of the arch. The truss consists of the Top Chords, Bottom Chords, Verticals and Diagonals. The two planes of the truss are placed 12 m apart so as to be able to provide two-lane carriageway. The Truss planes are connected together through cross girders at the bottom level and tie beams at top level. The total length of the Truss bridge is 74.5m and the centre to centre distance between the bearings is 74m.



VI. DESIGN LOAD CONSIDERATION

A. Dead loads (DL)

As per IRC:6-2014
Self weight for plain, reinforced and prestressed concrete – 2.5T/m³
Density for steel is considered – 7.85 T/m³
Weight of steel considered for calculation of Dead load - 475T

B. Superimposed Dead loads (SIDL)

Deck slab - 200mm
Wearing coat - 80mm
Crash barrier - 450mmx450mm
Kerbs - 750Kg/m
Footpath - 4.74kN/m

C. Live Load (LL)

The live load considered is the most critical values from the 2 Lanes of class A vehicle and 1 Lane of 70R vehicle as per IRC loading for carriageway width of 12m.

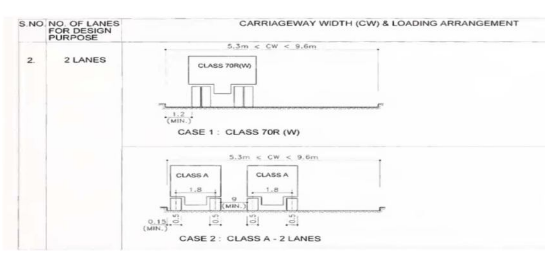


Fig. 4 – Vehicular Load Consideration

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2 lanes of class A vehicle load configuration

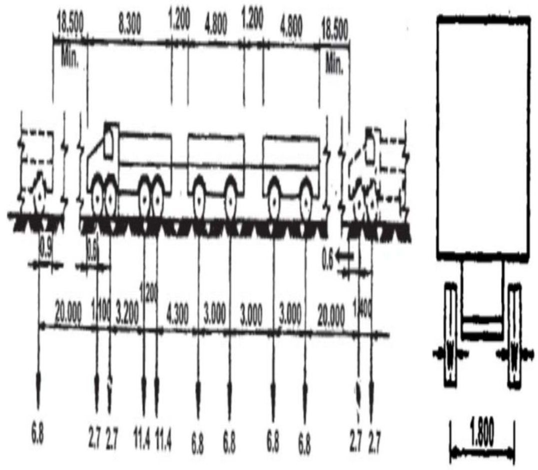

Fig. 5 – 2 lanes of class A vehicle

1 Lane of 70R vehicle configuration

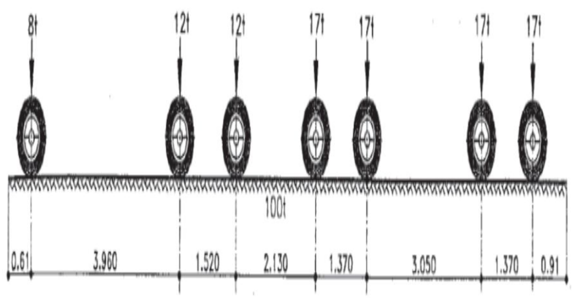

Fig. 6 – 1 Lane of 70R

D. Traffic Live Loads

The live loads will be in accordance with IRC:6-2014. The bridge has to cater for 2-lane of carriageway with 7.5m wide carriageway.

Each carriageway will be loaded with Class A & Class 70R loadings with the following vehicle combinations as per IRC:6-2014:

Sl. No.	Carriageway Width (CW)	Number of Lanes for Design Purposes	Load Combination
1)	Less than 5.3	1	One lane of Class A considered to occupy 2.3 m. The remaining width of carriageway shall be loaded with 500 kg/m²
2)	5.3 m and above but less than 9.6 m	2	One lane of Class 70R OR two lanes for Class A
3)	9.6 m and above but less than 13.1	3	One lane of Class 70R for every two lanes with one lanes of Class A on the remaining lane OR 3 lanes of Class A
4)	13.1 m and above but less than 16.6 m	4	One lane of Class 70R for every two lanes with one lane of Class A for the remaining lanes, if any, OR one lane of Class A for each lane.
5)	16.6 m and above but less than 20.1	5	
6)	20.1 m and above but less than 23.6	6	

Vertical impact factor (IF)

For L=74m,Impact Factor for class A=0.154

For Class 70 R wheeled vehicles, impact shall be taken equal to 25 percent for spans upto 23 m and in accordance with the below figure for spans more than 23 m.

For L=74m,Impact Factor for class A=0.154

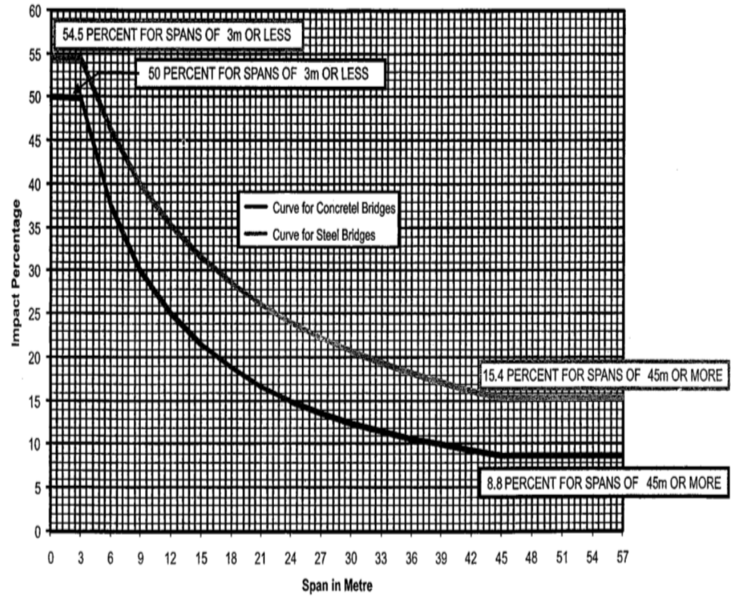

Fig. 7 – Vertical Impact factor

E. Wind load (WL)

Wind Load for Vb = 44m/s
No Wind on Live load- As per Cl-209 of IRC:6-2014
Type of terrain – 1
Basic wind speed – 44m/s
Height of pier – 6m
Height of structure - 18m

F. Transverse (FT) and Logitudinal (FL) Wind Force on Superstructure

Transverse wind force (FT)= Pz X A1 X G X Cd
Where Pz= Hourly mean wind pressure (N/m²)
A1= Solid Area (m²)
G= Gust Factor
Cd= Drag Coefficient

VII. MATERIAL CHARACTERISTICS

A. Concrete

The concrete properties shall be taken as per Table 6.5 of IRC: 112-2011.
Compressive strength of concrete – M35
Poisson's ratio – 0.2
Coefficient of expansion - 12x10-6 /°c.

B. Structural Steel

Grade of structural steel – E250
Modulus of elasticity – 200000 Mpa

C. Steel Reinforcement

Grade of reinforcement bars – Fy 250
Modulus of elasticity – 200000 Mpa
Proof stress of steel reinforcement – 0.2%

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VIII. RESULTS AND DISCUSSIONS

A. Section Provided

1) Bottom chord
2) Required sectional area (maximum) – 101236.2 mm^2
3) Section provided – box section- 2 flanges(700x40)mm+2 web(650x36)mm
4) Provided Sectional Area – 102800mm^2

B. Top Chord

1) Required sectional area (maximum) – 83733.83 mm^2
2) Section provided – box section- 2 flanges (700x32)mm+2 web(650x32)mm
3) Provided Sectional Area – 86400mm^2

C. Vertical Member

1) Required sectional area (maximum) – 26770.45 mm^2
2) Section provided – I-section- 2 flanges (700 x 16)mm + web(650x10)mm
3) Provided Sectional Area – 28900mm^2

D. Diagonal member

1) Required sectional area (maximum) – 42846.4 mm^2
2) Section provided- I-Section – 2 Flanges(700x20)mm+2 web(650x25)mm
3) Provided Sectional Area – 44250mm^2

E. Cross Girder

1) Section provided - box section- 2 flanges (700x16)mm+2 web(650x12)mm

F. Roof-Section

1) Section provided – box section – 2 flanges(600x18)mm+2 web(400x18)mm

G. Total Axial Force

1) Bottom Chord
2) Maximum tension Axial Force
3) Maximum Axial Force due to Live load, Dead load, SIDL – 9449.39 kN (T)
4) Maximum Axial force due to wind load -1787.14kN (T)
5) Total Maximum Axial Force – 11236.53 kN(T)

H. Top Chord

1) Maximum compression Axial Force
2) Maximum Axial Force due to Live load, Dead load, SIDL – 9919.24 kN (C)
3) Maximum Axial force due to wind load -440.9kN (C)
4) Total Maximum Axial Force – 10360.14 kN (C)

I. Vertical Member

1) Maximum compression Axial Force
2) Maximum Axial Force due to Live load, Dead load, SIDL – 3425.83 kN (C)
3) Maximum Axial force due to wind load -61.6kN(C)
4) Total Maximum Axial Force – 3487.43 kN(C)

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J. Maximum tension Axial Force
1) Maximum Axial Force due to Live load, Dead load, SIDL – 2576.66 kN (T)
2) Maximum Axial force due to wind load -142.99kN(T)
3) Total Maximum Axial Force – 2719.65 kN(T)

K. Diagonal Member
1) Maximum compression Axial Force
2) Maximum Axial Force due to Live load, Dead load, SIDL – 6556.45 kN(C)
3) Maximum Axial force due to wind load -486.55kN(C)
4) Total Maximum Axial Force – 6558.33 kN(C)

L. Maximum tension Axial Force
1) Maximum Axial Force due to Live load, Dead load, SIDL – 4398.89 kN(T)
2) Maximum Axial force due to wind load -48.56kN(T)
3) Total Maximum Axial Force – 4447.45 kN(T)

M. Interaction Ratio Of Truss Members(IR)
1) The interaction ratio of the truss members are calculated from the axial forces and the permissible stresses. The interaction ratio for every truss members should not be more than 1.
2) Maximum Interaction ratio for various members of truss is as follows.
3) Bottom chord=0.79
4) Top chord=0.86
5) Vertical Member=0.69
6) Diagonal Member=0.71

N. Weight Of The Steel Required For Construction
1) Weight of steel of various components of structures= 3688kN
2) Weight of gusset and other connections=442.5kN
3) Total weight of steel =4130kN=413T

IX. APPLYING CHECKS

A. Check for Deflection

As per steel bridge code, maximum deflection limit is L/600.

BOTTOM CHORD	P	DEFLECTION
	(N)	(mm)
L0L1	5332650	2.34
L1L2	533265	2.34
L2L3	7556930	2.58
L3L4	9298510	2.98
L4L5	10501830	3.31
L5L6	11236530	3.80
TOP CHORD	P	DEFLECTION
	(N)	(mm)
U1U2	7146130	4.08
U2U3	8477850	4.00
U3U4	9392290	4.12

U4U5	10066820	4.85
U5U6	10360140	5.54
VERTICAL MEMBER	P	DEFLECTION
	(N)	(mm)
U1L1	1423690	0.00
U2L2	3487430	0.14
U3L3	2682840	0.40
U4L4	2116850	0.70
U5L5	1606760	1.20
U6L6	2719650	2.68
DIAGONAL MEMBER	P	DEFLECTION
	(N)	(mm)
U0L0	6558330	4.11
U1L2	4447450	0.24
U2L3	3774530	0.54
U3L4	2757300	0.97
U4L5	2223690	1.42
U5L6	2090550	2.13

Total Deflection from the members combined is 108.92mm which is less than the allowed permissible deflection which is 123.33mm(L/600). Hence the structure is safe in deflection.

Fatigue check and value of fatigue stress range from IRS steel bridge code, page 74,clause 10.2,graph,endurance,number of cycles N,for 5million cycles ,detail category dsc(N/mm²)=100N/mm²,stress range should not be greater than 74N/mm²,table 10.1,Numerical values for fatigue strength curves for normal stress range.
Stress range is the difference of stress occurred in the structure by application of only dead weight and the stress calculated for fully loaded condition.
The stress Range for various truss members are as follows:

bottom chord	stress due to dead load(N/mm²)	stress due to total load(N/mm²)	stress range (N/mm²)
L0L1	91.68	151.165	59.49
L1L2	91.68	145.701	54.02
L2L3	110.08	149.273	39.19
L3L4	114.42	143.496	29.08
L4L5	119.74	144.058	24.32
L5L6	116.78	138.466	21.69

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top chord	stress due to dead load(n/mm²)	stress due to total load(n/mm²)	stress range (n/mm²)
U1U2	68.68	99.667	30.99
U2U3	90.34	118.241	27.90
U3U4	105.45	130.994	25.54
U4U5	115.34	140.402	25.07
U5U6	118.32	144.493	26.17

vertical member	stress due to dead load (N/mm²)	stress due to total load(N/mm²)	stress range (N/mm²)
U1L1	48.02	77.165	29.14
U2L2	-153.78	-189.021	35.24
U3L3	-116.51	-145.411	28.90
U4L4	-94.68	-114.734	20.05
U5L5	-64.75	-87.629	22.88
U6L6	96.96	125.474	28.51

Diagonal member	stress due to dead load (N/mm²)	stress due to total load(N/mm²)	stress range (N/mm²)
LOU1	62.11	91.113	29.01
U1L2	-125.63	-136.508	10.88
U2L3	-162.87	-184.123	21.25
U3L4	-116.23	-134.502	18.28
U4L5	-95.79	-108.473	12.68
U5L6	-88.98	-101.978	12.99

X. CONCLUSIONS

A. The top chord members of the designed truss are all in Compression.
B. The maximum axial force on the top chord members is 10360.14kN.
C. The bottom chord members of the designed truss are all in Tension.
D. The maximum axial force on the bottom chord members is 11236.53kN.
E. First and last vertical members of the designed truss are in Tension and rest is in compression.
F. The maximum axial force on the vertical members is 3487.43kN.
G. A first diagonal member of the designed truss is in compression and rest all are in Tension.
H. The maximum axial force on the vertical members is 6558.33kN.
I. Weight of steel required for the construction is 413T.
J. All members are safe in fatigue.
K. Total deflection in the mid section of the bottom chord is 108.92mm which is within the permissible limit which is 123.33mm.

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