Pakistan Journal of Engineering and Technology, PakJET
Multidisciplinary | Peer Reviewed | Open Access
Volume: 2, Number: 1, Pages: 31- 35, Year: 2019

Field Testing & Strength Evaluation of Khushhal Garh Rail cum Road Bridge

M.A. Chaudhry[1,*], A.M. Zafar Khan[1], Z.A. Siddiqi[1]

[1]Department of Civil Engineering, The University of Lahore

*Corresponding author: M.A. Chaudhry (email: drmahboob@uol.edu.pk)

ABSTRACT*—Old age steel bridges mostly have various problems facing potentially catastrophic result. There is complex array of issues with the railway wrought iron bridges regarding their residual life. Road Cum Rail Bridge near Khushhal Garh is of wrought iron & crosses the River Indus. This bridge is 775 ft. long and consist of four deck truss spans i.e. a 303'-0" anchor arm, a 104'-8" east cantilever (Jand end) , a 261'-0" slung and a 104'-8" west cantilever span (Kohat end). The west cantilever is anchored deep into the rock by means of guys. The upper end of the guys is attached to the top boom while the lower end is connected to anchors of size 10'x 7'-6"x 4'. Roadway is supported on bottom booms of the trusses and railway track is on the top chords. The bridge was opened to traffic on 27th November, 1907. In the course of time this bridge showed some signs of distress, in December 2006, it was decided by the Pakistan Railways Authorities to carry out strength evaluation of this bridge.The task was awarded to a joint venture, Pakistan Railways Advisory and Consultancy Services (PRACS) and Multi-Dimensional Consultants (MDC, Lahore, to conduct field studies, carry out computed model analysis & suggest measures for the repair & rehabilitation of this bridge if required. For field testing, 30 strain gauges were installed at different critical locations of main members of truss. Tensile and compressive strain variation under standard test train were recorded and analyzed. Maximum tensile & compressive stresses in main members were assessed. 22.5 Ton axle group III engine were used with PR standard test train for the test. Stress range and number of loading cycles of the selected members were compared with Wohler Curves for residual fatigue life. On the basis of this comparison, it was concluded that bridge was safe under the loading given in Bridge Rules, 1971 Pakistan Railways & Pakistan Highways Code and residual life has been estimated.

***Index Terms*—Bridges, Repair, Rehabilitation, Strengthening, Truss Structures, Fatigue Life, Wöhler Curve.**

I. INTRODUCTION

Previous history of loading is almost unknown. Proper design standards have not been used for their design condition of these bridges varies greatly from site to site. Loadings and its number of cycles have no proper record. Interaction of moving vehicles and the type of bridge structures has variable effect on their response and life. Reliable structural behavior, integrality and residual fatigue life assessment become essential for evaluating and addressing these problems.

The multistory station of Kohat and Punjab is connected through a Rail-cum-Road Bridge which crosses the River Indus on four deck truss spans i.e. a 303'-0" anchor arm, a 104'-8" east cantilever (Jand end) , a 261'-0" slung span and a 104'-8" west cantilever (Kohat end) span (Figure 1).

Figure 1 Kohat End Span

The west cantilever is anchored deep into the rock by means of guys. The upper end of the guys is attached to the top boom while the lower end is connected to anchors of size 10'x 7'-6"x 4'. These spans carry broad gauge and were designed for standard B live loading of 1903. The railway track is at top booms and the roadway is at the bottom booms of the spans. The trusses are 45'-0" high and spaced at 20'-0" c/c.

The roadway on the bridge is 16' wide. The trough plates are laid parallel to track and rest on cross girders that are 25' c/c.

On each end of the bridge there are two stone masonry arches corridors. The road traffic passes through these corridors before entering the bridge. The overburden of the arches also provides support to the guys of 104-ft cantilever on western end of 471 ft. span.

Robertson, one of the Consulting Engineers who had been previously responsible for the erection of the well-known Lansdowne Bridge, described it as the most complicated structure he had ever dealt with.

II. INSPECTIONS OF BRIDGE

On November 26, 2006, a joint team of engineers from Multi-Dimensional Consultants and Pakistan Railways inspected the Khushhal Garh Bridge to assess the physical condition of the bridge for the purpose of the modeling & evaluation. The following worth mentioning points were noted during the inspection:

1) The turnbuckles provided at the top of rail-bridge connecting the two parts of the bridge across an expansion joint were buckled due to expansion and contraction. Similarly, the bracing plates provided in this region on lower side of the railway bridge were also buckled due to the temperature variation.
2) The remedial measures were suggested to provide slots for both turnbuckles and connecting plates to allow movement.
3) The road surface on the lower level bridge was in extremely bad shape. The traffic was still allowed to move on this bridge but due to uneven surface, excessive vibrations and impact loads were produced endangering the safety of the bridge. There seemed to be an urgent need to remove the top surface of the bridge deck for placing new wearing surface besides strengthening of buckled or damaged supporting members.
4) The bearings of the road bridge, at the abutments and at central pier, were required to be repaired to make them functional. These were to be rehabilitated by jacking up the bridge near these supports for their proper oiling & graphing.
5) Curved surfaces at the hinge supports were required to be cleaned and lubricated for its free rotation.
6) The overall condition of the substructure and the steel super-structure was found satisfactory.
7) The lower anchors at the abutments were thoroughly checked, cleaned and painted as these remain submerged during floods. This operation was required to be replaced after every flood season.
8) There is one way traffic system on this bridge. So, traffic signals must be installed to allow smooth movement of traffic.
9) A weigh bridge should be installed near this bridge to avoid overloaded traffic of trucks.

III. FIELD TESTING

Field Testing has been conducted in order to achieve the following objects:

1) To measure stress level at different critical locations.
2) To assess the bridge for its residual life and for rating of the bridge.
3) To recommend suitable measures for enhancing the residual life / capacity through suitable rehabilitation/strengthening measures.
4) To conduct economic feasibility study and prepare rehabilitation / strengthening (accompanied with estimates) for the overstressed/fatigued parts of bridge for making them fit for existing/increased speed of 65 mile/h.
5) To carry out the load and speed rating of the bridge in its existing condition, in case rehabilitation is expensive. Minor repair is accompanied with this option.

For this purpose, location of strain gauges and LVDT were fixed for computer analysis. There were 30 strain gauges. The detail of assignment of strain gauges to different member and locations were marked.

A test train of specified capacity was run to take readings on strain gauges installed at different location as shown in Figure 2.

Figure 2 Strain gauges installed at different locations

IV. STRUCTURAL ANALYSIS

Applicable documents

The following documents are used for analyzing the bridge using the design codes mentioned below.

Bridge Rules – Government of Pakistan, Ministry of Communications (Railway Wing), 1971.

Steel Bridge Code - Government of Pakistan, Ministry of Communications (Railway Wing) 1971.

Analysis software

SAP2000 version 8.3.3 was used for analysis of the Bridge. This Software is capable of performing Linear or Non - Linear analysis of concrete and steel structures. The Section Designer wizard has been used to define the section of truss members. The bridge has been analyzed for each load case. The results were reported for each load case so that they can be combined with the required load combinations.

Geometry of structure

The bridge is modeled as a 3D two span continuous frame structure as shown in Figure - 2. The axial releases are given in members L15L16, U16U17, L26L27 and U25U26. The anchor members L16U16 and L26U26 are simulated as tension members (Zero Compression). The inbuilt capability of software for moving load analysis is used for railway and highway loading.

Application of loads

RAILWAY LOADING

Broad Gauge Standard loading of 1926 for Branch Line (B.L) of Bridge Rules 1971, was modeled in software using its bridge load capacity. The train was programmed to run over the bridge length. The each member had been analyzed for maximum and minimum tensile and compressive forces. As per bridge rules Pakistan Railway, the following forces were considered

1. Impact factor for railway loading
2. Racking force
3. Longitudinal loads (tractive and braking)
4. Wind forces

V. ANALYSIS OF TEST DATA

Test data has been analyzed and shown in table 5.1 and also graphically represented (fig. 6.1& 6.2).

TABLE 5.1 Cumulative Data

LOCOMOTIVE GROUP	**CROSS GIRDER U29 - U29**		**BOTTOM CHORD L20 - L21**		**VERTICAL MEMBER U26 – L26**	
	STRESS RANGE (ksi)	**NO. OF CYCLES (10^5)**	**STRESS RANGE (ksi)**	**NO. OF CYCLES (10^5)**	**STRESS RANGE (ksi)**	**NO. OF CYCLES (10^5)**
3	0 – 6.45	0.24831	0-3.47	0.24831	0-4.6	0.24831
4	0 – 5.83	0.92994	0-3.13	0.92994	0-4.17	0.92994
Total		**1.17825**		**1.17825**		**1.17825**

VI. MEMBER FATIGUE EVALUATION PROCEDURE

From the actual test train, the variable-amplitude stress spectrum is calculated. The equivalent or constant-amplitude stress is calculated from the calculated variable – amplitudes stress spectrum using AREMA RMC relationship.

$$SR_e = \alpha\left(\sum \gamma_i \times SR_i^3\right)^{\frac{1}{3}}$$

Where,

SR_e = Effective stress range defined for the total number of variable stress cycles to failure (N_v).

SR_i = Stress range of a particular group having number of occurrences n_i.

γ_i = n_i / N_v, ratio of the number of occurrences of SRi to the total number of variable stress cycles N_v.

α = Ratio of stress range either measured from tests or estimated to the stress range calculated by structural analysis.

The calculated effective stress range (SR_e) along with the connection detail type were used to estimate the remaining life of the member using the ***WÖLHER CURVE*** (S-N curve). In this curve, if the stress range is less than the constant amplitude fatigue limit or the loading cycles are in compression, there is no fatigue and the fatigue life can be considered infinite. If the effective stress range is at or outside the S-N curve, the fatigue life of the member had already exhausted and replacement of part of the structure is required to ensure safety and to further use the bridge for the traffic loading.

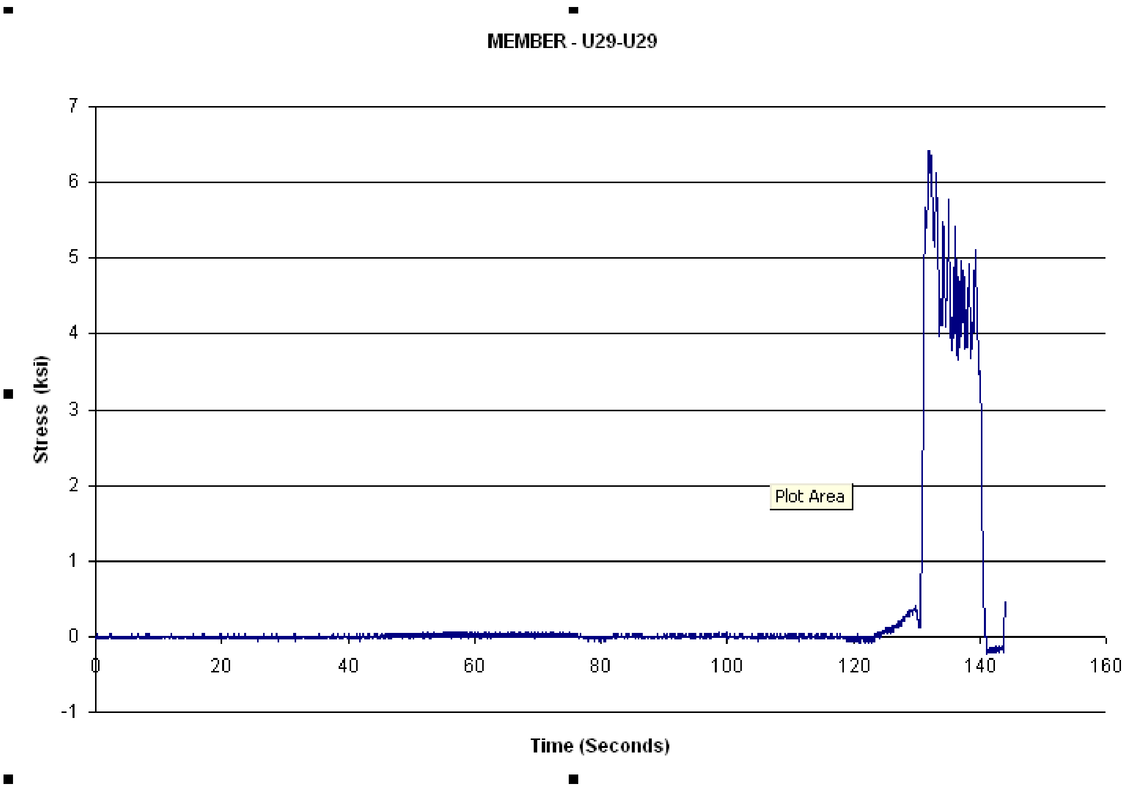

Figure 6.1 Test Train Load Spectrum for Cross Girder U29-U29

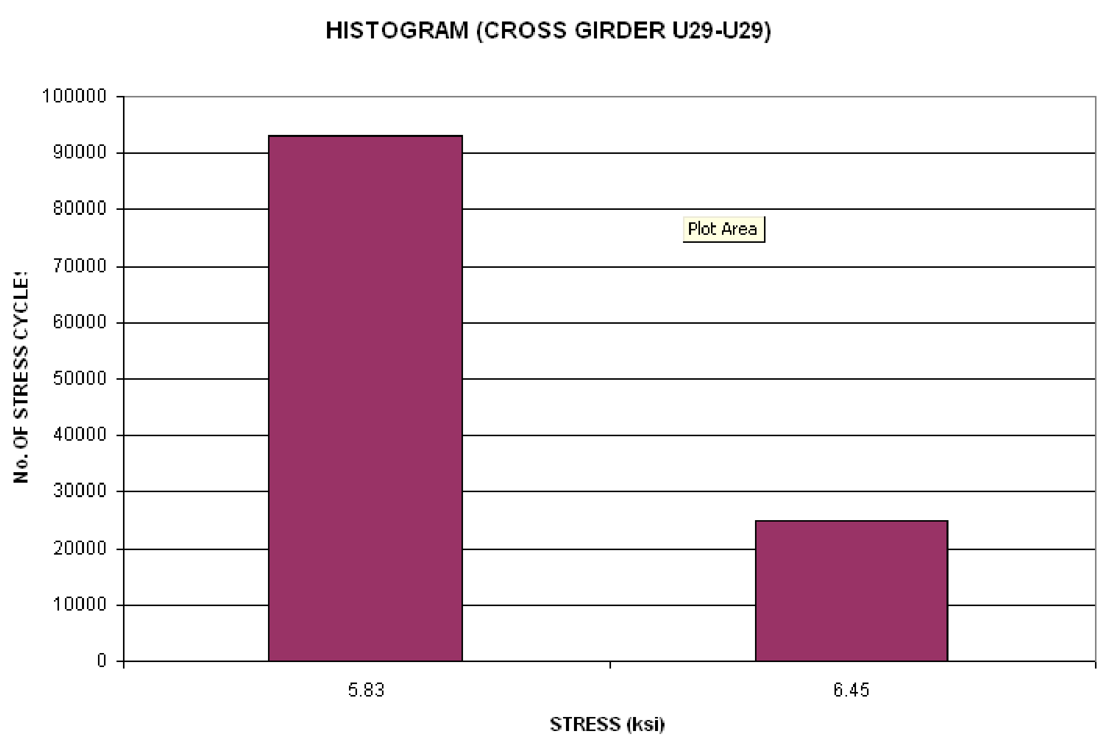

Figure 6.2 Histogram

N_v = 117825
N_1 = 92994`

$$\gamma_1 = \frac{92994}{117825} = 0.789$$

$SR_1 = 5.83ksi$

$N_2 = 24831$

$$\gamma_2 = \frac{24831}{117825} = 0.211$$

$SR_2 = 6.45ksi$

$$\alpha = \frac{SR_{(measured)}}{SR_{(calculated)}} = \frac{6.64}{4.7} = 1.37$$

$$SR_e = 1.37\left[\left(0.789 \times 5.83\right)^3 + \left(0.211 \times 6.45\right)^3\right]^{1/3}$$

$$= 8.166 ksi$$

The calculated effective stress range parameter (SR_e) for member U29-U29 and connection detail category 'D' gave the maximum number of loading cycles equal to about $6x10^6$ = 6,000,000 from *WÖHLER CURVE* (S~N curve) of figure 6.3. Out of these only 117,825 cycles had actually occurred. This showed that significant fatigue life was left for this member.

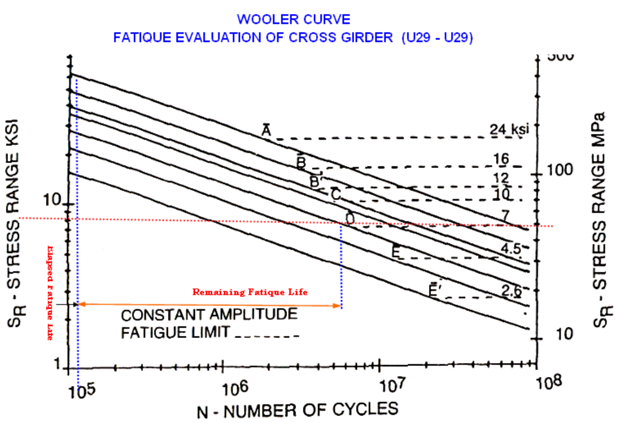

Figure 6.3 *WÖHLER CURVE* (S~N curve)

The same procedure was adopted for the calculation of fatigue life for bottom chord L20-L21 and vertical chord U26-U26.

The resulting applied stress parameter SR_e is compared with fatigue strength *WOOLER CURVE* and member is found safe against fatigue.

VII. CONCLUSIONS

On the basis of inspection, testing and evaluation, the following recommendations were made:

1. On physical inspection the croaked members and members buckled and broken due to expansion or contraction were suggested to be repaired.
2. The road surface on the lower portion bridge being severely in bad shape was recommended to be replaced.
3. The curved surfaces at hinged steel bearing were required to be cleaned and lubricated for free rotation.
4. On analysis of field testing over stressed members were pointed out and assessed for their residual life.
5. The fatigue life of members U29-U29 (cross girder) and member L20-L21 & U26-L26 were assessed using Wohler Curve. It is suggested to carry out regular maintenance to further extend the life of the bridge.

VIII. REFERENCES

1. BS 5400, "Part 10, Code of practice for fatigue, Steel Concrete and Composite Bridges." *British Standard Institutions,* 1980.
2. Fatigue Design of steel structures, Steel Construction, *Journal of the Australian Steel Instituue.*Vol.38, March 2004.
3. Korondi, L., Szittner, A., Kallo, M. and Krisrof, L., "Determination of fatigue safety and remaining fatigue life on a riveted railway bridge by measurement," *Journal of Constructional Steel Research*, Elsevier, 46 (1-3), 430, paper number 327, 1998.
4. Liu, Y., Stratman, B. and Mahadevan, S., "Fatigue crack initiation life prediction of railroad wheels" *International Journal of Fatigue*, Elsevier, 28(7), pp. 747-756, 2006.
5. Manual for Railway Engineering, *American Railway Engineering Association (AREA),* 1991.
6. Ministry of Communications (Railway wing), "Bridge Rules." Government of the Pakistan.
7. Ministry of Communications (Railway wing), "Steel Bridge Code." Government of the Pakistan, Railway Code of Practice for the Design of Steel or Wrought Iron Bridges Carrying Rail, Road or Pedestrian Traffic.
8. Pier and Abutment Standard Code of Practice for the Design of Bridge Pier and abutment.